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Foreword

The ESOFT International Conference 2026 (EICON 2026) was organized by ESOFT Uni (ESU), Sri Lanka, with the aim of providing an international platform for researchers, academics, industry professionals, and students to disseminate and discuss innovative research across a wide range of disciplines.

The proceedings comprise peer-reviewed abstracts and full papers presented at EICON 2026, representing contributions from diverse fields, including Engineering, Technology, Computer Science, Artificial Intelligence, Business and Management, Education, Humanities, Social Sciences, Creative Arts, Health Sciences, Medicine, Nursing, Pharmacy, and Psychology. All submissions underwent a rigorous peer-review process conducted by the conference's scientific review panels before acceptance.

The accepted abstracts and full papers have been edited to ensure consistency in formatting, language quality, and compliance with the conference guidelines. However, the responsibility for the accuracy of the content, opinions, and conclusions expressed in each publication rests solely with the respective authors.

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Message from the Keynote Speaker

It is with great pleasure that I extend my warmest greetings and heartfelt congratulations to the Organising Committee, academic community, researchers, students, and all participants of the ESOFT International Conference 2026 (EICON 2026).

The theme of this year's conference, "Transformative Intelligence: Integrating Tech, Society, and Sustainability," is both timely and highly relevant to the challenges and opportunities of our rapidly evolving world. We are living in an era in which technological advancement is transforming almost every aspect of human life. However, the true value of innovation lies not merely in technological progress, but in our ability to ensure that such progress contributes meaningfully to society, promotes equity, and supports a sustainable future.

EICON 2026 provides an important platform for scholars, researchers, professionals, innovators, and students to come together across disciplinary boundaries. The exchange of knowledge and ideas is fundamental to addressing complex global and local challenges, many of which cannot be solved through a single discipline or perspective. Conferences such as EICON encourage collaboration, critical thinking, creativity, and the development of innovative solutions that can create a meaningful and lasting impact.

I am particularly pleased to see the broad multidisciplinary focus of this conference, bringing together areas such as technology, engineering, artificial intelligence, business, health sciences, education, social sciences, creative arts, and sustainability. Such integration reflects the increasingly interconnected nature of knowledge and the importance of collaborative approaches in generating solutions for the future.

I would like to extend my sincere appreciation to the organisers, scientific committee, reviewers, session chairs, and all those who have worked tirelessly to make EICON 2026 a reality. Organising an international conference of this scale requires commitment, vision, teamwork, and dedication, and I commend everyone involved for their contribution.

I hope that the discussions, collaborations, and new ideas emerging from EICON 2026 will continue beyond the conference and lead to meaningful partnerships, impactful research, and innovative solutions. May this conference inspire all participants to think boldly, work collaboratively, and contribute towards a more intelligent, inclusive, and sustainable world.

I wish EICON 2026 every success and extend my very best wishes to all participants.

Senior Prof. Indika Gawarammana (MBBS, MD, MRCP, FRCPE, PhD)
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Message from the Keynote Speaker

It is a profound privilege to extend my warmest greetings to all distinguished academics, clinical researchers, tech innovators, and delegates attending the ESOFT International Conference 2026 (EICON 2026) at ESOFT Uni, Kandy.

We are currently standing at one of the most remarkable intersections in human history. The convergence of computational science, artificial intelligence, and advanced genetics is fundamentally redefining the landscape of modern medicine and biotechnology. As a Consultant Neurosurgeon and a researcher, I witness daily how surgical innovation and AI is transforming complex clinical neurosurgical care. Simultaneously, rapid developments in genomic mapping and precision medicine allow us to understand human pathology at an unprecedented molecular level. Harnessing AI to decipher multi-omic biological datasets is no longer a futuristic concept. It is an active frontier that holds the key to solving some of humanity's most complex healthcare challenges.

Conferences like EICON play an indispensable role in accelerating this transformation. By bringing together diverse minds across computing, engineering, life sciences, and business, EICON fosters the interdisciplinary dialogue required to translate abstract theoretical models into practical, life-saving clinical tools and scalable technologies.

This spirit of adaptation and forward-thinking vision is deeply rooted in the history of ESOFT itself. Established in 2000 as a focused provider of IT and computing qualifications, ESOFT has undergone a remarkable evolution over the past quarter century. What began as a modest educational initiative in Sri Lanka has grown into a premier degree-awarding university network. Through strategic global partnerships, continuous curriculum innovation, and expansion into fields such as engineering, business, and life sciences, ESOFT has consistently democratized access to world-class higher education. hosting EICON 2026 at ESOFT University stands as a powerful testament to the institution’s sustained commitment to academic excellence and cutting-edge research.

To all authors and presenters featured in this year's proceedings, I congratulate you on your contributions. Your research represents the driving force of tomorrow's solutions. To the delegates, I encourage you to actively engage in these sessions, push the boundaries of conventional thinking, and forge interdisciplinary partnerships that bridge the gap between computational power and human wellbeing. I extend my heartfelt appreciation to the EICON 2026 Organizing Committee, and the leadership of ESOFT Uni for their meticulous dedication in organizing this landmark event. I wish all participants an inspiring and impactful conference.

Warmest regards,

Dr. Charith Nanayakkara
MBBS (Colombo), MRCS (England), MRCS (Glasgow), MD - Surgery (Colombo), CTHE (KDU)
Consultant Neurosurgeon and Senior Lecturer
Faculty of Medicine, General Sir John Kotelawala Defence University

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Message from the Keynote Speaker

It is a privilege to address the delegates, researchers, students, and industry partners gathered for EICON 2026. Conferences like this one exist because progress rarely happens inside a single discipline — it happens where engineering meets medicine, where computer science meets clinical practice, and where academics, industry, and students are willing to sit in the same room and ask the same question from different angles.

I have spent the last two decades practising trauma and reconstructive orthopaedic surgery across northern Sri Lanka — in Mannar, Kilinochchi, Vavuniya, and now Jaffna — districts that were, for a long time, among the most under-resourced in the country. That work has taught me one thing above all: healthcare in underserved regions cannot wait for ideal conditions to arrive; it has to be built out of whatever constraints are in front of you. As Principal Investigator of the AEFIX external fixation trial in Jaffna, in partnership with SONA Global, I have seen this proven in practice — an affordable, reliable device replacing fixators that were previously too expensive or unreliable, now paired with structured courses to train the next generation of trauma providers.

That same principle — innovate inside the constraint, prove it with evidence, and build the people and systems that outlast you — is not unique to orthopaedics. It applies equally to the engineers, data scientists, and AI researchers presenting alongside the health sciences track at this conference. The most meaningful innovations are rarely the most resource-intensive ones; they are the ones that close a gap someone else walked past.

I want to thank the EICON 2026 Organizing Committee and ESOFT Uni for the invitation to speak, and for building a platform where this kind of exchange can genuinely happen. To the students and early-career researchers presenting their work here — your papers in these proceedings are not a footnote to your career. They are the beginning of a habit that, over time, changes how an entire field cares for the people it serves. My congratulations to every author and presenter in this volume.

With warm regards,

Dr. Sivananthan Sashikaran
MBBS (Jaffna) | MD (Ortho) | MRCS (Eng.) | ChM (T&O) | ISTP Fellow (UK) | Dip. Orth. Oncol. (BOOS) | FICS
Senior Lecturer and Consultant Orthopaedic Surgeon
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Message from the Deputy Vice Chancellor, ESOFT Uni, Colombo

It is with great pleasure that I extend a warm welcome to all distinguished academics, researchers, industry professionals, policymakers, and students attending the ESOFT International Conference (EICON) 2026, hosted by ESOFT Uni in the historic city of Kandy.

This year's conference theme, "Transformative Intelligence: Integrating Tech, Society, and Sustainability," captures the very essence of our current global juncture. As we gather, we find ourselves at a critical crossroads where the rapid evolution of technology, particularly in the realms of Artificial Intelligence, Machine Learning, and Data Science, is not merely changing the way we work, but fundamentally reshaping the way we live, interact, and govern.

In a rapidly changing world, the imperative for innovation has never been more urgent. Whether we are addressing challenges in health sciences, engineering, business resilience, or social progress, EICON 2026 provides a vital, multidisciplinary bridge between academic inquiry and practical application. By fostering collaboration across six diverse research tracks ranging from Health Sciences and Engineering to Creative Arts and Business Management, we aim to transform complex data into meaningful insights and innovative solutions that contribute to a sustainable and equitable future.

I believe that EICON 2026 will serve as an essential platform for sharing groundbreaking research, sparking interdisciplinary discourse, and forging connections that transcend traditional academic boundaries. Your presence here reflects a shared commitment to advancing knowledge and addressing the societal and technological challenges of our time.

I am confident that the insights gained and the networks established during these two days will contribute significantly to your professional journey and drive real-world impact. Thank you for your invaluable contributions and active participation. I wish you a highly successful, inspiring, and thought-provoking conference.

Dr. Dillina Herath (PhD, MBA)
Deputy Vice Chancellor
ESOFT Uni

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Message from the Chairman / Group Managing Director, ESOFT Uni

It gives me immense pleasure to extend my warmest greetings to all participants, researchers, academics, industry professionals, practitioners, and distinguished guests attending EICON 2026, the ESOFT International Conference.

This year's conference theme, "Transformative Intelligence: Integrating Technology, Society, and Sustainability," reflects the rapidly evolving world in which we live and the growing need to harness knowledge, innovation, and technology to create meaningful and sustainable impact. As technology continues to transform the way we live, work, learn, and interact, it is essential that innovation is guided not only by technological advancement but also by social responsibility and a commitment to a sustainable future.

EICON 2026 provides a valuable multidisciplinary platform for bringing together diverse perspectives, disciplines, and experiences. The complex challenges faced by our societies today cannot be addressed through isolated efforts. They require collaboration across academic disciplines, industries, communities, and nations. By encouraging dialogue and knowledge exchange, conferences such as EICON create opportunities for new ideas, meaningful partnerships, and innovative solutions to emerge.

Higher education has a particularly important role to play in this transformation. Universities and educational institutions must go beyond imparting knowledge and equip future generations with the critical thinking, creativity, ethical awareness, and adaptability required to navigate an increasingly complex world. Research and innovation must be encouraged to address real-world challenges and contribute to the economic, social, and environmental development of our communities.

I am confident that EICON 2026 will serve as an inspiring forum for researchers and practitioners to share their latest findings, exchange insights, explore emerging opportunities, and establish meaningful professional networks. I hope the discussions and collaborations initiated through this conference will continue beyond these proceedings and contribute to lasting advancements in knowledge and practice.

On behalf of ESOFT, I extend my sincere appreciation to the organizing committee, reviewers, speakers, partners, and everyone who has contributed to the successful organization of EICON 2026. I also warmly welcome all participants and encourage you to engage openly, challenge ideas, share perspectives, and make the most of this valuable platform.

I wish EICON 2026 every success and hope that it will inspire transformative ideas, foster impactful collaborations, and contribute to a more innovative, inclusive, and sustainable future.

Dr. Dayan Rajapakse (MBBS, MBA, MBCS, MCS)
Chairman & Group Managing Director
ESOFT Uni

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Message from the Chairperson, EICON-2026

It is with great pleasure and honour that I extend my warmest greetings to all distinguished guests, keynote speakers, researchers, presenters, participants, sponsors, and members of the organizing committee of the ESOFT International Conference 2026 (EICON 2026).

EICON 2026 provides a valuable multidisciplinary platform for scholars, professionals, researchers, and industry experts to come together, exchange knowledge, share innovative ideas, and engage in meaningful discussions. In a rapidly changing global environment, such academic gatherings play a vital role in promoting collaboration, encouraging innovation, and creating solutions to contemporary challenges.

I am delighted to welcome all our local and international delegates who have joined us to contribute to this significant academic event. Your valuable research, expertise, and active participation are the foundation of the success of this conference. I sincerely hope that EICON 2026 will provide opportunities for fruitful discussions, meaningful networking, new collaborations, and the exchange of diverse perspectives.

I would also like to express my heartfelt appreciation to the organizing committee, reviewers, speakers, sponsors, partners, and everyone who has contributed their time, effort, and commitment towards making this conference a reality. Their dedication and hard work have been instrumental in bringing together this important gathering.

As we come together for EICON 2026, let us embrace this opportunity to learn from one another, strengthen academic and professional connections, and inspire new ideas that can contribute to the advancement of knowledge and society.

On behalf of the organizing committee, I warmly welcome you all to EICON 2026 and wish you a rewarding, inspiring, and memorable conference experience.

Dr. Jeevan Dhanarisi (BPharm, PhD)
Chairperson, EICON 2026
Associate Dean, Faculty of Life Sciences, ESOFT Uni

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Transformative Intelligence in Cybersecurity: Enhancing Accuracy and Efficacy of Advanced Persistent Threat Detection Using Data Analytics – Evidence from a Sri Lankan Survey

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Abstract

Background:

The increasing sophistication of cyber threats has exposed the limitations of conventional signature-based detection methods, creating a need for data analytics-driven approaches to improve cyber threat detection. However, empirical evidence on their practical implementation within developing countries, particularly Sri Lanka, remains limited.

Objective/s:

This study investigates the factors influencing the accuracy and efficacy of advanced cyber threat detection mechanisms and provides empirical evidence from Sri Lanka on the practical application of data analytics in cybersecurity.

Methods:

A quantitative, positivist research design was adopted using a structured questionnaire administered to 93 participants selected through cluster sampling based on age, professional experience, and educational qualification. Data were analysed using reliability and validity tests, Spearman's rank correlation, multicollinearity diagnostics, Harman's Single Factor Test, and a Generalized Linear Model (Gaussian family with identity link function) to evaluate the effects of six independent variables on cyber threat detection performance.

Results:

The findings indicate that the level of cyber threat sophistication, type of cyber threat detection mechanism, choice of analytical tools and platforms, and frequency of data collection and analysis significantly improve the accuracy and efficacy of advanced cyber threat detection ($p < 0.05$). In contrast, the use of machine learning algorithms and dataset complexity were not statistically significant predictors, reflecting the current cybersecurity maturity and resource constraints within the Sri Lankan context.

Conclusion/s:

This study provides context-specific empirical evidence that extends existing cybersecurity research by demonstrating that organizational implementation practices currently have a greater influence on detection performance than technological sophistication alone. The findings offer practical guidance for policymakers and industry in strengthening cybersecurity capacity, improving analytical capabilities, and supporting evidence-based adoption of advanced cybersecurity technologies in Sri Lanka.

Keywords: *Accuracy, Cyber Threat Detection, Efficacy, Sustainable Cybersecurity, Transformative Intelligence.*

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Introduction

Significance of Study

This study contributes to cybersecurity research by evaluating the practical effectiveness of data analytics in enhancing the accuracy and efficacy of advanced cyber threat detection mechanisms, using primary survey data collected from cybersecurity professionals and digitally experienced users in Sri Lanka.

The principal contribution of this research lies in providing empirical evidence from a developing-country context, where limited research has examined the real-world implementation of data analytics in cybersecurity. Unlike many previous studies that primarily focus on developing or benchmarking ML algorithms using publicly available datasets, this study investigates how organizational and operational factors influence the effectiveness of cyber threat detection in practice.

By generating empirical evidence from Sri Lanka's resource-constrained cybersecurity environment, this study bridges the gap between theoretical advancements and practical organizational implementation. The findings have provided valuable guidance for practitioners, policymakers, and organizations seeking to make cybersecurity investments, allocate resources effectively, and develop sustainable, analytics-driven cyber defence strategies, while establishing a foundation for future comparative survey-based research across developing economies.

Review of Literature

Accuracy and Efficacy of Advanced Cyber Threat Detection Mechanisms

Advanced Persistent Threats (APTs) have become one of the most challenging cybersecurity issues due to their stealth, persistence, and multistage attack life cycle. Unlike conventional cyberattacks, APTs employ sophisticated techniques that enable adversaries to evade signature-based detection while maintaining long-term unauthorized access to organizational networks. Consequently, recent studies have increasingly shifted towards intelligent detection mechanisms that integrate data analytics, machine learning (ML) and deep learning (DL) to improve detection accuracy while minimizing false positive rates [1, 2], demonstrating that conventional IDS approaches often fail to detect the complete lifecycle of APTs as they rely heavily on isolated network events rather than longitudinal behavioural evidence, future highlighting the level of sophistication of the algorithms would be helped in accuracy of APT detection1. To extend, more recent studies have shown this perspective by incorporating deep learning architectures and Transformer models, which are more effective than classical ML classifiers, exceeding 95% accuracy[2, 3], a notable methodological limitation across the literature is the predominant use of offline experimentation. Furthermore, several studies prioritize overall accuracy while giving comparatively limited attention to recall, precision, detection latency, and false alarm rates, despite these metrics being critical for practical cybersecurity operations[1, 2]. The growing adoption of Explainable Artificial Intelligence (XAI) seeks to address this challenge, but empirical validation of XAI-based APT detection remains limited, particularly within developing countries[2]. The present Sri Lankan survey would address the deficiency by evaluating how cybersecurity practitioners perceive the contribution of data analytics to improve detection accuracy and operational effectiveness within organizational environments.

Sophistication Level of the Cyber Threat

Contemporary APTs employ multi-stage attack chains involving reconnaissance, initial compromise, privilege escalation, lateral movement, persistence, command-and-control communication, and data exfiltration, which occur over several months, making detection substantially more difficult[1, 4]. Recent literature emphasizes that attackers increasingly exploit AI automation, zero-day vulnerabilities, and social engineering to bypass conventional security controls. As static detection mechanisms relying on predefined signatures have become progressively less effective, an alternative, i.e., behavioural analytics capable of modelling long-term user and system activities, has received greater research attention. Methodologically, many investigations adopt the MITRE ATT&CK framework to characterize attacker behaviours across different phases of an intrusion, enabling researchers to detect attack sequences rather than isolated malicious events, thereby improving contextual understanding of sophisticated threats. However, even the most published studies evaluate only selected attack phases, rather than modelling the complete APT lifecycle, reducing the practical applicability of their findings in enterprise environments[4, 5]. Another important limitation concerns geographical diversity, as most datasets originate from North America, Europe, or China, with relatively limited empirical evidence from South Asian organizations. This geographical concentration reduces the external validity of many published findings. The present survey therefore contributes novel evidence by examining how Sri Lankan cybersecurity professionals

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perceive the sophistication of contemporary threats and whether existing analytical capabilities adequately address these evolving attack characteristics.

Type of Cyber Threat Detection Mechanism Used

Signature-based Intrusion Detection Systems (IDSs) remain effective for detecting previously identified attacks but perform poorly against novel APT campaigns as attackers continuously modify malicious payloads and execution techniques. Consequently. anomaly-based detection methods have become increasingly popular for identifying previously unseen behaviours. Behaviour-based approaches analyse long-term interactions among users, devices, applications, and network traffic, enabling earlier identification of persistent malicious activities. Recent reviews consistently conclude that hybrid architectures achieve superior performance as they combine complementary strengths from different analytical paradigms[1, 2, 5]. Methodologically, many comparative studies benchmark algorithms using publicly available datasets such as CICIDS2017, UNSW-NB15, NSL-KDD, and DARPA have substantially advanced cybersecurity research, they primarily represent generalized intrusion scenarios rather than authentic APT campaigns[1,2]. Another weakness concerns interoperability. Numerous proposed frameworks have been evaluated as standalone research prototypes without integration into existing organizational security architectures. These findings suggest that future research should evaluate not only technical performance but also organizational readiness to implement advanced detection technologies. Unlike previous algorithm-centric studies, the present survey would investigate which detection mechanisms organizations should currently employ, how practitioners evaluate their effectiveness, and whether data analytics enhances real-world cybersecurity decision-making.

Choice of Analytical Tools and Platforms

The effectiveness of APT detection depends substantially on the analytical tools and platforms used to process large volumes of heterogeneous cybersecurity data. Contemporary research increasingly combines Security Information and Event Management (SIEM) platforms, big data frameworks, cloud computing, distributed analytics, and AI-driven security orchestration to improve detection capability, facilitating the integration of network traffic, endpoint telemetry, authentication logs, system events, and external threat intelligence into unified analytical environments[1, 2]. Despite these technological advances, methodological inconsistencies remain evident. Many studies provide limited justification for selecting particular analytical platforms, making direct comparison between investigations difficult. Several investigations further evaluate algorithms using relatively small experimental environments rather than enterprise-scale infrastructures containing millions of daily events. Accordingly, an important research gap exists regarding the organizational adoption of analytical platforms in developing economies. This survey extends existing literature by examining the analytical tools currently employed within organizations, practitioners' perception of their effectiveness, and the extent to which these platforms improve APT detection performance and cybersecurity decision-making.

Use of Machine Learning algorithms

Machine Learning (ML) has emerged as one of the most effective approaches for detecting Advanced Persistent Threats (APTs) due to its ability to identify hidden behavioural patterns that are difficult to detect using conventional rule-based systems, as it continuously learns from historical and real-time security data, enabling identification of zero-day attacks, anomalous network behaviour, and previously unseen attack vectors. Current literature categorizes ML approaches into supervised, unsupervised, semi-supervised, ensemble, and deep learning methods. Conversely, unsupervised approaches, including k-means clustering and autoencoders, are increasingly adopted for detecting unknown attacks where labelled data are unavailable. Deep learning architectures including Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, Graph Neural Networks (GNNs), and Transformer-based models have demonstrated superior capability in modelling temporal attack sequences and complex relationships among system events [6, 7]. Despite these advances, the literature reveals several methodological shortcomings. Many investigations report exceptionally high accuracy values using benchmark datasets but evaluate only offline datasets through cross-validation, which rarely consider adversarial attacks, evolving attacker behaviour, concept drift, computational overhead, or real-time deployment constraints[7, 8]. Emerging research has begun incorporating explainable artificial intelligence (XAI) and federated learning to improve model transparency and privacy-preserving collaborative detection. Although these approaches demonstrate considerable promise, empirical validation remains limited and large-scale industrial implementation is still at an early stage9, 10. These observations indicate that existing research primarily emphasizes algorithmic optimization rather than organizational adoption. Accordingly, the present survey contributes novel empirical evidence by investigating practitioners' perceptions regarding the effectiveness of ML algorithms in improving APT detection accuracy.

Frequency of Data Collection and its Analysis

Unlike conventional cyberattacks that produce immediate observable effects, APT campaigns evolve gradually through multiple attack stages, requiring continuous monitoring rather than periodic security assessments. Therefore, recent research increasingly advocates real-time or near-real-time data collection strategies integrated with continuous behavioural analytics[6, 7]. Most contemporary detection frameworks collect data from multiple heterogeneous sources including network traffic, endpoint logs, authentication records, DNS requests, firewall logs, system events, application telemetry, and external threat intelligence feeds. Integrating these diverse information sources enables security platforms to reconstruct attack sequences across different stages of the MITRE ATT&CK framework, thereby improving contextual awareness and reducing false negatives[7, 11]. A limitation concerns data refresh frequency. Many published studies inadequately describe the temporal characteristics of their datasets, including collection intervals, observational duration, and event frequency. Without this information, reproducing experimental results and comparing detection models becomes increasingly difficult. However, recent advances in cloud computing, big data analytics, and distributed processing platforms have improved the feasibility of continuous cybersecurity monitoring. Nevertheless, implementing real-time analytics requires substantial computational resources, scalable storage architectures, and skilled cybersecurity personnel, factors that remain challenging for many organizations, particularly within developing economies, which can be seen as an important research gap[7, 8]. This study would address this gap by examining how frequently Sri Lankan organizations collect and analyse cybersecurity data, and whether continuous analytical practices are perceived to improve APT detection effectiveness.

Complexity of the Dataset

Modern cybersecurity environments generate enormous volumes of heterogeneous data characterized by high velocity, variety, dimensionality, and uncertainty. These characteristics present significant challenges for feature engineering, model training computational efficiency, and detection accuracy. Consequently, recent literature increasingly emphasizes dataset complexity as a critical determinant of machine learning performance[7, 11]. Although datasets such as NSL-KDD, UNSW-NB15, CICIDS2017, DARPA, and newer Linux-APT datasets have substantially advanced cybersecurity research, they primarily represent generalized intrusion detection scenarios rather than authentic long-duration APT campaigns[2, 11]. The present study would address this gap from an organizational perspective by investigating the perceptions regarding dataset availability, complexity, and quality within Sri Lankan organizations while determining whether dataset characteristics influence the effectiveness of data analytics, thereby extending existing technical research with empirical organizational evidence. It is to be noted that the following review has been done with studies ranging from the years 2020 to 2025.

Research Statement and Objectives

The main objective of this study was to investigate the role of data analytics in detecting and combatting advanced cyber threats, determine its relationship with the efficacy and accuracy in the cyber threat detection mechanisms, identifying key influencing factors, while collecting and analysing primary data and trends in detection and combat advanced cyber threats, understanding the current landscape of advanced cyber threats and conclusively to propose an ideological framework for proactive and sustainable cybersecurity practices. These factors include the selection of analytical tools and platforms, the specific type of Cyber Threat Detection Mechanism utilized, the intricacy of the dataset, the sophistication level of the cyber threat, the machine learning algorithms employed, and the frequency of data collection and analysis.

Limitations of the Study

Geographical Scope

One limitation of this study is the geographic scope of the research topic. This research may be limited by the availability of data and resources in certain regions. For instance, cyber threat detection mechanisms may differ across various regions due to variations in technology infrastructure, regulations, and cybersecurity measures, such as in the country of Sri Lanka. Therefore, the findings of this study cannot be universally applied or generalized to all geographical areas at this time.

Sample Size

The effectiveness of modern cyber threat detection systems could vary depending on the dataset size and the number of organizations or individuals included in the study, using the Krejcie and Morgan Table. The findings'

generalizability might be restricted by a small sample size resulting from the chosen sampling technique, making it impossible to conduct a comprehensive analysis of the accuracy or effectiveness of these mechanisms.

Time Constraint

The study took place within six to seven months, and research generally requires a significant amount of time. Time constraints could impact data collection, data analysis, and the formulation of conclusions.

Diversity

The study could be limited by the diversity of the sample population. The effectiveness of cyber threat detection mechanisms may differ depending on the diversity of organizations or individuals involved in the study. To ensure the validity and generalizability of study findings, researchers should strive for a diverse sample size.

The Focus on Specific Industry/Sector

This study will center on the IT industry, and while it may be challenging to apply the results to new areas, a greater number of participants with expertise will lead to more specialized analysis.

Methods

Study Design and Setting of the Questionnaire

This study adopted a positivist paradigm, assuming an objective, observable reality that can be examined through empirical methods to uncover causal relationships. A quantitative, cross-sectional survey design was employed to collect primary data at a single point in time, enabling efficient assessment of relationships between variables within practical constraints. For this study, an online questionnaire was provided to a calculated target group in Sri Lanka, where they would not be required to be present in a physical manner, and was collected over a cross-sectional time horizon.

The questionnaire was based on the aforementioned factors and included four questions for each independent variable due to the time constraint given and also for the ease of the respondents. Once scripted, the questions went through a formal process within the stated institute of this study, except for institutional ethical approval provided within the study's institution, and items with Item-level CVI (I-CVI) below 0,78 were revised or totally removed. To test this, participants in a pilot test were asked to comment on the clarity, readability, relevance, and ease of understanding of the questions. Their feedback was used to refine wording, remove ambiguities, and improve the logical flow of the survey itself. The final questionnaire-based survey was conducted with a particular sample selected from the target population, and primary data were collected, where each construct contained approximately four items measured on a 5-point Likert scale according to a Likert scale Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree (ranging from 1 being Strongly Disagree to 5 being Strongly Agree).

Characterization of the Participants with the Inclusion/Exclusion Criteria

Participants were required to be mainly IT professionals, cybersecurity administrators, and digital system operators in Sri Lankan organizations. and must have experienced or encountered cyber threats or attacks in the past, such as phishing, ransomware, malware, or social engineering. Additionally, a few criteria related to their use of digital systems and exposure to cyber threats were used in the selection of participants such as age groups (e.g., 18–25, 25–35, 35–45, and above 45), years of professional experience in digital or related fields (e.g., less than 2 years, 2–5 years, 6–10 years, and above 10 years), and current professional/educational level (Ordinary Level, Advanced Level, HND, BSc, MSc).

Inclusion criteria emphasized prior exposure to threats, professional experience in digital environments, and varying levels of cybersecurity expertise. Exclusion criteria included incomplete responses and lack of informed consent. The recruitment strategy was to simply contact them with a verbal affirmation (discussed later) on whether they would like to be involved with the study, while acknowledging the loopholes and potential setbacks that could occur during the survey completion.

Sample size considerations and calculation

The target population comprises Sri Lankan individuals who regularly use digital systems and possess varying levels of exposure to cybersecurity practices, including undergraduates, IT professionals, cybersecurity

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practitioners, digital system operators, etc. Owing to the heterogeneous nature of this population, a cluster sampling approach was adopted to improve coverage while maintaining feasibility within the given study period.

Clusters were formed as mentioned in the previous subsection, which have been considered likely to influence participants' awareness and their experience in this particular field, enabling the inclusion of participants with diverse levels of technical knowledge, professional exposure, and cybersecurity awareness while remaining aligned with the study's objective.

To achieve this, the sample size was calculated using the concept of the Krejcie and Morgan Table and also by means of a sample size calculator[12]. While considering the ethical considerations and the limitations of the overall study population size, which was considered to be 122, in different levels of expertise from novices to experts, and in addition, margin of error and confidence levels to ensure that there are no potential biases or statistical errors with respect to an adequate representation of all populations involved in these studies. The sample size was calculated to be 93 participants once a 95% confidence level and a 5% margin of error were applied.

Although probability-based sampling was initially intended, practical constraints influenced participant recruitment. As the survey was conducted over a six-to-seven-month timeline, participant availability, varying response rates, and limited access to cybersecurity professionals constrained the number of respondents that could be recruited from each cluster. Consequently, the clusters were designed to maximize diversity rather than achieve proportional national representation.

Description of Procedures

Cluster sampling was employed to recruit participants from the predefined demographic clusters established during the sampling stage. Rather than using geographical regions alone, the clusters were based on age group, years of professional experience, and education qualifications they had at the time of the study, as these factors were considered more relevant to cybersecurity knowledge and practical exposure. Participants were recruited through academic institutions, professional IT networks, and organizational contacts within the region. Every eligible participant within the accessible clusters was invited to participate voluntarily until the required sample size of 93 respondents was achieved, enabling the inclusion of respondents with varying levels of cybersecurity expertise while remaining feasible within the allocated time period.

Statistical analysis methods used

For Data Analysis, statistical software was used to generate tabulated reports, charts, and plots of distributions and trends, descriptive analysis, and complex statistical analyses. In the case of descriptive analyses, where it would be used charts, graphs, and tabular forms were used to represent data and information. Reliability was assessed via Cronbach's Alpha. Validity checks included the Kaiser-Meyer-Olkin measure and Bartlett's test of sphericity. Due to non-normality (Kolmogorov-Smirnov test and skewness), non-parametric Spearman's Rho correlation was used to examine bivariate relationships.

For multivariate analysis, A Generalized Linear Model with a Gaussian family and an identity link function was fitted to evaluate the simultaneous effects of the six independent variables on the dependent variable, comprising composite Likert scale scores measured on an approximately continuous scale, while preliminary tests indicated deviations from normality. Results reported correlation coefficients, standardized coefficients, effect sizes, confidence intervals, and p-values for transparency and interpretability. All analyses accounted for potential common method bias and outliers.

This rigorous methodology ensures reproducibility, minimizes bias, and provides robust empirical evidence on the practical value of data analytics in enhancing cybersecurity resilience in the Sri Lankan context.

Results

In this pivotal chapter of the research report, we delve into the heart of the study's findings and offer a comprehensive overview of the results attained through rigorous data collection and analysis. Through the scrupulous presentation of results, it has aimed to give a detailed account of the data collected, analyzed, and interpreted, offering a transparent view of the study's issues.

Pilot Test Analysis

The pilot study was especially useful when they helped identify design issues. The adjusted aspects of the study were then added into the final survey. These initial investigations through pilot studies, while smaller in scale,

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proved consequential yet impactful in terms of the benefits they offered to the research process. At its core, the pilot study was a testing ground for the tools, techniques, and strategies that were employed in the main study. By test-driving these elements, weaknesses or areas of improvement in the methodology were able to be identified, ensuring that when the full future study was conducted, the methods used were sound, reliable, and capable of yielding meaningful results. One of the significant advantages gained in this pilot testing is the potential for resource optimization. As the pilot study delves deep into participants' personal experiences, emotions, and perceptions, it also provided an opportunity to ensure that the research process was respectful, sensitive, and ethically sound. By contesting the interactions within the smaller group, an improved approach to ensure participants felt valued, understood, and comfortable was gained, which not only enhanced the quality of the insights collected, but also fostered trust and rapport with the research subjects.

Main Survey Analysis

Demographic Analysis

The following table has been shown as an overall representation of the considered demographics of the participated sample group of 93.

Table 1. Overall Demographic Analysis of the Sample Group.

Age Groups of Participants	
18-25	71,77%
25-35	15.16%
35-45	3.3%
Above 45	4.4%
The Current Educational Level of Participants	
Ordinary Level	4%
Advanced Level	9%
Higher National Diploma	31%
Bachelor’s Degree	54%
Master’s Degree	2%

The above table shows that the research is favoured due to high involvement of the Bachelor’s Degree Group and the 18-25 Age Group, whereas the minority here was labelled as the participants belonging to the 35-45 Age Group and the Master’s Degree group.

Inferential Analysis

Before conducting any further analysis, it was important to check if the data were reliable, valid, and also normally distributed. Respectively, the applications of Cronbach's coefficient alpha, the Kaiser-Meyer-Olkin (KMO) Test, and the Kolmogorov-Smirnov test were used (since the sample size is > 50).

Table 2. Inferential Analysis of the Research’s Reliability, Validity and Normality.

Reliability Analysis	
Cronbach’s Alpha	0.993
Validity Analysis	

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Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.877	
Bartlett's Test of Sphericity	Approx. Chi-Square	379.419
	Sig.	0.000
Normality Testing		
Dependent Variable		
Accuracy and Efficacy of Advanced Cyber Threat Detection Mechanisms	Skewness	- 0.040
	Kolmogorov-Smirnov's Sig.	0.007
Independent Variables		
Level of Sophistication of the Cyber Threat	Skewness	- 0.023
	Kolmogorov-Smirnov's Sig.	0.011
Type of Cyber Threat Detection Mechanism used	Skewness	- 0.057
	Kolmogorov-Smirnov's Sig.	0.015
Choice of Analytical Tools and Platforms	Skewness	- 0.010
	Kolmogorov-Smirnov's Sig.	0.009
Use of Machine learning algorithms	Skewness	- 0.049
	Kolmogorov-Smirnov's Sig.	0.017
Frequency of Data Collection and its Analysis	Skewness	0.071
	Kolmogorov-Smirnov's Sig.	0.010
Complexity of the Dataset	Skewness	- 0.040
	Kolmogorov-Smirnov's Sig.	0.007

As per the above table, the research's reliability, which was checked using Cronbach's Alpha, proved that the internal consistency of the questionnaire is preserved, as a value greater than 0.7 was taken to be reliable[13]. Also, the research's validity was checked using factor analysis, as the KMO (Kaiser-Meyer-Olkin) value was above 0.7 and the Bartlett's Test of Sphericity's p-value (Sig.) was less than 0.05[14].

However, when it came to the Normality Testing, certain factors weren't found to be normally distributed because the Kolmogorov-Smirnov p-value (Sig.) was greater than 0.05 and the skewness values fell between -1 and +1[15]. Therefore, it did not match the typical criteria that needed to be met, and it was concluded that the data was not normally distributed. As this has been the case, it was decided to conduct a few more tests such as Spearman's Rho and, finally, a Generalized Linear Model (GLM) that extends the capabilities of traditional linear models to encompass non-numerical measures of outcome[16].

Table 3. Correlational Analysis.

Correlational Analysis of the Independent Variables in relation to the Dependent Variable		
Sophistication Level of the Cyber Threat	Spearman's Rho Correlation Coefficient	0.995
	Sig.	< 0.001

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Type of Cyber Threat Detection Mechanism used	Spearman's Rho Correlation Coefficient	0.991
	Sig.	< 0.001
Choice of Analytical Tools and Platforms	Spearman's Rho Correlation Coefficient	0.995
	Sig.	< 0.001
Use of Machine Learning algorithms	Spearman's Rho Correlation Coefficient	0.943
	Sig.	< 0.001
Frequency of Data Collection and its Analysis	Spearman's Rho Correlation Coefficient	0.956
	Sig.	< 0.001
Complexity of the Dataset	Spearman's Rho Correlation Coefficient	0.911
	Sig.	< 0.001

When there are outliers in the sample data, as seen in Table 2, Spearman's Rho is frequently used for correlation. There should be a monotonic relationship between the two variables. This indicates that there is consistency in the direction of the relationship between the variables. For example, an increase in one variable generally causes an increase in the other[17]. As the significance values of all independent variables were noted to be less than any reasonable significance value (< 0.001) and also the correlation coefficients were noted to be between 0.50 and 1.0, it can be concluded that the relationship of the dependent variables possesses a statistically significant association with each of the independent variables, supporting the notion that the relationship exists in the population.

It is to be noted that Correlation coefficients ranging from 0.911–0.995 can be seen as exceptionally high for behavioural survey research and may indicate multicollinearity or common method bias. In order to tackle the hypothesis, assessing multicollinearity using appropriate diagnostics (such as VIF), can be used here.

Table 5. VIF and Tolerance values of the independent variables.

Independent Variable	**Tolerance**	**VIF**
Sophistication Level of the Cyber Threat	0.442	2.264
Type of Cyber Threat Detection Mechanism used	0.410	2.440
Choice of Analytical Tools and Platforms	0.343	2.912
Use of Machine Learning algorithms	0.464	2.157
Frequency of Data Collection and its Analysis	0.421	2.375
Complexity of the Dataset	0.416	2.402

A VIF score starts at 1.0, indicating that the predictor is not correlated with any other variables in the model. As a general rule, a VIF value greater than 5 (or 10) and a Tolerance value less than 0.20 indicate that multicollinearity is high and may cause instability[18]. However, the total opposite is seen here and therefore can be used to indicate that the multicollinearity is low and does not cause instability.

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Another test can be done to address the potential Common Method Bias (CMB) that would cause to invalidate the study, which is known as Harman's Single Factor Test. Researchers have frequently used this test when their data comes from a single source (i.e., the same respondents answer all questions on a questionnaire). Passing this test would provide the reassurance that the relationships between variables are valid and not merely an artifact of the survey instrument, as failing this test would be advised as a potential bias or, rather, a limitation[19].

Table 6. Harman's Single Factor Component Matrix.

Variable	**Component 1**
Accuracy and Efficacy of Advanced Cyber Threat Detection Mechanisms	0.464
Level of sophistication of the cyber threat	0.439
Type of Cyber Threat Detection Mechanism used	0.436
Choice of analytical tools and platforms	0.361
Use of Machine Learning algorithms	0.795
Frequency of Data Collection and its Analysis	0.272
Complexity of the Dataset	0.811

While observing Table 6, it has been noted that except for the variables 'Complexity of the Dataset' and 'Use of Machine Learning algorithms', the rest of the variables possess a non-significant issue as they do not reach a value greater than 0.5 (or 50%). Therefore, except for the variables 'Complexity of the Dataset' and 'Use of Machine Learning algorithms', the common bias does not inflate the data's correlation, and it would not be a study limitation.

The generalized linear model (GLM) is a useful technique that extends the capabilities of traditional linear models to encompass non-numerical measures of outcome. The variables consisted of composite Likert-scale scores and therefore a GLM was considered more appropriate, as it has provided greater flexibility in handling data that deviate from normality while estimating the contribution of multiple predictors simultaneously. For this study, a Gaussian distribution with an identity link function specified GLM has allowed the expected value of the dependent variable to be modelled directly as a linear combination of the predictor variables.

Before model estimation, several assumptions were assessed. Each questionnaire represented a unique respondent, and no participant contributed multiple responses, satisfying the assumption of independent observations. As for multicollinearity among the factors, Table 5 has already indicated acceptable levels of multicollinearity, as all VIF values were below five and tolerance values exceeded 0.20. As all the variables were collected using the same questionnaire, the Harman's Single Factor Test results shown in Table 6 suggested that the common method bias was unlikely to substantially bias the observed relationships.

The adequacy of the fitted GLM was evaluated using the model deviance and Wald Chi-Square goodness-of-fit statistics. This evaluated whether an individual regression coefficient or a group of coefficients significantly differs from a hypothesized value (being zero). The values must exceed a critical chi-square limit to deem a predictor statistically significant or not. At a standard of the alpha value equal to 0.05 significance level, the degrees of freedom being one must surpass the critical Chi-square limit of 3.841 to be considered statistically significant[20].

An effect size measure summarizes the answer in a single, interpretable number. This is important as the effect sizes allow comparison of effects both within and across studies and to estimate power[21]. Using Spearman's Rho, the correlations could be taken as very large effects. However, to warrant the potential limitations or bias, Table 5 and Table 6 have been used to address it. Alternatively, Wald Chi-square with confidence intervals and p-values can be shown, as it would be a test statistic rather than an effect size. A confidence interval gives a range of plausible values for a population parameter based on the sample data while assessing its width, where a wide interval should indicate a smaller sample, meaning more uncertainty about the true population value[22].

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The significance value in the Hypothesis Test (taken from the Parameter Estimates table) should be either greater than or less than 0.050. The significance value should be greater than 0.050 to accept that the independent variable has no significant effect on the dependent variable. Or less than 0.050 to reject the null hypothesis and accept that the independent variable has a significant effect on the dependent variable.

Table 7. Generalized Linear Model (GLM) for the above relationships.

Predictor	Wald Chi Square Value	Degrees of Freedom (df)	p-value (Sig.)	Assessment
Sophistication Level of the Cyber Threat	43.792	1	0.000	Significant
Type of Cyber Threat Detection Mechanism used	88.187	1	0.000	Significant
Choice of Analytical Tools and Platforms	5.175	1	0.023	Significant
Use of Machine Learning Algorithms	3.146	1	0.076	Insignificant
Frequency of Data Collection and its Analysis	4.214	1	0.040	Significant
Complexity of the Dataset	3.290	1	0.070	Insignificant

Table 8. Confidence Intervals.

Predictor	Wald Confidence Intervals	
	Lower	Higher
Sophistication Level of the Cyber Threat	0.237	0.437
Type of Cyber Threat Detection Mechanism used	0.387	0.591
Choice of Analytical Tools and Platforms	0.008	0.104
Use of Machine Learning Algorithms	- 0.004	0.075
Frequency of Data Collection and its Analysis	0.002	0.095
Complexity of the Dataset	- 0.003	0.072

As mentioned above, the independent variables present themselves with either the presence or absence of a significant effect on the dependent variable. The results obtained have been summarized above as well.

With that, it should be noted that, in the end, the factors Level of sophistication of the cyber threat, Type of Cyber Threat Detection Mechanism used, Choice of analytical tools and platforms, and Frequency of data collection and its analysis would affect the Accuracy and Efficacy of Advanced Cyber Threat Detection Mechanisms.

Discussion

Relevance of Findings

This study extended existing Advanced Persistent Threat (APT) detection research by providing empirical evidence from the Sri Lankan context, where organizational implementation factors were examined alongside technological capabilities. Unlike many previous studies that primarily evaluated machine learning (ML) and deep learning algorithms using benchmark datasets under controlled environments[2,3,4], this study employed a quantitative survey and Generalized Linear Model (GLM) to identify independent predictors of cyber threat detection performance. The findings demonstrated that the level of sophistication of the cyber threat, type of cyber threat detection mechanism used, analytical tools and platforms, and frequency of data collection and analysis significantly improve detection accuracy and efficacy. These results supported previous studies advocating behavioural

analytics, hybrid detection mechanisms, integrated analytical platforms, and continuous monitoring for effective APT detection while extending their applicability through organizational evidence from a developing-country setting.

On the other hand, the use of ML algorithms and complexity of the dataset were not statistically significant predictors. Although this contrasts with many algorithm-focused studies reporting high detection accuracy, the difference is likely attributable to contextual factors. Existing literature largely evaluates ML under ideal laboratory conditions, whereas the present study reflects operational environments where limited computational infrastructure, quality datasets, cybersecurity expertise, and organizational maturity constrain the practical benefits of advanced AI techniques.

Consequently, the findings suggested that organizational readiness, continuous monitoring, and effective implementation currently exert greater influence on cybersecurity performance. Furthermore, these findings provided important implications for Sri Lanka's cybersecurity ecosystem. Instead of prioritizing sophisticated AI technologies alone, policymakers should support building more cybersecurity capacity, professional training, and standardized security frameworks, while the industry should invest in integrated analytics and threat intelligence capabilities to enhance cyber resilience and enable the gradual adoption of advanced AI-driven cybersecurity solutions.

Ethical Considerations

Ethical considerations in research are a set of principles that guide the research designs and practices. When collecting data from people, scientists and researchers must always respect a certain code of conduct. These considerations aim at protecting research participants' rights, enhancing the validity and scientific or academic integrity. Furthermore, this covers that they've been protected in terms of the rights of participants and their wellbeing, ensuring that the research findings are valid and trusted; It's not a box for them to fill in; This is an essential consideration that can have a major impact on the results of this research[23,24].

Notwithstanding these ethical safeguards, several methodological limitations should be considered when interpreting the findings. First, the cross-sectional design of this study captured respondents' perceptions at a single point in time, limiting the ability to infer causal relationships between the investigated variables. Longitudinal studies would provide stronger evidence regarding changes in organizational cybersecurity capabilities and APT detection effectiveness over time. Secondly, the reliance on self-reported survey responses introduces the potential for self-report and social desirability biases, whereby participants may have overestimated their organizations' cybersecurity practices. Thirdly, although Harman's Single Factor Test indicated that common method bias cannot be entirely excluded due to the use of a single data collection instrument.

As it must be voluntary participation, nobody was forced to be part of it, or they were pressured to do something that they were not pleased to do. This meant that people had the choice and could even back out of the study if they initially agreed to participate. As Informed consent was not just an ethical consideration, it was also a requirement in the law. What they agreed to, including potential risks and benefits, needed to be fully understood by participants. Information on the advantages, risks, funding, and institutional approval of a study was included. A method of anonymizing research data, which required the creation of a numeric ID for participants who cannot be linked back to their original identity by means of numerical codes used so that it was not possible to trace individual participants. Information gathered in the course of the study was kept confidential. In determining whether a research study should be conducted, the potential for harm was of paramount importance. All possible sources of harm to participants were taken into consideration as a researcher. Harm could come in many different forms, such as psychological harm, social harm, physical harm, and legal harm. Also, the findings may not be fully generalizable to the broader Sri Lankan Population.

Conclusion

This study observed how data analytics affects the accuracy and overall effectiveness of Advanced Persistent Threat (APT) detection in organizations across Sri Lanka. It used a quantitative cross-sectional survey, then applied a Generalized Linear Model (GLM) to see what really mattered. Overall, the results suggested that the level of sophistication in the cyber threats, the kind of cyber threat detection mechanism, the analytical tools and platforms in place, and how often data is collected and analysed were all meaningful drivers of effective detection. At the same time, the use of machine learning algorithms and the complexity of the datasets did not show up as statistically significant independent factors that were surveyed.

The study also has three main contributions. First, it gives one of the relatively few empirical investigations of data analytics-enabled APT detection in a developing-country setting, addressing a noticeable geographical gap within the cybersecurity literature. Second, it complements research that mostly focuses on algorithms, as it argues that certain factors, such as organizational implementation capability and day-to-day operational practices, may shape detection performance more than raw technical sophistication alone. Third, the findings offer practical guidance for organizations, since they highlight continuous monitoring, integrated analytical platforms, and strong detection architectures as top priorities for improving cybersecurity resilience. Collectively, these contributions move the conversation forward on how data analytics can be leveraged well to strengthen APT detection, and they also help researchers and practitioners who seek to improve capabilities in environments where resources are limited.

Future Directions

Future researchers should carefully consider these factors to ensure their chosen methodology aligns with the aims of their study and yields meaningful insights. As per other methodologies such as Time Frame, Sampling Strategy and Data Collection and Analysis should be also tailored accordingly. Future studies should employ a larger, more diverse samples and incorporate multiple data sources or longitudinal designs to improve generalizability and future reduce potential response and method biases. Although realism is another approach that can be recommended, the approach of the study should be focused on numbers and the graphical representations formed through it and not through experiences through theoretical representations. Realism embraces the subjective construction of meanings made by and attached to people's experiences, which provide sophistication and insights into social processes and action. However, the research design in realism stresses the adaptability of the research methodologies to suit different situations and contexts of social realities. It would be also possible for the researchers to fully or partly employ both the positivist and realist approaches to the studies. Finally, comparative international studies are recommended to evaluate whether organizational determinants identified in the study remain consistent across countries with different levels of cybersecurity maturity, regulatory environments, and technological infrastructure, which would improve the generalizability of findings while facilitating the development of context-sensitive frameworks and evidence-based policies.

References

1. Stojanović B, Hofer-Schmitz K, Kleb U. APT datasets and attack modeling for automated detection methods: A review. Computers & Security [Internet]. 2020 Jan 29; 92:101734. Available from: https://doi.org/10.1016/j.cose.2020.101734
2. Mutalib NHA, Sabri AQM, Wahab AWA, Abdullah ERMF, AlDahoul N. Explainable deep learning approach for advanced persistent threats (APTs) detection in cybersecurity: a review. Artificial Intelligence Review [Internet]. 2024 Sep 18;57(11). Available from: https://doi.org/10.1007/s10462-024-10890-4
3. Hallaji E, Razavi-Far R, Saif M. A study on the importance of features in detecting advanced persistent threats using machine learning. arXiv (Cornell University) [Internet]. 2025 Feb 11; Available from: http://arxiv.org/abs/2502.07207
4. Rani N, Saha B, Shukla SK. A comprehensive survey of automated Advanced Persistent Threat attribution: Taxonomy, methods, challenges and open research problems. Journal of Information Security and Applications [Internet]. 2025 May 20; 92:104076. Available from: https://doi.org/10.1016/j.jisa.2025.104076
5. Li W. A Comparative Analysis of Advanced Persistent Threat Detection Methodologies: A Systematic review. Applied and Computational Engineering [Internet]. 2025 Jul 11;165(1):102–8. Available from: https://doi.org/10.54254/2755-2721/2025.ld24900
6. Salim DT, Singh MM, Keikhosrokiani P. A systematic literature review for APT detection and Effective Cyber Situational Awareness (ECSA) conceptual model. Heliyon [Internet]. 2023 Jun 16;9(7): e17156. Available from: https://doi.org/10.1016/j.heliyon.2023.e17156
7. Krishnapriya S, Singh S. A comprehensive survey on Advanced Persistent Threat (APT) Detection techniques. Computers, Materials & Continua/Computers, Materials & Continua (Print) [Internet]. 2024 Jan 1;80(2):2675–719. Available from: https://doi.org/10.32604/cmc.2024.052447
8. Ali AH, Charfeddine M, Ammar B, Hamed BB, Albalwy F, Alqarafi A, et al. Unveiling machine learning strategies and considerations in intrusion detection systems: a comprehensive survey. Frontiers in Computer Science [Internet]. 2024 Jun 10;6. Available from: https://doi.org/10.3389/fcomp.2024.1387354
9. Nelles F, Yazdinejad A, Dehghantanha A, Parizi RM, Srivastava G. A federated learning approach for multi-stage threat analysis in advanced persistent threat campaigns. arXiv (Cornell University) [Internet]. 2024 Jun 19; Available from: http://arxiv.org/abs/2406.13186

10. Shenderovitz G, Nissim N. Bon-APT: Detection, attribution, and explainability of APT malware using temporal segmentation of API calls. Computers & Security [Internet]. 2024 Apr 24; 142:103862. Available from: https://doi.org/10.1016/j.cose.2024.103862
11. Karim SS, Afzal M, Iqbal W, Abri DA. Advanced Persistent Threat (APT) and intrusion detection evaluation dataset for Linux systems 2024. Data in Brief [Internet]. 2024 Mar 5; 54:110290. Available from: https://doi.org/10.1016/j.dib.2024.110290
12. Ahmad H, Halim H. Determining Sample Size for Research Activities: The Case of Organizational Research. Business Review Journal [Internet]. 2017 Dec. 1 [cited 2026 Apr. 21];2(1):20-34. Available from: https://sbr.journals.unisel.edu.my/index.php/sbr/article/view/12
13. DeVellis R. F. Inter-Rater reliability. In: Encyclopedia of Social Measurement [Internet]. 2005. p. 317–22. Available from: https://doi.org/10.1016/b0-12-369398-5/00095-5
14. Dodge Y. The concise encyclopedia of statistics. Springer Science & Business Media; 2008 Apr 15. Available from: https://doi.org/10.1007/978-0-387-32833-1
15. OnlineSPSS.com. How to run normality test in SPSS - OnlineSPSS.com [Internet]. OnlineSPSS.com. 2022. Available from: https://www.onlinespss.com/how-to-run-normality-test-in-spss
16. Beyond the Bell Curve: A Practical Guide to Statistical Tests for Non-Normal Biomedical Data [Internet]. Clyte. 2025 [cited 2026 Jul 15]. Available from: https://www.clyte.tech/post/guide-to-statistical-tests-for-non-normal-biomedical-data?srsltid=AfmBOorvahBGvCmmGLpIC2Bi179CJFZ-5Yjk4gmEGfQcsyfPtMVFYmju
17. Spearman's Rho [Internet]. StatsTest Blog. 2020. Available from: https://www.statstest.com/spearmans-rho/
18. Bock T. What are Variance inflation factors (VIFs)? [Internet]. Displayr. 2025. Available from: https://www.displayr.com/variance-inflation-factors-vifs/
19. Datapott Analytics & Research. How to do Harman's Single Factor Test in SPSS [Internet]. Medium. 2021 [cited 2026 Jul 15]. Available from: https://datapottanalytics.medium.com/how-to-do-harmans-single-factor-test-in-spss-79c9d878f5a5
20. Bhalla D. Understanding Wald Chi-Square in Plain English [Internet]. ListenData. [cited 2026 Jul 17]. Available from: https://www.listendata.com/2015/10/calculate-wald-chi-square-mathematically.html
21. Effect size in Statistics - the Ultimate guide [Internet]. Available from: https://www.spss-tutorials.com/effect-size/
22. Pius. How to interpret confidence intervals in spss [Internet]. SPSS Dissertation Help. 2025 [cited 2026 Jul 17]. Available from: https://spssdissertationhelp.com/how-to-interpret-confidence-intervals-in-spss/
23. Bhandari P. Ethical Considerations in Research | Types & Examples [Internet]. Scribbr. 2024 [cited 2026 Jul 15]. Available from: https://www.scribbr.com/methodology/research-ethics/
24. Denison G. Ethical Research: Best practices for responsible Studies [Internet]. Prolific. 2025 [cited 2026 Jul 15]. Available from: https://www.prolific.com/resources/ethical-considerations-in-research-best-practices-and-examples

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OP 02

AI-Powered Dental Prosthetic and Recommendation System

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Abstract

Dental prosthetic selection is largely subjective, exhibiting inter-practitioner variability and typically requiring multiple consultation visits. Existing dental artificial intelligence (AI) solutions concentrate on radiographic diagnosis and stop short of producing actionable, patient-specific treatment recommendations that integrate clinical, demographic, and financial factors. This study developed an integrated, explainable web-based decision-support prototype that combines automated dental radiograph analysis with structured patient data to generate ranked prosthetic treatment recommendations supporting consistent clinical workflow. A three-tier system (Next.js, FastAPI, MongoDB, Flask reporting service) was implemented. A YOLOv8-Nano detector was fine-tuned for 20 epochs on the public Rob flow Dental X-Ray Panoramic v3 dataset (16,995 annotated radiographs, ten conditions, CC BY 4.0). A hybrid rule-based and heuristic scoring engine over a nine-treatment knowledge base produces ranked top-five recommendations with rationale and indicative costs. On the validation split, the fine-tuned detector achieved Precision 0.60, Recall 0.56, mAP@0.5 0.55, and mAP@0.5:0.95 0.28 across ten dental classes. The end-to-end pipeline executed within seconds on commodity hardware, returning annotated radiographs alongside ranked recommendations and downloadable PDF reports compiling patient data, detected conditions, suitability scores, rationales and indicative costs for clinical handover. The prototype demonstrates the feasibility of an integrated, explainable, web-deployable decision-support pipeline linking radiograph analysis with patient-specific data for prosthetic planning. Detection accuracy is moderate at this prototype stage. Expanded training data, held-out clinical validation and electronic health record integration are identified as priorities for future work.

Keywords: *clinical decision support, dental prosthetics, hybrid recommendation engine, object detection, YOLOv8*

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Introduction

Dental prosthetic treatment planning is a complex clinical activity that requires the integration of radiographic findings, demographic factors, the patient's medical history and financial considerations. In conventional practice, the selection of a suitable prosthetic restoration is largely a subjective decision dependent on the experience of the individual practitioner, which leads to inter-practitioner variability and consultation pathways that may extend over multiple visits before a treatment plan is finalised. This variability is particularly pronounced in resource-constrained settings where access to specialist consultation is limited.

Artificial intelligence (AI) has emerged as a transformative force in dentistry over the past decade [1]. Deep-learning approaches have produced strong performance across a range of diagnostic tasks, including the automated detection of caries, periapical lesions and other dental pathologies on panoramic and periapical radiographs [2,3]. Comprehensive scoping reviews of machine-learning applications in dentistry confirm rapid growth in the number and scope of such studies [4].

Object-detection architectures, and convolutional neural networks (CNNs) more broadly, have featured prominently in this body of work. Chen demonstrated automatic tooth detection and numbering on periapical radiographs using deep object-detection methods [5]. Londono evaluated CNN algorithms for landmark detection on cephalometric images [6]. Earlier work also explored hybrid multi-convolution networks for dental X-ray analysis [7]. A growing body of literature confirms that deep learning can deliver clinically meaningful detection performance on dental imagery [8].

In parallel, commercial AI-driven dental imaging platforms have emerged. Systems such as Overjet [9], Denti.AI [10], WeDiagnostiX [11] and Pearl AI [12] provide automated radiograph analysis, often integrated with practice-management software. These offerings emphasise the detection and annotation of pathology, but generally stop short of producing structured treatment recommendations that are tailored to the individual patient. The system presented in this paper is explicitly distinguished from these platforms because, rather than confining AI to image diagnosis, it integrates explainable, patient-specific treatment recommendations into the same workflow. As Aldahabani [13] and Najeehs [14] highlight, the application of AI to dental prosthetics and restorative planning, as opposed to diagnostic imaging, remains comparatively under-explored.

This gap motivates the present study. While detection-only systems can flag conditions, the clinical question of which treatment to perform still requires the practitioner to manually map detected findings to suitable interventions and to weigh patient-specific factors such as age, comorbidities, expected outcomes and cost. An integrated decision-support system that performs this mapping explicitly has the potential to standardise reasoning, document the rationale behind a recommendation and reduce the number of consultation iterations needed to converge on a plan [15].

The aim of this work is therefore to design, implement and demonstrate an end-to-end, web-deployable decision-support prototype that (i) detects dental conditions from panoramic radiographs using a fine-tuned YOLOv8-Nano object detector, (ii) combines the detection output with structured patient information through a hybrid rule-based and heuristic scoring engine and (iii) produces a ranked, explainable list of prosthetic treatment recommendations together with a downloadable clinical-handover report.

Methods

Study approach

This study followed a design-science research approach in which a software artefact was built and evaluated rather than a clinical hypothesis tested. The research progressed through six phases. These were problem identification (subjectivity and inter-practitioner variability in prosthetic selection); a structured literature review covering deep learning in dentistry [1-4], object detection for dental radiographs [5-8] and commercial dental AI products [9-12], which confirmed that recommendation-oriented systems remain under-explored [13,14]; requirements definition covering radiograph upload, automated condition detection, patient-data capture, ranked recommendation, rationale explainability and downloadable reporting; design of a three-tier web architecture and the recommendation engine; implementation; and evaluation, measuring detection performance on the validation split using Precision, Recall and mean average precision (mAP) at intersection-over-union (IoU) thresholds of 0.5 and 0.5:0.95, with the end-to-end pipeline reviewed qualitatively on sample radiographs.

The study did not involve human participants. All images came from a publicly available, CC BY 4.0 licensed collection on Roboflow Universe. No patient-identifiable information was processed, and no ethics approval was required.

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Implementation was managed as a single-developer Scrum across seven two-week sprints, each closing with a working increment, covering dataset acquisition and training-pipeline assembly (sprints 1-2), backend, persistence layer, and recommendation engine (3-4), frontend, reporting microservice and integration (5-6), and validation, documentation, and packaging (7). Version control was managed through GitHub, with sprint tasks tracked as Issues.

Dataset

Training and validation images were obtained from the Dental X-Ray Panoramic (version 3) dataset distributed through the Roboflow Universe platform under a Creative Commons Attribution 4.0 (CC BY 4.0) licence. The release contained 16,995 panoramic radiographs annotated for ten clinically relevant classes, namely Bone Loss, Caries, Crown, Filling, Implant, Missing Teeth, Periapical Lesion, Root Canal Treatment, Root Piece and Impacted Tooth. Pre-processing included auto-orientation with EXIF-orientation stripping, resizing to 640 × 640 pixels (stretch), conversion to greyscale, and histogram-equalisation auto-contrast. Online augmentation introduced 50 % horizontal flip, 50 % vertical flip, ±15° rotation, and ±25 % brightness adjustment. Annotations were supplied in YOLOv8 format, and the train/validation split followed the dataset distributor's published split.

Detection Model

Object detection was performed using YOLOv8-Nano, the smallest variant of the YOLOv8 family (≈3.01 M parameters). The model was initialised from the publicly distributed yolov8n.pt COCO-pre-trained weights and fine-tuned end-to-end on the dental dataset. An initial 10-epoch schedule was extended by further fine-tuning to a total of 20 epochs. The Ultralytics framework's "auto" optimiser selection was used with an initial learning rate $lr_0 = 0.01$, momentum 0.937, weight decay 5×10^{-4}, and a three-epoch warm-up. Training was performed in a Google Colab environment using cloud-provisioned GPU resources, with the best-performing checkpoint (selected by validation fitness) retained for inference.

Recommendation Engine

Following detection, an explainable recommendation engine maps the detected conditions to candidate treatments and ranks them according to a composite suitability score. The engine maintains a knowledge base of nine prosthetic and restorative treatments, namely Dental Implant, Dental Filling, Crown, Bridge, Denture, Root Canal Treatment, Veneer, Inlay/Onlay and Composite Bonding. Each treatment record contains the conditions it can address, an indicative cost range (in Sri Lankan Rupees), an expected duration, a documented success-rate estimate, age-suitability bounds, contraindications, a risk-level label, and qualitative descriptions of pros and cons. The knowledge base was compiled by the authors from published prosthodontic reference material and indicative cost information for Sri Lankan clinical practice; its parameter values are heuristic estimates selected by the researcher and have not yet been calibrated by an expert panel.

For each radiograph, the engine first extracts the set of detected condition labels from the detector output and selects the treatments whose condition lists include any detected label. Each candidate receives a base suitability score of 80 on a 0-100 scale, adjusted additively by five factors, (i) an age-suitability adjustment, awarding a bonus when the patient's age lies within the treatment's optimal window and a penalty when it falls outside the acceptable bounds; (ii) a budget-fit adjustment, strongly penalising treatments whose indicative cost exceeds the patient's stated budget and rewarding those well within it; (iii) medical-history modifiers for recorded comorbidities such as diabetes, smoking and bleeding disorders, including explicit contraindication penalties for implant and other surgical procedures; (iv) a success-rate bonus favouring treatments with higher documented success rates; and (v) a condition-severity weight reflecting the seriousness of the detected condition. A lightweight heuristic adjustment layer then refines the score using normalised features (age, gender, budget, treatment cost, success rate, risk level and the number of detected conditions), and the final score is clamped to the 0-100 range.

Because all adjustments are additive and bounded, conflicting clinical factors- for example, a clinically ideal treatment that exceeds the stated budget- lower a candidate's ranking rather than eliminate it, keeping alternatives visible to the practitioner. Treatments are sorted by final score and the top five are returned, each accompanied by a structured rationale, indicative cost range, expected duration, and success-rate estimate. The scoring logic is deterministic, so every ranking is fully traceable; the output is advisory, and the final treatment decision remains with the clinician.

System Architecture

The prototype is organised in three tiers (Figure 1). The presentation tier is a Next.js (TypeScript) single-page application that supports radiograph upload, patient-data entry, recommendation review and report download. The interface uses Tailwind CSS and is responsive across desktop, tablet and mobile form factors. The application tier

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is a FastAPI service that exposes REST (Representational State Transfer) endpoints for radiograph inference (invoking the YOLOv8-Nano model), patient management and recommendation generation. A separate Flask microservice handles PDF report generation using ReportLab, isolating heavy rendering work from the main inference pipeline. The data tier is MongoDB and stores patient records, detection results and generated recommendations. As the prototype is intended for use exclusively by dental technicians and dentists in a single-tenant environment, no end-user authentication is implemented, and access control is deferred to deployment-environment safeguards.

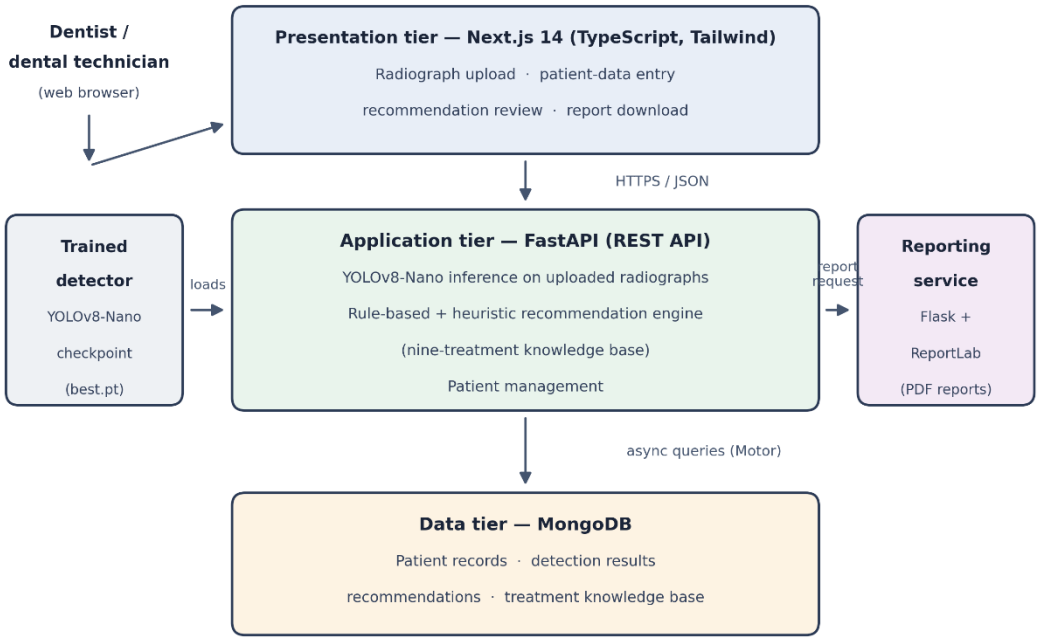

Figure 1. Three-tier architecture of the prototype (presentation, application and data tiers, with the reporting microservice).

Implementation environment

Development used Python 3.11, FastAPI 0.110, Flask 3.0, Ultralytics 8.3, Next.js 14, MongoDB 6.0 and PyTorch 2.x. The trained model checkpoint (best.pt) is bundled with the backend service. Inference runs on CPU or GPU, and no specialised hardware is required.

Results

Detection performance

The fine-tuned YOLOv8-Nano detector was evaluated on the dataset's validation split. Aggregate performance across the ten dental classes is summarised in Table 1.

Table 1. Validation-set detection performance of the fine-tuned YOLOv8-Nano detector.

Metric	Value
Precision	0.60
Recall	0.56
mAP@0.5	0.55
mAP@0.5:0.95	0.28

These figures reflect the performance of the model after 20 epochs of fine-tuning from a COCO-pre-trained backbone. They should be interpreted as prototype-stage rather than production-stage results, and deeper training schedules and larger backbones are expected to improve them further.

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Qualitatively, the detector localised larger and visually distinctive structures, such as crowns, dental implants and root canal treatments, more reliably than fine pathologies such as small caries lesions and periapical lesions, which are more sensitive to the confidence threshold. Figure 2 shows a representative inference output in which the detector has placed bounding boxes around several visible features of a validation-set panoramic radiograph.

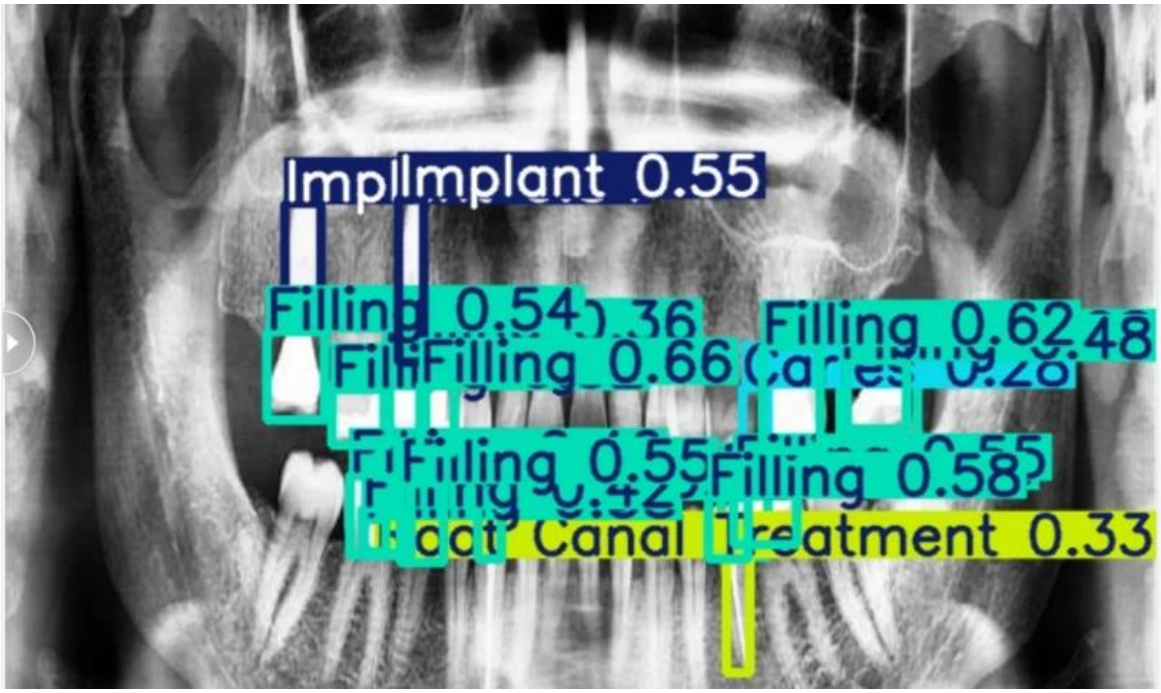

Figure 2. Representative annotated radiograph showing YOLOv8-Nano detection of dental conditions on a validation-set panoramic image.

End-to-end pipeline behaviour

The end-to-end pipeline ran without modification on commodity hardware. The radiograph is uploaded through the Next.js client, the FastAPI service runs inference and returns the detected conditions, and the recommendation engine scores candidates against the nine-treatment knowledge base. The frontend presents the top-five ranked recommendations alongside the patient-data form and an annotated copy of the radiograph. On request, the Flask reporting service compiles a multi-section PDF containing the patient details, an annotated radiograph thumbnail, the detected conditions and the ranked recommendations with rationale and indicative cost ranges.

In informal local benchmarks on a mid-range laptop with CPU-only inference, per-radiograph processing (including detection, scoring and rendering) completed within a few seconds, and PDF generation added on the order of one second.

Recommendation output

For a representative test radiograph containing detected “Caries” and “Missing Teeth” labels, the engine returned (in descending suitability order) Dental Filling, Composite Bonding, Crown, Dental Implant and Bridge. Each item in the output carried an explicit rationale string linking the detected condition(s) to the chosen treatment, an indicative cost range, an expected duration and a documented success-rate estimate sourced from the knowledge base.

Discussion

The prototype described in this paper differs from the current generation of dental AI tools in three respects. First, where systems such as Overjet [9], Denti.AI [10], WeDiagnostiX [11] and Pearl AI [12] focus on detection and annotation, the present system goes further and produces an explicit ranked treatment recommendation. Second, the recommendation logic combines radiographic findings with patient-specific demographic, medical and budget factors, addressing the multifactorial nature of prosthetic decision-making that purely image-driven systems cannot capture. Third, the rule-based scoring engine makes every recommendation explainable, since the rationale for any ranking can be inspected directly without looking inside opaque model internals.

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In the published literature, the closest contributions are the review-style papers of Aldahabani [13] and Najeehs [14], which discuss the future of AI in prosthetic and restorative dentistry but do not present an integrated end-to-end working system. Systematic reviews of AI in prosthodontics and implant dentistry similarly report that published models concentrate on laboratory, design and diagnostic tasks, such as automated restoration design, implant-type recognition and implant-success prediction, rather than on integrated, patient-specific treatment recommendation [16,17]. To the authors' knowledge, no published system yet combines panoramic-radiograph condition detection with demographic, medical and financial patient factors to produce ranked prosthetic recommendations, which precludes a direct quantitative comparison and underlines the gap the present prototype addresses as a concrete, inspectable reference implementation.

The detection performance achieved, mAP@0.5 of 0.55 across ten classes, is moderate; although it improves substantially on the initial short-schedule prototype, it remains below the level required for clinical use. Three factors plausibly explain the remaining gap. First, training still used a relatively short 20-epoch schedule from a COCO-pre-trained initialisation, and deeper schedules and larger backbones are expected to lift the mAP further. Second, the training data are community-contributed via the Roboflow Universe platform and have not been validated against a clinical gold-standard annotation protocol; annotation quality, class balance and the demographic and equipment diversity of the collection are not documented, so annotation noise and dataset bias cannot be excluded, and clinically validated datasets remain necessary before any pre-deployment evaluation. Third, the reported metrics are aggregated across the ten classes and are sensitive to class imbalance, and smaller or visually subtle classes (ex-periapical lesions) typically achieve lower per-class performance than larger structures.

The moderate detection performance has direct implications for the downstream recommendations and for patient safety. A missed detection (false negative) can remove an appropriate treatment from the candidate list entirely, while a false-positive detection can introduce candidates that are not clinically indicated; in both cases the ranking presented to the practitioner is degraded. Three design decisions mitigate this risk at the prototype stage. The annotated radiograph is displayed alongside the recommendations so the practitioner can visually verify every detection; the output is explicitly advisory, with the practitioner retaining full decision-making authority; and each recommendation carries a traceable rationale naming the detected condition it responds to, so an implausible detection is immediately visible rather than hidden inside an aggregate score. Nevertheless, substantially higher detection accuracy is a precondition for any clinical deployment.

Ethical, regulatory and medico-legal considerations also warrant discussion. The system is a clinical decision-support tool, not an autonomous diagnostic device, as clinical accountability for the selected treatment remains entirely with the treating clinician. Deployment beyond research would require conformity with the medical-device regulations applicable to software as a medical device (SaMD) in the target jurisdiction, together with documented risk management and transparent reporting of intended use and performance. The deterministic, rule-based design supports AI transparency, and the persistence of every recommendation with its rationale provides an audit trail relevant to medico-legal review. Patient-safety governance, informed consent regarding AI involvement and a clear delineation of responsibility between developer and practitioner would need to be established before clinical use.

Several limitations should be acknowledged. The evaluation reported here uses the dataset's published validation split rather than a held-out test set; a strict train/validation/test partition is a clear next step. No clinical validation has been performed, and the recommendation engine encodes deterministic heuristics whose cost ranges, age windows and severity weights have not yet been calibrated against published clinical guidelines or expert consensus. Likewise, the engine itself has been reviewed only qualitatively on sample cases; no quantitative measure of recommendation quality has yet been obtained. A planned evaluation will measure top-k recommendation accuracy against reference plans produced by practising dentists and prosthodontists, inter-clinician agreement and user satisfaction using standardised usability instruments. The system also lacks user authentication, acceptable for a controlled single-tenant deployment but required before any multi-tenant clinical use. Finally, the engine exposes a stable scoring interface deliberately designed so that the deterministic logic can later be replaced by a learned ranking component.

Regarding generalisability, the detection model was trained on Roboflow-distributed panoramic radiographs and performance on radiographs from substantially different imaging protocols, sensors or populations cannot be guaranteed without further validation. The recommendation knowledge base likewise encodes Sri Lankan Rupee cost ranges, and beyond costs, treatment availability, clinical conventions and patient expectations differ between healthcare systems; adapting the system to another setting would therefore require local clinicians to review its treatments, severity weights, cost data and contraindication rules. Despite these limitations, the prototype demonstrates the feasibility of an integrated, explainable, web-based pipeline that links radiograph analysis with

patient-specific data to deliver actionable treatment recommendations. Recent reviews [4,8] anticipate this class of integrated decision-support tool as a near-term direction for clinical AI in dentistry, and the present work contributes a working artefact in that direction.

Conclusions

This paper presented an integrated, web-deployable decision-support prototype for dental prosthetic treatment planning. The system combines a fine-tuned YOLOv8-Nano detector with a hybrid rule-based and heuristic scoring engine over a nine-treatment knowledge base and produces ranked, explainable recommendations together with a downloadable clinical-handover report. Detection performance on the validation split was moderate (mAP@0.5 0.55 across ten dental classes), reflecting the prototype-stage training schedule. The principal contribution is the end-to-end integration and the explicit, traceable mapping from detected conditions to ranked treatments through patient-specific factors.

Future work will proceed in three directions. Technical hardening will expand the training schedule, evaluate larger backbones and introduce a strict train/validation/test partition on clinically validated data. Clinical evaluation will assess recommendation accuracy and appropriateness with practising dentists and prosthodontists, including top-k agreement studies and usability testing measuring perceived usefulness, trust and workflow integration. System evolution will calibrate the knowledge base against published clinical guidelines, compare the deterministic engine with learned ranking approaches, including supervised and reinforcement-learning models trained on expert-labelled treatment decisions, and integrate the platform with electronic health record (EHR) systems and longitudinal patient records.

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References

1. Schwendicke F. Artificial intelligence in dentistry: a comprehensive overview. J Dent Res. 2020;99(7):769-74.
2. Sivari E. Deep learning in diagnosis of dental anomalies and diseases. Diagnostics (Basel). 2022;13(15):2512.
3. Khan MA. A comprehensive artificial intelligence framework for dental diagnosis and charting. J Clin Med. 2022;14(14):1-23.
4. Arsiwala-Scheppach LT. Machine learning in dentistry: a scoping review. J Clin Med. 2023;12(3):937.
5. Chen H. A deep learning approach to automatic teeth detection and numbering based on object detection in dental periapical films. Sci Rep. 2019;9(1):3840.
6. Londono J. Evaluation of deep learning and convolutional neural network algorithms accuracy for detecting and predicting anatomical landmarks on 2D lateral cephalometric images. Saudi Dent J. 2023;35:487-97.
7. Fonseka H. Automatic dental X-ray detection using a hybrid multi-convolution neural network. J Med Imaging. 2020;12(3).
8. Shekarapp C. Artificial intelligence-powered dentistry: enhancing patient care and efficiency. Dent Technol J. 2023;16(1):15-9.
9. Overjet. AI for dental X-ray analysis: complete guide [Internet]. 2025 [cited 2025 Jul 20]. Available from: https://www.overjet.com/
10. Denti.AI. AI-powered dental scribe, perio charting and X-ray diagnostics [Internet]. 2024 [cited 2025 Jul 20]. Available from: https://www.denti.ai/
11. WeDiagnostiX. AI-powered dental X-ray report [Internet]. 2024 [cited 2025 Jul 20]. Available from: https://wediagnostix.ai/en/automated-dental-x-ray-analysis-with-ai
12. Pearl AI. The growth of AI in dental radiology [Internet]. 2025 [cited 2025 Jul 20]. Available from: https://hellopearl.com/
13. Aldahabani S. The future of dental prosthetics: artificial intelligence and machine learning applications. Afr J Biomed Res. 2024;27(3):1063-70.

14. Najeehs M. Artificial intelligence (AI) in restorative dentistry: current trends and future prospects. J Dent Res. 2025;25(1):392.

15. Joda T. Health data in dentistry: an attempt to master the digital challenge. Public Health Genomics. 2019;22(1-2):1-7.

16. Bernauer SA. The use and performance of artificial intelligence in prosthodontics: a systematic review. Sensors (Basel). 2021;21(19):6628.

17. Revilla-León M. Artificial intelligence applications in implant dentistry: a systematic review. J Prosthet Dent. 2023;129(2):293-300.

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OP 03

Designing a Cloud-Connected Adaptive Serious Game Platform for Continuous Screening of ADHD in Sri Lankan Children Aged 5 to 12 Years

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Abstract

Background:

One of the most prevalent neurodevelopmental disorders of children is attention-Deficit/Hyperactivity Disorder (ADHD). The traditional ways of assessing ADHD are largely based on behavioural observations, questionnaires and parental and teacher subjectivity. Such techniques may lead to inconsistencies and delays in early identification. The field of serious games has seen recent progress, along with cloud computing, mobile sensing, and machine learning technologies, creating new opportunities for objective behavioural screening systems.

Objective:

The objective of this study is to develop and validate a cloud-based adaptive serious game system to assess behavioural parameters associated with ADHD in Sri Lankan children aged 5 to 12 years.

Methods:

A mobile serious game based on Unity was created to gather behavioural and motion data from children. The system measured omission errors, commission errors, reaction time, and device momentum during gameplay sessions. Data were transferred to an ASP.NET Core cloud backend system and analysed using a Support Vector Machine (SVM) model implemented with ML.NET. The final dataset consisted of 50 participants, including 24 ADHD-positive children and 26 non-ADHD children.

Results:

The proposed SVM classification model showed an accuracy of 90.9%, precision of 85.7%, recall of 100% and F1-score of 92.3%. The ROC analysis gave an AUC value of 0.93, indicating strong classification capability.

Conclusions:

The proposed system shows the feasibility of incorporating serious games, cloud technologies and machine learning for objective behavioural assessment of ADHD in Sri Lankan children.

Keywords: *ADHD, Behavioural Data Analysis, Machine Learning, Serious Game, Unity Game Engine*

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Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder that affects millions of children worldwide [1]. The disorder is commonly associated with behavioural symptoms such as inattention, impulsivity, and hyperactivity. Children diagnosed with ADHD often experience difficulties in academic performance, social interactions, emotional regulation, and behavioural control [2]. If the condition is not detected early, it can have a negative impact on educational development and psychological well-being in the long-term.

The traditional way of assessing ADHD involves clinical interviews, teacher rating scales, behavioural observation and questionnaires filled out by the parents [3]. These strategies are commonly employed in clinical work but rely on subjective human judgment and can yield variable outcomes. There is limited awareness of ADHD and access to specialised behavioural assessment services in many developing countries, including Sri Lanka. This means there is a great need for objective, affordable and scalable solutions for behavioural screening.

New opportunities for objective ADHD screening systems have emerged recently in the field of Machine Learning, Mobile Sensing, and Digital Behavioural Analysis [4]. It has been found that gameplay interactions, reaction patterns, motion sensor behaviour, and touch-based interaction data can be linked to characteristics of behaviour associated with ADHD [5]. These behavioural patterns can be analysed by machine learning algorithms, and symptoms of ADHD can be classified with a level of promise in terms of accuracy.

Corti et al. studied how to use mobile sensing and machine learning methods to quantify hyperactivity behaviours from accelerometer and gyroscope data [6]. They showed in their study that using movement-based digital biomarkers could aid in objective hyperactivity assessment. Likewise, Zakani et al. studied touchscreen interaction patterns and developed supervised learning algorithms for establishing correlations with touch interaction dynamics and ADHD risk prediction [7].

Game-based behavioural screening systems have also received a lot of research interest as children are naturally interacting with games, and the behavioural interaction data is measurable [8]. García-Murillo et al. created a serious game using machine learning for ADHD screening of children between 5 and 12 years of age [9]. Their study showed that machine learning methods can adequately aid in the classification of ADHD based on omission errors, commission errors, reaction times, and movement-related variables.

Although such technological developments have progressed, the majority of the studies that are currently undertaken have been with non-local populations and laboratory settings. Very limited research has focused on Sri Lankan children or culturally adapted game-based ADHD screening systems. Furthermore, there is a lack of cloud-connected adaptive systems capable of continuously collecting gameplay behavioural data and performing automated machine learning analysis.

Therefore, this research proposes a cloud-connected adaptive serious game platform designed specifically for Sri Lankan children aged 5 to 12 years. The proposed system integrates a Unity-based mobile game, ASP.NET Core cloud services, and ML.NET machine learning technologies to support objective behavioural ADHD screening using gameplay and motion-based behavioural indicators.

The aims of this research are:

- To design an interactive Unity game that measures children's attention, reaction, and impulsivity.
- To develop a web-based cloud system for storing and analysing gameplay data.
- To build a machine learning model using ML.NET to detect ADHD patterns from collected data.
- To create adaptive gameplay that adjusts difficulty based on player performance.
- To evaluate system accuracy, usability, and effectiveness in screening ADHD.

Methods

System Architecture

The proposed cloud-connected adaptive serious game platform is divided into three components: a Unity-based mobile game, a cloud-based web platform and a machine learning module. The Unity game was used to capture behaviours as children engaged in a series of interactive gameplay tasks to assess attention, impulsivity, reaction

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time and hyperactivity. In the game, the behaviour information was safely provided via RESTful APIs to an ASP.NET Core backend and stored in a Microsoft SQL Server database for further analysis.

The cloud platform offers participant management, gameplay data storage, behavioural analytics, and machine-learning prediction services. After collection, the behavioural features were extracted, and a Support Vector Machine (SVM) classifier was trained using ML.NET. The overall architecture of the proposed system is presented in Figure 1.

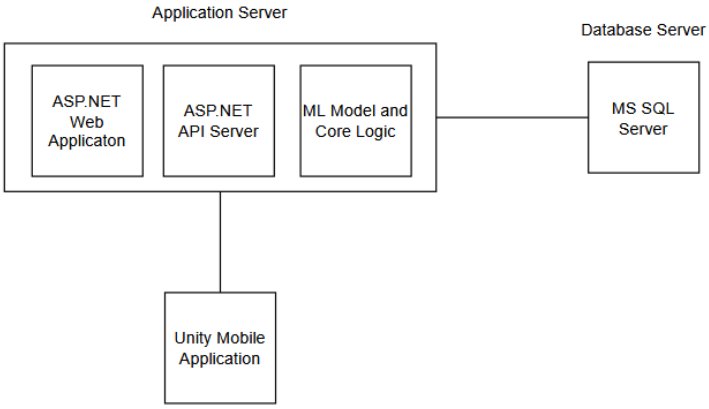

Figure 1 – System Architecture

Participant Recruitment

The study involved 50 children aged 5-12 years, comprising 26 non-ADHD and 24 ADHD positive children.

The non-ADHD children were chosen from local preschools through a convenience sampling technique. Parents verified that these children did not have any prior diagnoses or treatment history of ADHD.

ADHD-positive participants were selected using the snowball sampling method. Parents of children who had previously been diagnosed with ADHD introduced other eligible participants currently receiving medical treatment for ADHD. ADHD diagnosis was confirmed using available medical reports together with parental confirmation before participation.

To ensure the reliability of the selection of participants, the medical reports sent were checked by psychology lecturers who have experience in child behavioural assessment before finalisation of the data set. The distribution of the participants is summarised in Table 1.

Table 1 - Summary of participants

Participant Group	**Number**
Non-ADHD	26
ADHD	24
Total	**50**

Serious Game Design

The Unity game engine was used to create a serious game to objectively measure behavioural characteristics of ADHD. The proposed system is different from the traditional questionnaire-based screening methods in that it continually monitors during children's gameplay, as they would be at ease interacting with the game environment.

The game is comprised of four activities designed to test various behavioural traits of ADHD.

Omission Errors

The target shooting activity consists of recording the number of target objects missed during a predetermined time period, and it is used to measure omission errors. Higher omission error values indicate reduced sustained attention.

Commission Errors

A memory-based gameplay activity measures commission errors by recording incorrect selections. Higher commission error values indicate increased impulsive behaviour and reduced inhibitory control.

Reaction Time

Reaction time is calculated as the average time required for participants to respond to randomly presented game stimuli. Slower responses may indicate reduced attention and delayed cognitive processing.

Device Momentum

Device momentum is computed from the accelerometer and gyroscope sensor data gathered while playing the game. Hyperactivity is indicated by excessive movement during the game.

These were chosen based on their relevance as four behavioural features found in the game, and their effectiveness in identifying behavioural characteristics associated with ADHD according to the previous studies [6].

Adaptive Gameplay

To maintain participant engagement and obtain reliable behavioural measurements, the serious game incorporates adaptive gameplay mechanisms. The game continuously monitors player performance and dynamically adjusts difficulty levels according to the participant's behavioural responses. Children demonstrating improved performance receive increasingly challenging gameplay, whereas participants having trouble are presented with simplified game scenarios.

Adaptive gameplay enables behavioural measurements to be collected under varying levels of cognitive demand while reducing boredom and maintaining participant motivation throughout the assessment.

Behavioural Dataset

Following gameplay completion, behavioural records were automatically uploaded to the cloud database and exported for machine learning analysis.

Each participant record contained the following variables:

- Participant ID
- Gender
- Age
- Omission Errors
- Commission Errors
- Reaction Time
- Device Momentum
- ADHD Class Label

The first 26 records represent non-ADHD participants, while the remaining 24 records represent ADHD-positive participants. The ADHD class labels were assigned based on verified medical reports together with parental confirmation.

Table 2 - The behavioural features used for machine learning.

Feature	**Description**
Omission Errors	Number of missed targets

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Commission Errors	Incorrect responses during gameplay
Reaction Time	Average response time to stimuli
Device Momentum	Accelerometer and gyroscope movement score
ADHD Label	ADHD Positive / Non-ADHD

Data Preprocessing

The behavioural data collected was then preprocessed to enhance the quality of the information before using the data for machine learning model development.

The records were checked for incomplete gameplay sessions, invalid behavioural measurements and duplicate records. Records with incomplete information were excluded from the dataset. This resulted in a dataset without missing behavioural measurements after data cleaning.

This cleaned dataset was then structured for machine learning analysis to create a structured set of four behavioural variables with the corresponding labels of ADHD class for binary classification.

Machine Learning Model Development

To classify the participants as ADHD-positive and non-ADHD, a Support Vector Machine (SVM) classifier was chosen with the four extracted behavioural features.

The choice of SVM was motivated by the previous study conducted by Zakani et al. [11], who demonstrated that Support Vector Machine (SVM) classifiers are able to classify ADHD behavioural patterns from serious game data. Further, SVM has proved to be well suited for binary classification and is generally adept at learning with relatively small behavioural data sets, which makes it well suited for this prototype study.

The behavioural features used as input variables were:

- Omission Errors
- Commission Errors
- Reaction Time
- Device Momentum

The cleaned data set was then randomly split for model training into an 80% training set and a 20% test set. The training data set was used for the development of the classification model, and the testing data set was set apart for independent evaluation.

Behavioural feature preprocessing was performed using the ML.NET machine learning pipeline before model training. Five-fold cross-validation was applied during model development to improve model reliability and reduce the possibility of overfitting.

The proposed model was subjected to standard classification performance measures such as Accuracy, Precision, Recall, F1-score, Receiver Operating Characteristic (ROC) analysis, Area Under the Curve (AUC) analysis and a confusion matrix analysis.

This study is based on Support Vector Machine classification, but further study should be carried out to verify the proposed method with other machine learning algorithms such as Random Forest, Logistic Regression, XGBoost, and Neural Networks to find out which model is the most appropriate for the screening of behavioural ADHD.

Model Validation

The performance of the proposed SVM classifier was evaluated using the testing dataset. Classification performance was assessed using Accuracy, Precision, Recall, F1-score, ROC curve analysis, Area Under the Curve (AUC), and confusion matrix analysis.

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Table 3 - Performance Metrics of the Proposed SVM Model

Metrix	**Value**
Accuracy	0.909
Precision	0.857
Recall	1.000
F1 Score	0.923

Confusion Matrix Analysis

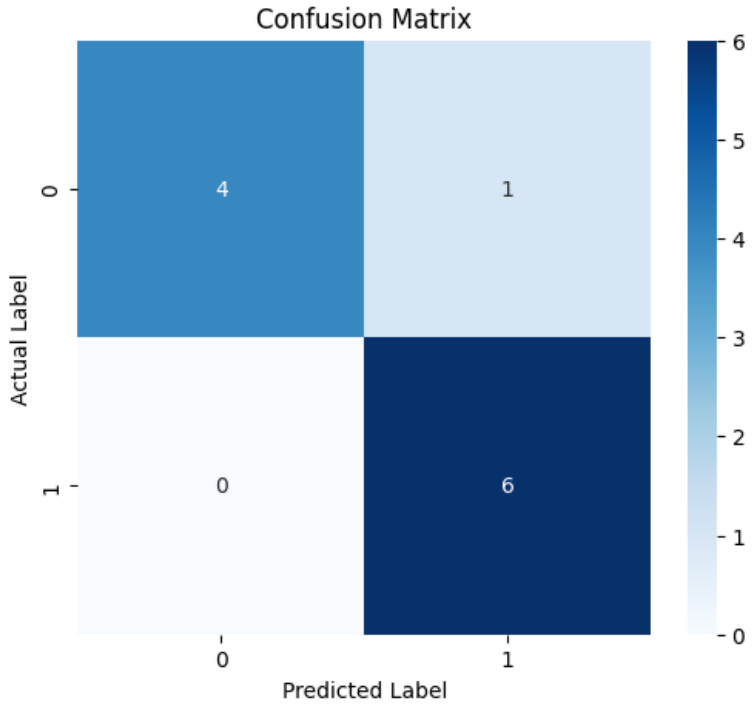

Figure 2 - Confusion Matrix Results

ROC Curve and AUC Analysis

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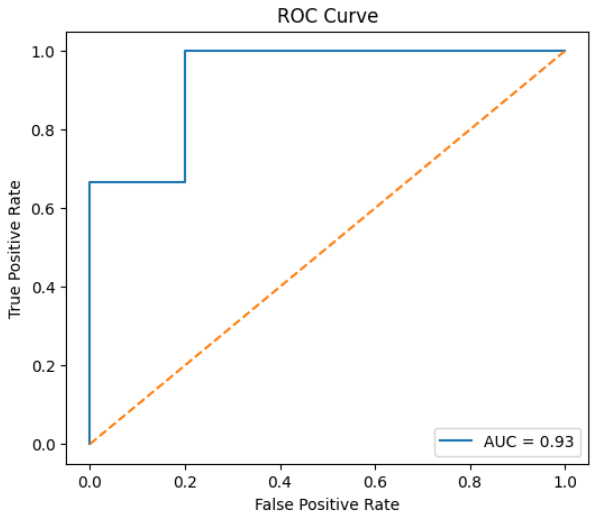

Figure 3 - ROC Curve

The current evaluation is prototype-level validation with the gathered behavioural dataset. The results obtained show the potential of the classifiers, but a larger and independent sample of participants is needed before the results can be used in practice.

To validate the results, future work will involve external validation with participants from various institutions and comparing the predictions of the machine learning models to the formal diagnostic assessments performed by qualified healthcare professionals.

Ethical Considerations

Parents and legal guardians were informed about the study and gave their consent for their children to take part in the study before the data were collected. The use of machine learning analysis excluded personal information, and each person was given a unique identification number to ensure confidentiality.

Data from gameplay sessions were reliably uploaded to the cloud service via authenticated RESTful APIs and securely stored in a SQL Server database with limited access for researchers.

The suggested system will only be used as an assistive behaviour screening system and should not be used as a substitute for professional clinical diagnosis. Children who are identified as potentially at risk should be assessed comprehensively by trained health care professionals.

Discussion

Results from this study show how gameplay behaviour and mobile sensor data can be effectively used to support behavioural ADHD screening of children. The achieved classification accuracy of 90.9% shows that the omission error, commission error, reaction time and device momentum can be used as meaningful behavioural indicators in the machine learning analysis.

This high recall score is significant as behavioural screening systems should minimise the possibility of missing children who may be at risk of ADHD. A recall value of 100% means that every ADHD-positive participant in the testing dataset was correctly identified by the model. While one false positive was noted, this kind of behaviour is acceptable in an early-stage behavioural screening system when there is more interest in detecting potential ADHD risk than in reducing false alarms.

The results are in line with a previous study by García-Murillo et al. [9], who showed that machine learning-based serious games are a suitable instrument for objective assessment of ADHD in children. Likewise, using machine learning methods, Corti et al. [6] found motion sensor data to be useful for quantifying hyperactivity-related behaviour.

The present study is an addition to the previous studies by creating a culturally adapted cloud-based ADHD screening platform unique to children in Sri Lanka. This study departs from many previous studies that focused on

laboratory-based gameplay scenarios and international participants by employing local participants and mobile devices.

The integration of Unity, ASP.NET Core, and ML.NET technologies also showcases how it is possible to integrate cutting-edge software engineering techniques with behavioural health screening programs. Adaptive gameplay also increased engagement and provided user behaviour data on an ongoing basis.

The selected behavioural variables showed good connections with ADHD symptoms. Errors of omission were the attention-related error type, and errors of commission were the impulsive behavioural error type. The cognitive response speed was measured by reaction time, and the hyperactivity-related behaviour of movement by device momentum.

Although these are encouraging results, there are several limitations to this study. The number of participants in the dataset was small (50 participants). There is a potential risk of overfitting and over-optimistic classification performance with small behavioural datasets. Thus, the results presented should not be considered as clinical diagnostic results.

One of the limitations was a prototype-level deployment environment. Gameplay sessions were run on a local server infrastructure rather than a large-scale deployment in a cloud environment. Future implementations should explore scalable cloud hosting solutions, such as scalable container deployment environments like Kubernetes.

Future research should focus on:

- Increasing dataset size using larger participant groups
- Expanding data collection across multiple geographic regions
- Investigating deep learning-based behavioural classification methods
- Collaborating with healthcare professionals for clinical validation
- Deploying the system using cloud-native architectures
- Comparing the proposed SVM model with Random Forest, Logistic Regression, XGBoost, and Neural Network classifiers

The proposed system shows substantial potential for scaling up for educational and healthcare applications of screening for behavioural ADHD. Serious games and machine learning technologies can be used to complement low-cost and low-tech behavioural screening solutions in developing countries.

Conclusions

This study proposed a cloud-based adaptive serious game platform for behavioural ADHD screening of children in Sri Lanka between the ages of 5 and 12 years. The proposed system integrated Unity-based gameplay, ASP.NET Core cloud services, and ML.NET machine learning technologies to analyse behavioural indicators related to attention, impulsivity, and hyperactivity.

The machine learning classification model showed excellent performance with 90.9% accuracy, 85.7% precision, 100% recall, 92.3% F1 score, and 0.93 AUC score. These results show that the gameplay interactions and motion sensor data can enhance objective behavioural screening methods that are used for ADHD.

The proposed platform was enhanced by its adaptive gameplay mechanism and cloud-connected architecture, further enhancing its functionality and scalability. However, the study was performed with a small sample size in prototype tests, so the results suggest that this idea of large-scale behavioural screening systems is feasible in the future.

The culturally adapted screening solution for Sri Lankan children is a contribution to the emerging area of serious games, behavioural analytics and machine-learning-based healthcare applications.

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References

[1] American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders. 5th ed. Washington DC: APA; 2013.

[2] World Health Organisation. Attention Deficit Hyperactivity Disorder in Children and Adolescents. Geneva: WHO; 2021.

[3] Barkley RA. Attention-Deficit Hyperactivity Disorder: A Handbook for Diagnosis and Treatment. 4th ed. New York: Guilford Press; 2014.

[4] Bishop CM. Pattern Recognition and Machine Learning. New York: Springer; 2006.

[5] Géron A. Hands-On Machine Learning with Scikit-Learn and TensorFlow. Sebastopol: O'Reilly Media; 2019.

[6] Corti C, Oldrati V, Ferrari E, Mazzarol G, Cattaneo Z. Objective Measurement of Hyperactivity Using Mobile Sensing and Machine Learning: Pilot Study. JMIR Form Res. 2022;6(3):e31258.

[7] Zakani Z, Stewart MW, Yuen T, et al. Predicting ADHD Risk from Touch Interaction Data. Sensors. 2023;23(7):3561.

[8] Arvidsson J, Gullberg M, Jansson G, Nilsson L. Behavioural Interaction Patterns and ADHD Screening Using Touch-Based Systems. Int J Hum Comput Stud. 2019;128:34-42.

[9] García-Murillo G, et al. The Validity of a Machine Learning-Based Video Game in the Objective Screening of Attention Deficit Hyperactivity Disorder in Children Aged 5 to 12 Years. Children (Basel). 2023;10(4):701.

[10] Microsoft Corporation. ML.NET Machine Learning Framework Documentation. Redmond: Microsoft; 2024.

[11] Zakani Z, Moradi H, Ghasemzadeh S, Riazi M, Mortazavi F. The Validity of a Machine Learning-Based Video Game in the Objective Screening of Attention Deficit Hyperactivity Disorder in Children Aged 5 to 12 Years; 2023.

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OP 04

Assessing Writers' Awareness, Perception, and Fairness Concerns Regarding the Use of Creative Works in Artificial Intelligence Model Training

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Abstract

Background: The use of writers' creative works to train artificial intelligence models without consent has sparked significant ethical and professional debate. While existing research has predominantly focused on established, professionally published authors, the perspectives of small, independent, and emerging writers who lack institutional protection remain largely absent from the literature.

Objective/s: This study aims to assess these writers' awareness, perceptions, and fairness concerns regarding AI training practices, and to evaluate how these factors relate to perceived fairness, creativity impact, and support for regulatory solutions.

Methods: A quantitative survey was conducted with 80 writers recruited from online writing communities. The survey measured five constructs: awareness, general perceptions, fairness concerns, creativity impact, and support for solutions. Data were analyzed using descriptive statistics, Pearson correlations, and multiple linear regression.

Results: The results reveal strong, cohesive opposition to unauthorized AI training. Awareness alone did not drive opposition; instead, fairness concerns and concerns about the devaluation of human creativity emerged as the strongest predictors. Writers also strongly supported consent-based models, attribution systems, and fair compensation.

Conclusion/s: This study demonstrates that for small, passion-driven writers, the threat of AI training is not about lost revenue but about the erosion of human value and creative meaning. Compensation-focused solutions alone will miss what matters most to this population. Unlike prior research on traditionally published authors, this study centres writers who create without financial gain, revealing that creative devaluation outweighs both ethical and economic concerns. These findings have direct implications for AI governance, copyright policy, and the future of creative labour in the age of generative AI.

Keywords: *Artificial intelligence, Consent, Creative writing, Fairness concerns, Training data*

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Introduction

Artificial Intelligence (AI) has become central to technological growth and now influences creative and professional industries [1, 2]. Modern AI models are trained on extensive internet datasets that often include creative materials such as stories, articles, and other written works [3, 4]. These datasets allow AI systems to generate human-like text and perform complex language tasks with high accuracy. However, many creative works are used without the explicit consent or awareness of their original authors, raising ethical and professional questions about ownership, fairness, and intellectual property [5, 6].

The increasing use of writers' work in AI training has sparked significant debate about fairness and the broader impact on the creative sector, particularly because independent and emerging writers often lack the protections afforded to established authors [7, 8, 9]. Although some writers view the integration of AI as an unavoidable aspect of digital publishing, many express unease or uncertainty about its legal and ethical ramifications. This diversity of perspectives underscores the necessity for systematic research into writers' attitudes, moving beyond anecdotal evidence to ensure that technological advancement respects creative rights and ethical standards. As web-scale data collection often conflicts with established ethical norms, it is essential to understand the factors motivating writers to engage in consensual data sharing, especially as platforms increasingly restrict access [11, 12, 13].

Previous research has primarily examined established, professionally published authors [5, 16] or focused on legal analyses of copyright frameworks [17, 18]. The perspectives of small, independent, and emerging writers are notably underrepresented in the literature. This omission is significant, as the experiences and concerns of non-commercial, passion-driven writers are likely to differ substantially from those of professional authors who depend on writing for income. For emerging writers, opposition may be rooted less in concerns about lost revenue and more in perceived threats to the intrinsic meaning and value of their creative work. Studying this population is therefore essential not only to broaden representation but also to understand a distinct set of ethical and creative dynamics that existing research has largely overlooked.

This study addresses this gap by employing quantitative methods to examine independent and emerging writers, offering the first systematic evidence regarding their awareness, attitudes, and concerns about AI training. Rather than presupposing whether writers should want their work used as training data, the research systematically explores how writers reason about this issue, the concerns they express, and the solutions they propose. The study investigates the following research questions:

- RQ1: To what extent are writers aware that their creative works may be used in training AI models?
- RQ2: How do writers perceive the use of their creative works in AI training, and what attitudes do they hold toward its influence on their creative practices?
- RQ3: Do writers believe that the use of their creative content without explicit permission is fair and ethically acceptable?
- RQ4: How do writers perceive the impact of AI training on creativity, originality, and the value of human-created content?
- RQ5: What level of support do writers show for potential measures to regulate the use of creative works in AI training?

To address these questions, a quantitative survey was administered to 80 writers and content creators recruited from online writing communities. The findings provide empirical insights into writers' concerns and lay the foundation for developing fair, transparent, and ethically robust AI training practices that recognize and protect the value of human creativity.

Methods

Recruitment and Participants

Participants were recruited through purposive sampling targeting small, independent writers and content creators who publish original written work in online spaces. Data collection occurred over two weeks. Recruitment posts were shared in publicly accessible online writing communities.

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The inclusion criteria for participation were that participants self-identified as writers who produce and publish original written work, including fiction, poetry, or fan fiction. Respondents who did not meet this requirement or did not provide informed consent were excluded. The final validated sample consisted of 80 respondents who met all inclusion criteria and provided complete responses to all survey items.

Procedure and Data Preparation

The survey instrument was developed specifically for this study to operationalize five research objectives: Awareness, Perceptions, Fairness, Creativity Impact, and Support for Solutions. Items were generated from a comprehensive review of the literature on writers' attitudes toward AI training [5, 7, 15, 16] and broader scholarship on data ethics and consent in AI research [11, 12]. The initial item pool reflected key themes such as consent, fairness, creative devaluation, and regulatory preferences.

The instrument underwent review by the research supervisor for clarity, relevance, and alignment with the objectives. Items were refined to improve wording and ensure adequate representation of each construct, resulting in a 19-item instrument. All items, except the two awareness questions, used a five-point Likert scale from "Strongly Agree" (coded as 1) to "Strongly Disagree" (coded as 5), in line with standard attitudinal research practice.

The instrument comprised five sections: Awareness (2 items), Perceptions and Attitudes (5 items), Fairness and Ethics (4 items), Impact on Creativity (4 items), and Support for Solutions and Regulation (4 items). The Awareness section measured general knowledge of AI training practices and the perceived likelihood that personal work would be included in them. Perceptions covered legitimacy, concerns about unauthorized use, value of AI as a resource, views on restricting AI, and whether permission-seeking would alter attitudes. Fairness examined ethical acceptability, fairness of current practice, corporate responsibility, and whether societal benefits justify unauthorized use.

Creativity Impact included the devaluation of human creativity, a threat to professional livelihood, AI as a collaborative tool, and whether AI-generated content increases appreciation of human writing. Support addressed legal regulations for opt-in consent, attribution or royalty systems, ethical guidelines, and willingness to participate under fair compensation.

After the survey closed, responses were exported for processing. Likert-scale responses were converted to numerical values. Eight items (Perception01, Perception03, Perception04, Fairness02, Fairness04, Creativity03, Creativity04, and Support04) were reverse-coded so that higher scores consistently indicated more negative or critical attitudes toward AI training practices. For each construct, composite scores were calculated by averaging the constituent items after reverse-coding.

Statistical Analysis

Descriptive statistics, including means, standard deviations, and ranges, were calculated for all variables. Pearson correlation coefficients were computed to examine bivariate relationships between constructs. To assess the internal consistency of the multi-item scales, Cronbach's alpha was calculated for each construct. The overall Cronbach's alpha for the 19-item instrument was .543. Item-level examination revealed that the Perceptions scale (initial alpha = .147) contained one item (Perception05) with a negative corrected item-total correlation. Following the "alpha if item deleted" criterion, this item was removed, resulting in a revised four-item Perceptions scale with acceptable internal consistency (alpha = .690).

Before conducting regression analyses, assumption testing was performed. Multicollinearity was assessed using the Variance Inflation Factor (VIF), with values below 10 indicating acceptable levels of collinearity [19]. All VIF values fell below 2.5, confirming that multicollinearity did not unduly influence the regression estimates. Residual analysis was conducted by examining standardized residuals against predicted values and Q-Q plots, which indicated that the assumptions of linearity, homoscedasticity, and normality of residuals were reasonably satisfied. Effect sizes are reported as standardized beta coefficients and R^2 values. Confidence intervals (95%) are reported for all regression coefficients in Table 2.

Construct validity was assessed through exploratory factor analysis. Bartlett's test of sphericity was significant ($\chi^2 = 466.37$, df = 171, $p < .001$), confirming adequate inter-item correlations, and the Kaiser-Meyer-Olkin measure of sampling adequacy (.660) indicated acceptable sampling adequacy for factor analysis. Descriptive statistics for all constructs are presented in the Findings section.

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Results

Across all constructs, a consistent pattern emerged: writers hold strong, cohesive opposition to unauthorized AI training, driven primarily by concerns about creative devaluation and ethical violation rather than mere awareness of the practice. Table 1 presents the descriptive and bivariate correlations for all constructs.

Table 1 - Descriptive Statistics and Pearson Correlation Matrix

Construct	M	SD	1	2	3	4	5
Awareness	4.08	0.70	—				
Perceptions	4.18	0.43	.177	—			
Fairness Concerns	4.78	0.41	.296**	.456**	—		
Creativity Impact	3.79	0.66	.273*	.148	.288**	—	
Support for Solutions	4.22	0.41	.084	.159	.248*	-.048	—
Overall Opposition	4.60	0.44	-.015	.266*	.395**	.451**	.230*

Note: N = 80; *p < .05, *p < .01

Table 2 presents the full multiple regression results.

Table 2 - Multiple Linear Regression Predicting Overall Opposition

Predictor	B	SE B	β	t	p	95% CI	VIF
Awareness	-0.150	0.061	-.242	-2.453	.017	[-0.272, -0.028]	1.12
Perceptions	0.102	0.105	.100	0.964	.338	[-0.108, 0.312]	1.45
Fairness Concerns	0.258	0.117	.246	2.199	.031	[0.024, 0.492]	1.33
Creativity Impact	0.290	0.065	.441	4.437	< .001	[0.160, 0.420]	1.28
Support for Solutions	0.207	0.102	.195	2.021	.047	[0.003, 0.411]	1.09

Note: $R^2 = .370$, Adjusted $R^2 = .328$, $F(5, 74) = 8.710$, $p < .001$; DV = Overall Opposition Index

Awareness

Most participants were highly aware that AI models are trained on large internet text datasets, with a mean awareness score of 4.08 out of 5 (SD = 0.70), indicating that participants were generally well-informed about AI training practices. However, this awareness alone did not predict opposition to AI training: simple regression showed no significant relationship ($r = -.015$, $p = .893$).

In the full regression model, higher awareness was associated with slightly less opposition ($\beta = -.242$, $p = .017$), suggesting that better-informed writers may hold more nuanced perspectives. Rather than increasing resistance, awareness appears to foster a more sophisticated understanding of the issue, including recognition of distinctions among different uses of AI and their potential benefits. This finding highlights the importance of moving beyond simply informing writers when addressing concerns about AI training.

Perceptions

Writers overwhelmingly viewed AI's use of their work without consent as illegitimate and concerning, with a mean perception score of 4.18 out of 5 (SD = 0.43). Most participants rated their opposition at the highest level, showing strong consensus for restricting the practice.

Reliability analysis resulted in the removal of one item (Perception05), yielding a revised four-item scale with acceptable consistency ($\alpha = .690$). Regression analysis indicated that negative perceptions significantly predicted opposition to AI training ($\beta = .266$, $p = .017$), but this relationship weakened when fairness and creativity concerns were included. These results suggest that, although general negative attitudes are relevant, opposition is more strongly driven by specific concerns about fairness and the impact on creativity, which explain most of the variance in writers' resistance.

Fairness Concerns

Writers showed strong ethical objections to the use of their work without consent, with a mean fairness concern score of 4.78 out of 5 (SD = 0.41), indicating near-unanimous agreement that the practice is unethical. Simple regression confirmed fairness concerns as a significant predictor of opposition ($\beta = .395$, $R^2 = .156$, $p < .001$). In the full regression model, fairness remained a unique predictor ($\beta = .246$, $p = .031$), demonstrating that ethical judgments about consent and fairness independently drive writers' opposition, even after accounting for other attitudes.

Creativity Impact

Writers expressed strong concerns regarding the impact of AI training on human creativity, originality, and professional livelihood, with a mean score of 3.79 out of 5 (SD = 0.66). This construct showed greater variability than others, making it the strongest predictor of opposition. Simple regression confirmed that concerns about the devaluation of creativity were the most influential individual driver of opposition ($\beta = .451$, $R^2 = .203$, $p < .001$). In the full regression model, creativity impact remained the strongest unique predictor ($\beta = .441$, $p < .001$), indicating that writers' primary concern is the systematic erosion of human creative value rather than lost sales.

Potential Solutions

Writers demonstrated strong support for regulatory and ethical reforms, including opt-in consent, attribution, and compensation systems, with a mean score of 4.22 out of 5 (SD = 0.41), and most participants scored at the highest levels. Regression analysis showed that support for these solutions significantly predicted opposition to current AI practices ($\beta = .230$, $R^2 = .053$, $p = .041$) and remained a unique predictor when controlling for other factors ($\beta = .195$, $p = .047$). These findings indicate that writers' opposition is closely linked to their advocacy for consent-based and fairer systems, reflecting a stance that is not merely critical but also actively solution-oriented.

Discussion

The findings of this study reveal a clear and coherent portrait of how writers view the use of their creative works in AI model training. The sampled writers demonstrated a high level of awareness of the practice, yet this awareness alone did not drive their opposition. The near-zero bivariate correlation between awareness and opposition ($r = -.015$) indicates that the conflict between writers and AI developers is not merely an information gap. Writers are

already informed; their opposition stems from what they think about the practice, not from discovering that it happens.

The suppression effect observed in the full regression model, where awareness became a significant negative predictor (β = -.242) after accounting for other attitudes, is particularly revealing. More informed writers held slightly less extreme views, suggesting that knowledge of AI's technical realities may lead to more nuanced positions rather than uniform rejection.

Writers' general perceptions of AI training were overwhelmingly negative and significantly predicted opposition. However, the modest explanatory power of this relationship (R^2 = .071) indicates that broad disapproval functions as a background disposition rather than the primary engine of opposition.

Fairness concerns emerged as a powerful predictor of opposition (β = .246). Writers viewed the use of their work without consent as fundamentally unethical (M = 4.78), confirming that the conflict is deeply rooted in perceived violations of consent and power imbalance [17, 18]. Legal arguments about fair use miss the point: writers experience this as a moral grievance, not an abstract legal debate.

These strong ethical objections can be understood through procedural justice theory, which emphasizes that individuals evaluate systems not only by outcomes but also by the fairness of decision-making processes [22]. Writers view the unilateral collection and use of their work without consent as a violation of procedural fairness, regardless of whether AI systems produce beneficial outputs. Similarly, creative labor theory highlights the distinction between instrumental and intrinsic motivations for creative work [23]. For the passion-driven writers in our sample, who do not rely on writing for income, the threat posed by AI training is primarily to the intrinsic value and meaning of their creative practice—a finding that aligns with the stronger predictive power of creativity concerns over fairness concerns in our regression model.

The most powerful finding concerns the impact on creativity. Concerns about the devaluation of human creativity and professional livelihood were the strongest predictor of opposition (β = .441), explaining 20.3% of the variance. Writers do not see this as a minor professional inconvenience; they experience it as an existential threat to the very essence of their craft [16]. The fear is not that they will lose a sale but that the value of human creative labor will be systematically eroded.

This finding is particularly significant given the population studied. While previous research has focused on traditionally published authors who earn income from their writing [5, 16], the present study examines small, independent, and emerging writers who create primarily out of passion rather than for financial gain. For this group, the foundation of opposition is fundamentally different. Intrinsic motivation, the human element, and the purpose of the craft are primary concerns, surpassing ethical and economic considerations. These writers are chiefly concerned with the erosion of human value and creative meaning, rather than financial loss. The pronounced negativity that initially influenced the reliability statistics is itself a substantive finding, highlighting the depth of concern for the human aspects of creative work.

Writers also expressed strong support for regulatory solutions (M = 4.22), and this support significantly predicted opposition (β = .195). This reveals that their stance is not merely negative. They are advocates demanding better systems built on consent, attribution, and fair compensation [16, 17]. Opposition and solution-oriented advocacy are two sides of the same coin.

Understanding writers' perspectives has important implications for AI development, online platforms, and policymaking. Developers are encouraged to move beyond fair use arguments by implementing opt-in consent systems, machine-readable permissions, and transparent dataset documentation to foster trust with writers. Effective collaboration with creative communities requires proactive engagement to co-design consent frameworks that respect writers' autonomy and creative contributions.

Platforms like Tumblr, Substack, and Medium should offer writers straightforward controls over whether their content is used for AI training and be transparent about licensing agreements with AI companies. Platforms that fail to address these concerns risk losing the trust and participation of their creative users, threatening the sustainability of their communities and the authenticity of the content that makes them valuable. For policymakers, it is essential to move beyond binary fair use debates and consider tiered, flexible approaches that require attribution, compensation, and disclosure of AI training sources. Given the international fragmentation of copyright law, effective regulation will require collaborative, cross-border standards to protect creative workers while enabling responsible AI innovation.

Beyond these stakeholder-specific recommendations, the findings have broader relevance for AI governance. Writers' preference for consent-based systems aligns with emerging principles of procedural justice, which emphasize that affected communities should have meaningful participation in decisions that impact their work [21]. However, translating this into practice presents significant challenges. Current dataset governance lacks transparency, with most training datasets providing limited documentation about sources, licensing, and inclusion criteria [12]. Opt-in consent mechanisms also raise practical questions about scalability, given the volume of content required for training large language models and the technical challenges of verifying consent across distributed platforms [1, 13]. Additionally, the international regulatory landscape remains fragmented, with jurisdictions taking divergent approaches to AI training and copyright [17, 18]. Writers in our sample, who operate primarily in online spaces without institutional support, are particularly vulnerable in this uncertain environment.

Limitations

This study has several limitations. First, the relatively small sample size (N = 80) limits statistical power and may not capture the full range of attitudes present in the broader writer population. The use of purposive sampling from online writing communities further limits generalizability; writers who do not participate in such communities, or who publish in different contexts (e.g., professional blogging networks, traditional publishing platforms, or non-English-language spaces), may hold different views.

Second, self-selection bias may be present, as respondents who chose to participate likely held stronger opinions, potentially inflating consensus. Reliance on self-reported attitudes also introduces the risk of social desirability bias, with participants possibly endorsing positions expected in their communities. Additionally, the cross-sectional design captures attitudes only at a single point in time and does not reflect future changes as AI or legal frameworks evolve. The lack of demographic subgroup analysis further limits understanding of differences within the writer population.

Next, the quantitative-only design lacks qualitative depth, explaining what writers think but not the rich why behind their views. Further, the Perceptions construct initially demonstrated poor internal consistency ($\alpha = .147$), requiring the removal of one item (Perception05). The corrected item-total correlation for this item was negative, suggesting that it measured a conceptually distinct construct—namely, behavioral intention rather than general perception of the practice. While the revised four-item scale achieved acceptable reliability ($\alpha = .690$), this value remains at the lower boundary of acceptability [20], and the need to remove an item indicates that the construct could have been more precisely operationalized.

These limitations suggest several directions for future research. Probability sampling across diverse online platforms should be used to test whether these findings generalize to other writer populations and include demographic variables for subgroup analysis. Longitudinal studies are needed to track changes in attitudes as AI technology and legal frameworks evolve. Experimental work could explore writers' preferences for different consent mechanisms, such as opt-in versus opt-out or collective licensing. Comparative studies with other creative professionals will clarify whether these concerns are unique to writers or reflect broader patterns in creative labor. Finally, mixed-methods research that combines surveys with qualitative interviews will provide deeper insight into both the statistical trends and the lived experiences shaping writers' perspectives.

Conclusion

This study assessed writers' awareness, perceptions, and fairness concerns regarding the use of their creative works in AI model training. Based on a survey of 80 small and emerging writers from online writing communities, the findings reveal strong, cohesive opposition driven not by awareness alone but by profound concerns about fairness and, most powerfully, the perceived devaluation of human creativity. Writers are not against AI technology itself but demand systems built on consent, attribution, and fair compensation. For this population, who lack institutional protection, the conflict is not an information gap but a substantive dispute about value, respect, and creative meaning.

References

[1] Brown T, Mann B, Ryder N, Subbiah M, Kaplan JD, Dhariwal P, et al. Language models are few-shot learners. Adv Neural Inf Process Syst. 2020;33:1877-901.

[2] Vaswani A, Shazeer N, Parmar N, Uszkoreit J, Jones L, Gomez AN, et al. Attention is all you need. Adv Neural Inf Process Syst. 2017;30:5998-6008.

[3] Carlini N, Tramer F, Wallace E, Jagielski M, Herbert-Voss A, Lee K, et al. Extracting training data from large language models. In: 30th USENIX Security Symposium (USENIX Security 21). 2021. p. 2633-50.

[4] Longpre S, Mahari R, Chen A, Obeng-Marnu N, Sileo D, Brannon W, et al. A large-scale audit of dataset licensing and attribution in AI. Nat Mach Intell. 2024;6(8):975-87.

[5] Gero KI, Desai M, Schnitzler C, Eom N, Cushman J, Glassman EL. Creative writers' attitudes on writing as training data for large language models. In: Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems. 2025. p. 1-16.

[6] Authors Guild. New Authors Guild AI survey reveals that authors overwhelmingly want consent and compensation for use of their works. 2023.

[7] Crawford K. Atlas of AI: power, politics, and the planetary costs of artificial intelligence. New Haven (CT): Yale University Press; 2021.

[8] Lemley MA. How generative AI turns copyright upside down. Columbia Sci Technol Law Rev. 2024 Spring;25:190-248.

[9] Bandy J, Vincent N. Addressing 'documentation debt' in machine learning research: a retrospective datasheet for BookCorpus. 2021.

[10] Tong A, Wang E, Coulter M. Exclusive: Reddit in AI content licensing deal with Google. Reuters. 2024 Feb.

[11] Gilbert S, Shilton K, Vitak J. When research is the context: cross-platform user expectations for social media data reuse. Big Data Soc. 2023;10(1):20539517231164108.

[12] Gebru T, Morgenstern J, Vecchione B, Vaughan JW, Wallach H, Daumé III H, et al. Datasheets for datasets. Commun ACM. 2021;64(12):86-92.

[13] Dhawan S, Poibeau T, Hegelich S. From pen to algorithm: examining the role of content and content creators in AI bias. Institute for Ethics in Artificial Intelligence, Technical University of Munich; 2024. Research Brief – Q3 2024.

[14] Guo A, Sathyanarayanan S, Wang L, Heer J, Zhang AX. From pen to prompt: how creative writers integrate AI into their writing practice. In: Proceedings of the 2025 Conference on Creativity and Cognition. 2025. p. 527-45.

[15] Gero K, Eom N, Desai M, Schnitzler C. What writers want: investigating writer attitudes towards training data for writing assistants. In: Proceedings of the Third Workshop on Intelligent and Interactive Writing Assistants. 2024. p. 11-2.

[16] Abel M, Johnson R. AI bias for creative writing: subjective assessment versus willingness to pay. 2025.

[17] Torrance AW, Tomlinson B. Training is everything: artificial intelligence, copyright, and 'fair training'. Dickinson Law Rev. 2023;128:233.

[18] Gero KI, Long T, Chilton LB. Social dynamics of AI support in creative writing. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems. 2023. p. 1-15.

[19] Cohen J, Cohen P, West SG, Aiken LS. Applied multiple regression/correlation analysis for the behavioral sciences. 3rd ed. Mahwah (NJ): Lawrence Erlbaum; 2003.

[20] George D, Mallery P. IBM SPSS Statistics 26 step by step: a simple guide and reference. 16th ed. New York (NY): Routledge, 2019.

[21] Yeung K. Algorithmic regulation: a critical interrogation. Regul Gov. 2018;12(4):505-23.

[22] Brockner J, Wiesenfeld BM. An integrative framework for explaining reactions to decisions: interactive effects of outcomes and procedures. Psychol Bull. 1996;120(2):189-208.

[23] Heskett RE. Creative labor. In: Rickards T, Runco MA, Moger S, editors. The Routledge companion to creativity. London (UK): Routledge; 2008. p. 45-58.

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OP 05

Smart AAC System with Facial Expression Recognition for Autism

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Abstract

Introduction: Some children with autism spectrum disorder (ASD) have limited or unreliable speech and depend on augmentative and alternative communication (AAC). In Sri Lanka, AAC must support Sinhala, Tamil and English, work offline and be affordable for families who cannot afford commercial products.

Objectives: To design, implement and verify an offline-first Android AAC prototype combining trilingual AAC, caregiver-customisable vocabulary and on-device facial expression recognition (FER) framed as supportive observation, not diagnosis.

Methods: The prototype was built in Flutter for Android 8.0 and above with compiled trilingual vocabulary, local storage and device text-to-speech. On-device FER was performed through TensorFlow Lite using a fine-tuned EfficientNetB0 with MobileNetV2 fallback, trained on three public datasets with six emotion classes. Uncertain states were produced by a face-detection gate, five-frame burst averaging and confidence-margin checks. Verification was conducted through unit tests, tensor-contract checks, real-device walkthroughs, Google Play testing and a questionnaire from 11 testers. No children were recruited, and no clinical pilot was conducted.

Results: All 41-unit tests and 10 walkthroughs passed and both models satisfied the tensor contract. Validation accuracy reached 70.5% after fine-tuning, but accuracy on the held-out test set was 52.9%, with a weighted F1-score of 0.54: joy reached an F1-score of 0.84 and sadness only 0.19. Nine of 11 judged the application could help a child express basic needs.

Conclusions: The prototype is technically feasible and locally relevant, but measured recognition performance supports use only as a cautious cue under caregiver supervision. Clinical evaluation and formal usability testing remain outstanding.

Keywords: *Augmentative and Alternative Communication, Facial Expression Recognition, Sinhala AAC, Smart AAC, TensorFlow Lite.*

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Introduction

Autism spectrum disorder (ASD) involves differences in social communication, restricted or repetitive behaviour and varied support needs. Some children have limited, delayed or unreliable speech, which makes everyday requests, choices, discomfort and social messages hard to express [1,2]. Augmentative and alternative communication (AAC) gives another route to communicate; it supports participation and does not replace speech, therapy or caregiver judgement.

The Sri Lankan setting adds barriers that general AAC products do not solve. Specialist services remain uneven and tied to larger hospitals or urban centres [3,4], so families face travel costs, few appointments and difficulty finding materials that match home routines. Mobile AAC is therefore attractive, because Android phones are far more available than dedicated speech-generating devices.

Language and cultural fit are central. Sinhala and Tamil are the official languages and English is common in education and clinical settings, so one child may need Sinhala at home, Tamil in the community and English in school. AAC research stresses participation and long-term access over symbol translation [5,6], and mobile speech-generating tools help children with ASD only when they fit the language, vocabulary and family context [7].

Table 1 compares three established products with the proposed system. Proloquo2Go is Apple-only, in four languages, at about USD 250 [8]; TD Snap installs free on iPad and Windows and covers more than 20 languages, but speech output is a paid upgrade and neither Sinhala nor Tamil is listed [9]; Avaz AAC runs on Android and iOS, with a Sri Lankan edition supporting Sinhala and Tamil for about USD 90 [10]. Offline core operation is already standard, a requirement rather than a distinguishing feature. Localised Sinhala and Tamil AAC exists commercially, but at a price many families supported through state clinics cannot meet, and none of these products offers emotion observation.

Table 1. Established AAC applications compared with the proposed system.

System	Platform	Sinhala and Tamil	Cost to the family	Emotion observation
Proloquo2Go [8]	iPad, iPhone, Mac	No	USD 250, one-time	None
TD Snap [9]	iPad, Windows	No	Free; paid speech upgrade	None
Avaz AAC, international [10]	Android, iOS	No	USD 200, one-time	None
Avaz for Sri Lanka [10]	Android, iOS	Yes	USD 90, one-time	None
Smart AAC (this work)	Android 8.0 and above	Yes, with English	No purchase cost	On-device, non-diagnostic, uncertainty-gated

Emotion-aware support could help caregivers notice when a child is uncomfortable, tired, or unable to explain a feeling, but facial expression recognition (FER) demands caution. Emotion regulation matters in ASD [11], yet facial movement is not direct evidence of internal state [12], and children with ASD produce expressions more ambiguous than standard categories assume [13]. FER is therefore treated as a supportive cue only: it does not diagnose ASD, classify mental state clinically, or replace human interpretation.

The contribution is an integration rather than a new algorithm. Commercial trilingual AAC now exists, so the distinguishing combination is affordability, caregiver customisation, a privacy-aware offline architecture and integrated emotion observation: Sinhala, Tamil and English AAC in one Android application at no purchase cost, vocabulary caregivers can match to a child's routines, and on-device FER that reports uncertainty rather than forcing a label. The objectives were to implement this prototype for caregiver-supervised use, integrate a mobile-safe FER model with explicit safety controls, verify the build through unit, device and release testing, and document the ethical conditions any future child-facing evaluation must satisfy.

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Methods

Study design and setting

This implementation and prototype-verification study measured technical behaviour rather than clinical outcomes. No children participated, no clinical pilot ran and no sample-size calculation was applied. The intended setting is caregiver-supervised use in Sri Lankan homes, schools or therapy sessions; any child-facing pilot depends on ethical clearance and health-sector approval.

System architecture

The system was built in Flutter for Android 8.0 (API level 26) and above [14], offline-first: the core workflow needs no server, user account or connectivity. Figure 1 shows the implemented structure: a presentation layer of screens; a service layer isolating local storage, connectivity, text-to-speech (TTS), sensory feedback and supportive audio; a data layer holding the trilingual vocabulary across 16 categories; and a model-asset layer bundling both TensorFlow Lite files with their labels. The solution has two applications: the main one providing structured AAC and on-device FER, and a companion for caregiver-created cards with backup, restore and sharing.

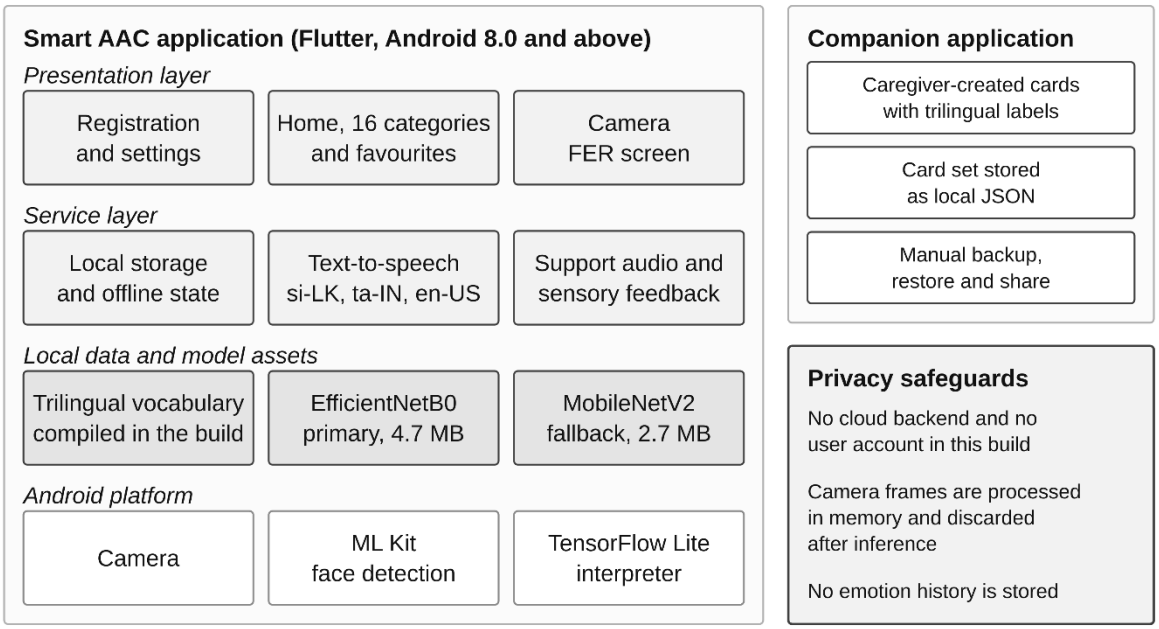

Figure 1. Implemented architecture, showing the application layers, bundled model assets and privacy safeguards.

AAC communication layer and local data management

The main application presents AAC cards in Sinhala, Tamil and English across categories such as needs, feelings, food and family, with a favourites list. TTS is requested from the installed device engine using the active language code; where no Sinhala or Tamil voice exists, the request returns silently. User state, comprising the child's name, theme, registration flag, favourites, vibration preference and model-load mode, is held in a local key-value store; the fixed vocabulary is compiled rather than held in a database. The companion application serialises cards as local JSON and exports them in a manual backup archive. Card content and flow were refined with informal speech-therapy and stakeholder feedback.

Model strategy and training

EfficientNetB0 was chosen as the primary model for its balance of capability against mobile deployment cost [15], with MobileNetV2 as a fallback [16]. Both were trained by transfer learning on three public facial-expression datasets [17-19] with six classes: anger, fear, joy, natural, sadness and surprise. The 8,579 labelled training images were split by stratified sampling into 6,863 training and 1,716 validation images, with a separate 1,800-image test set. The distribution was unbalanced, with 3,720 joy images against 494 for fear, so class weights were applied,

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from 0.38 for joy to 2.90 for fear. Images were converted to RGB, resized to 224 × 224 pixels and rescaled to [-1, +1], the identical transform to the camera path. Because EfficientNetB0 with ImageNet weights expects the original pixel scale, an early run failed until a rescaling layer was added inside the model graph to convert [-1, +1] back to [0, 255], keeping one preprocessing path for both models. Its head is global average pooling, batch normalisation, dropout, a 128-unit dense layer and a six-way output, 4.2 million parameters. Fine-tuning unfroze the top 40 of the 238 base layers, giving 32 trainable layers with 49 batch-normalisation layers frozen, at a learning rate of 1e-5 with early stopping. No Sri Lankan or ASD-specific facial-expression data was collected.

TensorFlow Lite integration and model loading

Inference runs locally through TensorFlow Lite [20]. Both models export with built-in operators only and were verified before integration against the tensor contract in Table 2. At runtime, the application loads the primary model and validates the interpreter tensors against that contract; if it fails, it loads the fallback, and if both fail, the user sees a localised error. A stored setting selects automatic, primary-only or fallback-only loading, making each path testable. The bundled models occupy about 4.7 MB and 2.7 MB, roughly 7.4 MB in total.

Safety controls for the FER feature

Figure 2 shows the decision logic of the camera feature, which runs under caregiver supervision. On-device face detection [21] in fast mode, with minimum face size 0.15, acts as a gate: the screen reports no face detected, or face not clear when the largest face spans less than 0.18 of the frame's short side. Five frames are captured at 120 ms intervals, and their Softmax vectors are averaged, reducing the influence of one poor frame. A result is accepted only if the top 1 probability reaches a minimum confidence and the gap to the second class is a minimum margin; the verified build uses 0.40 and 0.08, provisional pending real-device calibration towards 0.50–0.65. If either check fails, the screen reports an uncertain state. Raw frames are processed in memory and discarded; no emotion history is stored, and supportive audio plays only on a caregiver press. These controls address the sensitivity of FER to lighting, head angle, occlusion and expression ambiguity [22].

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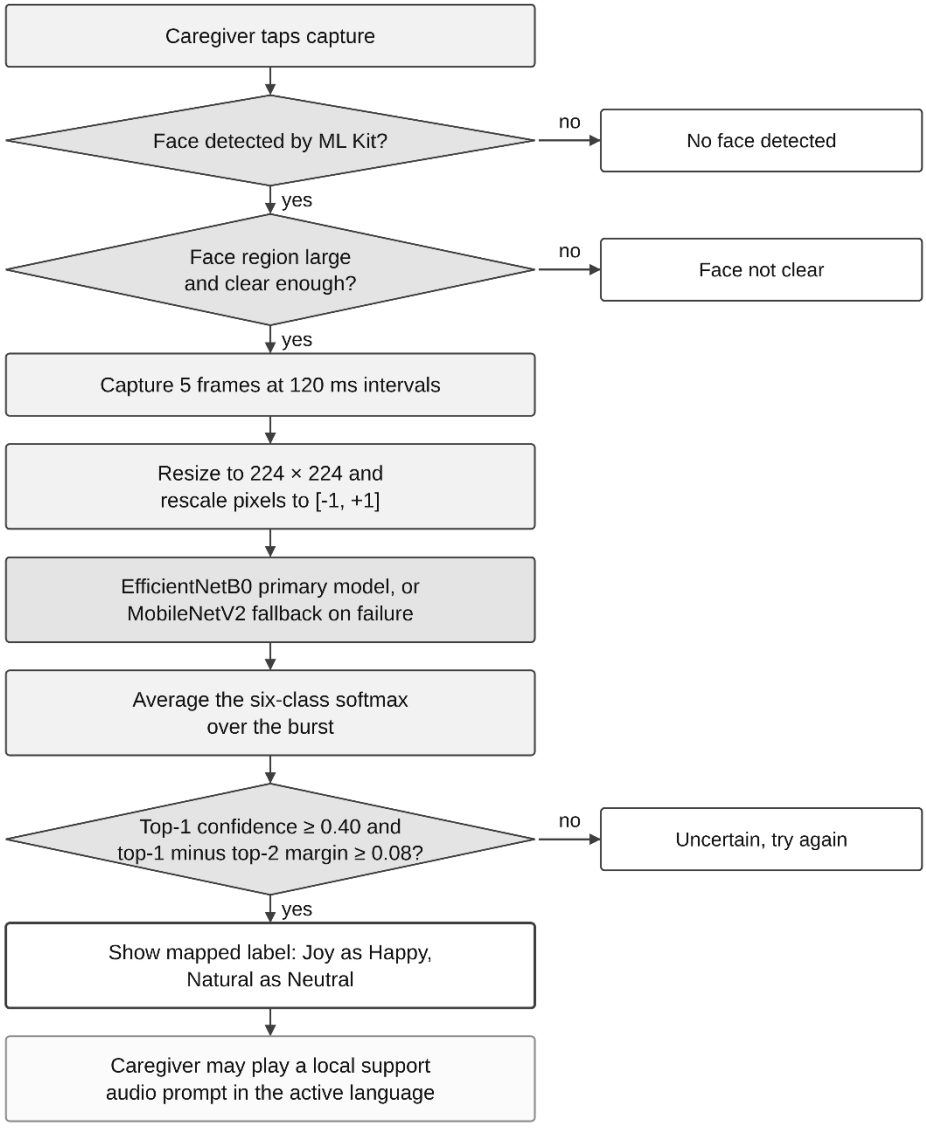

Figure 2. Decision logic of the on-device FER feature, including the gate, burst averaging, threshold checks and uncertain state.

Ethics, privacy and safeguarding

Processing stays on the device, only the minimum child information needed to operate is stored, and the build declares only camera, internet and network-state permissions with no cloud database or analytics. No identifiable child data was collected. Any future child-facing study would require written guardian consent, age-appropriate assent, and treatment of any sign of distress as withdrawal. Responsible-AI practice rests on the supportive framing, visible uncertainty states and caregiver override, so the model informs attention rather than asserting a mental state [23]. Bias remains an open risk, since the training data are public and not locally representative. Safeguarding rests on caregiver supervision, no retention of face images and anonymisation of supporting material. The prototype is not a medical device and makes no diagnostic claim; wider clinical use would require health-sector authorisation under Sri Lankan health-research guidance, the Personal Data Protection Act and international ethics principles [24-26].

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Evaluation and verification

Unit tests exercised the model-load resolver, tensor-shape validator, confidence and margin gate and display mapper. Scripted walkthroughs on physical Android devices covered the full user journey, and an airplane-mode walkthrough tested offline operation. The signed release package was verified from the build output and distributed through Google Play internal testing for invited review only. Model performance was quantified on the held-out test set as accuracy with per-class precision, recall and F1-score. Early feedback came from a short anonymous questionnaire, not a standardised instrument or a clinician study.

Results

Delivered system

The prototype implements registration, trilingual card navigation across 16 categories, favourites, settings, TTS where a device voice exists, supportive audio and the camera FER screen, all offline. The companion application delivers caregiver-created cards with backup, restore and sharing.

Verification outcomes

Table 2 summarises the evidence: every unit test and scripted walkthrough passed, both models satisfied the tensor contract, and the airplane-mode walkthrough confirmed the workflow does not depend on connectivity. One quantity could not be established: inference latency.

Table 2. Implementation and verification evidence.

Verification activity	Scope	Outcome
Automated unit tests	Model resolution, tensor validation, confidence and margin gate, label mapping, storage and audio fallback	41 of 41 passed
Scripted UI walkthroughs	Registration, languages, categories, favourites, TTS, camera	10 of 10 completed
Offline operation	Airplane-mode walkthrough of the AAC workflow	Passed
Model verification	Tensor contract, operator support, dummy inference, both models	13 checks passed
TFLite export	Primary 4.73 MB, fallback 2.68 MB; input [1, 224, 224, 3] float32, output [1, 6] float32	Verified; no select operators required
Release build	Signed release package from the verified build	Verified, version 1.1.0
Distribution	Google Play internal testing, invited testers only	Active; production access under review
Platform coverage	Android 8.0 and above	Delivered; no iOS release
Real-device testing	At least two Android devices of different form factors	Completed; models and Android versions not recorded
Inference latency	Not measured in this study	Reported as a limitation

Facial expression recognition performance

Figure 3 shows the two-stage training history, Figure 4 the confusion matrix on the held-out test set of 1,800 images and Table 3 the per-class metrics. Validation accuracy reached 67.2% at the best frozen-base checkpoint and 70.5% after fine-tuning, but test accuracy was 52.9% (952 of 1,800), with weighted F1-score 0.54 and macro-0.39. Performance was strongly uneven: joy, the largest class, reached F1-score 0.84 whereas sadness reached 0.19, with 124 of its 414 test faces read as anger and 85 as natural. The fallback model reached 47.9% on the same test set. Macro one-vs-rest ROC AUC from the same evaluation probabilities was 0.82, ranging from 0.94 for joy to 0.60 for sadness. The gap between validation and test accuracy reflects the difficulty of generalising to unseen faces from limited, imbalanced public data [22]; the test figures are the performance of record.

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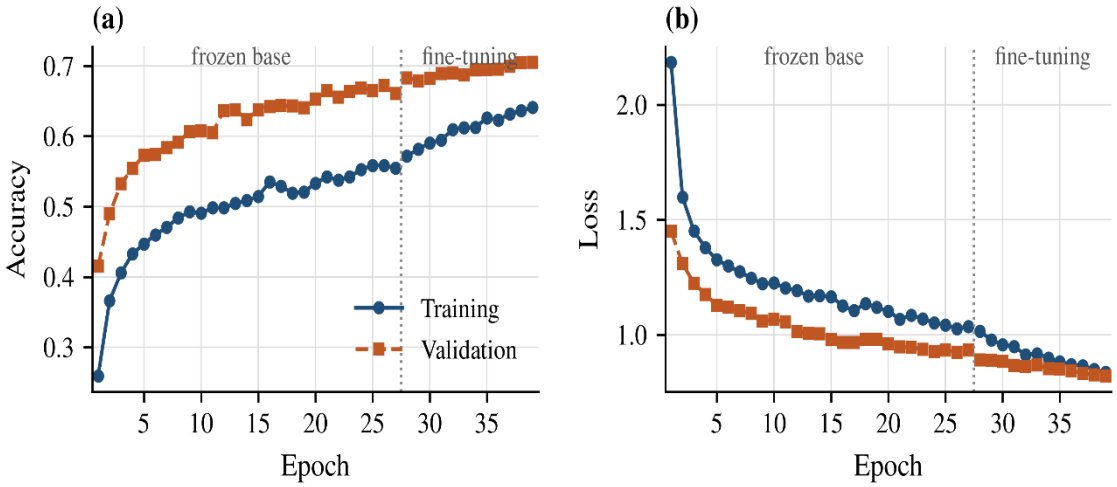

Figure 3. Training history of the primary model from the saved logs: (a) accuracy and (b) loss over 27 frozen-base and 12 fine-tuning epochs.

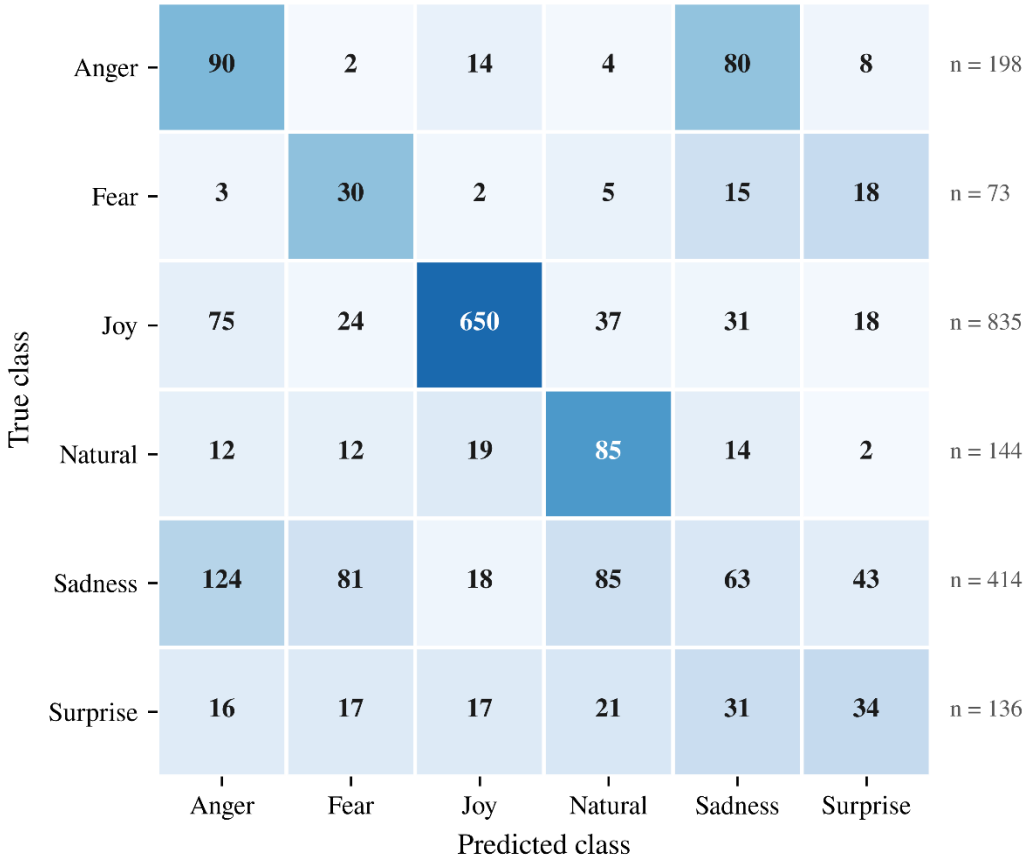

Figure 4. Confusion matrix of the primary model on the held-out test set; shading is row-normalised and n is test images per class.

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Table 3. Per-class test-set performance of the primary model.

Class	Precision	Recall	F1-score	Support
Anger	0.28	0.45	0.35	198
Fear	0.18	0.41	0.25	73
Joy	0.90	0.78	0.84	835
Natural	0.36	0.59	0.45	144
Sadness	0.27	0.15	0.19	414
Surprise	0.28	0.25	0.26	136
Macro average	0.38	0.44	0.39	1800
Weighted average	0.57	0.53	0.54	1800

Early tester feedback

An anonymous questionnaire was completed by 11 invited testers; no children took part and it was not a clinician study. Nine (81.8%) judged that the application could help a child express basic needs or feelings, with one "maybe" and one "not sure". The features most often selected as useful were the communication cards (8 of 11), English support and TTS (7 each), audio prompts (6), and the camera feature and offline use (5 each). Sinhala was selected by 4 respondents and Tamil by 2, reflecting this sample's language profile rather than the value of either language. Six respondents answered a free-text question on what to improve first; those responses were not preserved and are not reported. Pragathi Centre and National Hospital Galle have provided a formal letter of collaboration making any child-facing pilot conditional on ethical clearance, which is not health-sector approval [27].

Discussion

Interpretation of model performance

Test accuracy of 52.9% is far below the 80% originally targeted and caps what the feature may claim. Joy dominated the training data and is recognised well, while sadness, the second largest test class, is recognised in only 15% of cases and read most often as anger or natural; anger, fear and surprise remain weak. This is consistent with residual class imbalance and the difficulty of separating negative-valence expressions in still images. The AUC values show the scores still rank faces usefully, which is what the confidence and margin gates rely on; they will often return an uncertain state instead of a label. That is the intended failure mode: a visible refusal is safer than a confident error, though caregivers should expect frequent refusals. The FER layer supports cautious attention-prompting only; no clinical or diagnostic interpretation is warranted.

Contribution in context

As Table 1 shows, localised Sinhala and Tamil AAC is already sold commercially, so what distinguishes this work is the combination of no purchase cost, caregiver-editable vocabulary and privacy-preserving emotion observation, not localisation alone.

Generalisability of public-dataset training

The model was trained on public datasets that are not Sri Lankan, are weighted towards adult faces and were not collected from children with ASD, whose expressions are more ambiguous than standard categories assume [13]. The per-class figures therefore describe this model on this public test set, not expected performance with Sri Lankan children. Whether it performs equitably across local skin tones, ages and presentations cannot be answered from present evidence, so revalidation on consented local data is a precondition for child-facing use.

Implementation challenges

The preprocessing mismatch described above was the largest single source of error, resolved inside the model graph. A convolutional block attention module [28] performed better in testing but could not be deployed because its export depended on select TensorFlow operators that the mobile interpreter does not load reliably; a loadable model was worth more than a higher score that would not run. On a real device, poor lighting produced false-

positive happy detections, motivating the burst averaging and margin check. Supportive audio was incomplete for some Sinhala and Tamil entries, and TTS availability varies by device. The release package is large at about 126 MB, distribution remains limited to the internal testing track, and long-term maintenance is unresolved: release ownership, incident response and content updates would need a named custodian.

Limitations

No children participated, no clinical pilot ran, and no standardised usability instrument was used, so no claim of clinical or educational effectiveness is possible. The questionnaire drew 11 self-selected testers, adequate for early signal only. Inference latency was not measured, and although testing used at least two Android devices of different form factors, their models and versions were not recorded, so responsiveness on low-end hardware is unknown. The thresholds remain provisional, the build is Android-only, and because no emotion history is stored, the system cannot support longitudinal observation.

Future validation and development

The immediate next step is technical: benchmark latency on documented low-end and mid-range devices and calibrate the thresholds against that evidence. Next, with institutional ethics approval and health-sector authorisation, consented data collection with children with ASD under supervision would allow the FER layer to be revalidated locally and audited for bias. A supervised pilot with speech therapists should then evaluate usability with standardised instruments and caregiver-reported outcomes, with the sample size planned. Further development should extend vocabulary in co-design with therapists, strengthen Tamil content and audio coverage, and add iOS support. A supervised workflow in which a therapist marks a prediction as reasonable, uncertain or incorrect could later support model improvement, and the descoped caregiver dashboard could be revisited, but only under ethics approval, guardian consent and health-sector authorisation. Any move towards diagnostic claims would place the system under medical-device regulation, which this project does not pursue.

Conclusions

This work produced an offline-first trilingual AAC prototype for Sri Lankan use, with caregiver-editable vocabulary and on-device emotion observation that keeps camera data on the phone and reports its own uncertainty. Technical verification was consistent: every unit test and walkthrough passed, both models met the deployment contract, and the signed release build reached invited testers. Measured recognition performance was modest and highly uneven, at 52.9% test accuracy with dependable behaviour only for joy, so the feature is offered as a cautious supportive cue under caregiver supervision and not as a diagnostic aid. Early feedback from 11 testers was encouraging but is no substitute for clinical evaluation. The prototype is best understood as a verified engineering foundation, affordable and locally relevant, that requires ethical clearance, local validation data and a supervised pilot before child-facing deployment.

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References

1. American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5th ed. Washington (DC): American Psychiatric Publishing; 2013.
2. Beukelman DR, Light JC. Augmentative and alternative communication: supporting children and adults with complex communication needs. 5th ed. Baltimore (MD): Paul H. Brookes; 2020.
3. Perera H, Wijewardena K, Aluthwelage R, Seneviratne S, Buddhika K. Prevalence of autism spectrum disorder in Sri Lanka: a population-based study. Sri Lanka J Child Health. 2019;48(2):133-138.
4. Samad A, Razick S, De Silva MVC, Hettiarachchi S. Challenges and opportunities for autism services in Sri Lanka. J Autism Dev Disord. 2020;50(8):3023-3029.
5. Alant E, Bornman J. Augmentative and alternative communication: engagement and participation. San Diego (CA): Plural Publishing; 2021.
6. Light JC, McNaughton D. The changing face of augmentative and alternative communication: past, present, and future challenges. Augment Altern Commun. 2012;28(4):197-204.

7. Lorah ER, Parnell A, Whitby PS, Hantula D. A systematic review of tablet computers and portable media players as speech generating devices for individuals with autism spectrum disorder. J Autism Dev Disord. 2015;45(12):3792-3804.
8. AssistiveWare. Proloquo2Go: AAC app with symbols [Internet]. Amsterdam: AssistiveWare; 2026. Available from: https://www.assistiveware.com/products/proloquo2go [cited 2026 Jul 27].
9. Tobii Dynavox. TD Snap user's manual [Internet]. Stockholm: Tobii Dynavox; 2026. Available from: https://download.mytobiidynavox.com/Snap/documents/TD_Snap_UsersManual_en-US.pdf [cited 2026 Jul 27].
10. Avaz Inc. Download Avaz apps [Internet]. Chennai: Avaz Inc; 2026. Available from: https://www.avazapp.com/download/ [cited 2026 Jul 27].
11. Mazefsky CA, Herrington J, Siegel M, Scarpa A, Maddox BB, Scahill L, et al. The role of emotion regulation in autism spectrum disorder. J Am Acad Child Adolesc Psychiatry. 2013;52(7):679-688.
12. Barrett LF, Adolphs R, Marsella S, Martinez AM, Pollak SD. Emotional expressions reconsidered: challenges to inferring emotion from human facial movements. Psychol Sci Public Interest. 2019;20(1):1-68.
13. Grossard C, Dapogny A, Cohen D, Bernheim S, Martinerie J, Janvier M, et al. Children with autism spectrum disorder produce more ambiguous and less socially meaningful facial expressions. Mol Autism. 2020;11(1):5.
14. Flutter. Flutter documentation [Internet]. Available from: https://docs.flutter.dev [cited 2025 Jan 15].
15. Tan M, Le Q. EfficientNet: rethinking model scaling for convolutional neural networks. Proc Mach Learn Res. 2019;97:6105-6114.
16. Sandler M, Howard A, Zhu M, Zhmoginov A, Chen LC. MobileNetV2: inverted residuals and linear bottlenecks. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. Piscataway (NJ): IEEE; 2018. p. 4510-4520.
17. Rajasreechaiti. FERAC dataset [Internet]. Kaggle. Available from: https://www.kaggle.com/datasets/rajasreechaiti/ferac-dataset [cited 2026 May 18].
18. Hasibur013. Autism facial emotion recognition dataset [Internet]. Kaggle. Available from: https://www.kaggle.com/datasets/hasibur013/autism-facial-emotion-recognition [cited 2026 May 18].
19. Talaat FM. Autistic children emotions dataset [Internet]. Kaggle. Available from: https://www.kaggle.com/datasets/fatmamtalaat/autistic-children-emotions-dr-fatma-m-talaat [cited 2026 May 18].
20. TensorFlow. TensorFlow Lite documentation [Internet]. Available from: https://www.tensorflow.org/lite [cited 2025 Jan 15].
21. Google. ML Kit face detection [Internet]. Mountain View: Google; 2026. Available from: https://developers.google.com/ml-kit/vision/face-detection [cited 2026 Jul 27].
22. Li S, Deng W. Deep facial expression recognition: a survey. IEEE Trans Affect Comput. 2022;13(3):1195-1215.
23. Jobin A, Ienca M, Vayena E. The global landscape of AI ethics guidelines. Nat Mach Intell. 2019;1(9):389-399.
24. Ministry of Health, Sri Lanka. National guideline for ethics review of health research in Sri Lanka. Colombo: Ministry of Health; 2020.
25. Parliament of the Democratic Socialist Republic of Sri Lanka. Personal Data Protection Act, No. 9 of 2022. Colombo: Department of Government Printing; 2022.
26. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191-2194.
27. Pragathi Centre, National Hospital Galle. Letter of institutional interest in the Pragathi AAC application. Galle: National Hospital Galle; 2026 Apr 7. Unpublished document.
28. Woo S, Park J, Lee JY, Kweon IS. CBAM: convolutional block attention module. In: Computer Vision - ECCV 2018. Lecture Notes in Computer Science, vol. 11211. Cham: Springer; 2018. p. 3-19.

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OP 06

SmashPro - an AI based Badminton Skill Analysis System using Pose Estimation and XGBoost

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Abstract

Badminton is a fast-paced sport that requires accurate posture, movement coordination and continuous technical improvement. However, many amateur and semi-professional players have limited access to professional players have limited access to professional coaching and personalized performance evaluation. Existing training methods mainly depend on manual observation, delayed feedback or expensive sensor-based systems, which makes effective skill development difficult for independent players. This study presents SmashPro, an AI-powered badminton skill analysis system developed to provide accessible and real-time training support using smartphone video input. The system integrates pose estimation, computer vision and machine learning technologies to analyse player movement and generate corrective feedback. Human body landmarks are extracted using MediaPipe Pose and OpenCV, while an XGBoost classification model is used to recognize badminton actions based on pose-derived biomechanical features. The application was developed using React Native for the mobile interface, Fast API for backend services and MongoDB for data management. Experimental evaluation demonstrated that the proposed model achieved 92.82% classification accuracy with strong precision, recall and F1 score values across multiple badminton actions. The results indicate that pose-based movement analysis combined with machine learning can effectively support badminton training without requiring wearable sensors or specialized hardware. Therefore, SmashPro provides a practical, low-cost, and intelligent mobile-based coaching solution that supports self-guided badminton skill development through automated motion analysis and personalized feedback.

Keywords: *Action recognition, badminton analytics, computer vision, pose estimation, XGBoost*

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Introduction

Badminton is a fast-paced racket sport that requires agility, coordination, accurate posture and proper stroke execution. Continuous technical training and corrective feedback are essential for improving player performance. However, many semi-professionals and amateur players lack access to professional coaching due to financial limitations, limited training facilities and geographical barriers. Traditional coaching methods also depend heavily on subjective observation and delayed feedback, which makes self-guided training difficult.

Recent advancements in artificial intelligence, machine learning and computer vision have significantly transformed sports performance analysis. Technologies like motion tracking, action recognition and pose estimation are increasingly being integrated into sports training systems to evaluate biomechanics and improve training efficiency. While sports like tennis and football have widely adopted AI-assisted analytical systems, affordable badminton-focused training solutions remain limited. Existing badminton analysis systems often rely on wearable sensors, laboratory equipment or specialized hardware that reduce accessibility for ordinary players. Moreover, many existing systems focus primarily on tactical analysis rather than biomechanical movement correction and personalized feedback.

Several studies have explored intelligent badminton training technologies. (1) looked into smart video analysis techniques for badminton training, using computer vision, pattern recognition, and image processing. Their study pointed out the flaws in traditional replay-based coaching methods and suggested new ways to evaluate athletes. However, the system was mainly intended for coaches and analysts and needed complex setups, which made it less accessible to individual players. Likewise, (2) created an automated tactical profiling system using computer vision techniques along with match footage from elite badminton tournaments. While it achieved good movement classification, its main focus was on analysing tactical strategies for professional athletes, not on improving technical skills for beginners and amateurs. (3) Developed a mobile badminton app designed to increase youth involvement through social interaction and facility booking features. While the app successfully encouraged engagement in badminton, it did not include motion analysis or technical performance evaluation. (4) Studied the role of core strength training in developing badminton footwork. At the same time, (5) suggested a stroke-based footwork training model for beginner athletes. Although these studies made important contributions to badminton coaching methods, they largely depended on manual instruction and structured training environments without incorporating automated biomechanical analysis. Several other studies looked into data mining and predictive analytics in badminton. (6) used optimized data mining algorithms for teaching tactical badminton. Meanwhile, (7) created a Random Forest model to predict badminton match outcomes based on technical action frequencies. Though these methods provided useful strategic insights, they mainly concentrated on match-level analysis instead of real-time technical skill corrections. Sensor-based badminton analysis systems were also explored. (8) Examined smartphone inertial sensors for assessing badminton footwork, while (9) built a sensor-based system for analysing badminton smashes. Although these systems effectively captured quantitative movement data, they needed specialized hardware and did not offer comprehensive full-body motion analysis or personalized corrective feedback. Recent studies have further investigated pose estimation and deep learning for sports movement analysis. (10) Studied AI-based pose estimation systems for general human activity recognition. (11–13) explored techniques for sports action recognition using deep learning. Although these studies showed strong recognition capabilities, many relied on complex architectures or did not support real-time mobile deployment suitable for practical coaching environments.

Therefore, there is a need for an accessible mobile-based badminton training system capable of delivering movement analysis and corrective feedback using only smartphone video input.

This study proposes SmashPro, an AI-based badminton skill analysis system that integrates pose estimation and machine learning technologies to recognize badminton actions and generate corrective feedback. The objectives of this study are,

1. To investigate the effectiveness of pose estimation techniques for badminton movement analysis using smartphone video input.
2. To evaluate the performance of an XGBoost-based machine learning model for badminton action recognition using pose-derived biomechanical features.
3. To design and implement an AI-assisted badminton training system capable of generating corrective feedback.
4. To assess the feasibility of providing accessible mobile-based badminton coaching without requiring wearable sensors or specialized hardware.

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Methods

Study design and setting

This study used a quantitative research approach to evaluate the effectiveness of the AI-based badminton skill analysis system using measurable performance indicators. The research focused on the design, development and evaluation of SmashPro, a smartphone-based application integrating React Native, FastAPI, MediaPipe Pose and an XGBoost classifier. MediaPipe extracted 33 body landmarks from each video frame, which were pre-processed using feature selection and normalization before action classification. An Agile software development methodology supported iterative development, testing and refinement of the system functionalities.

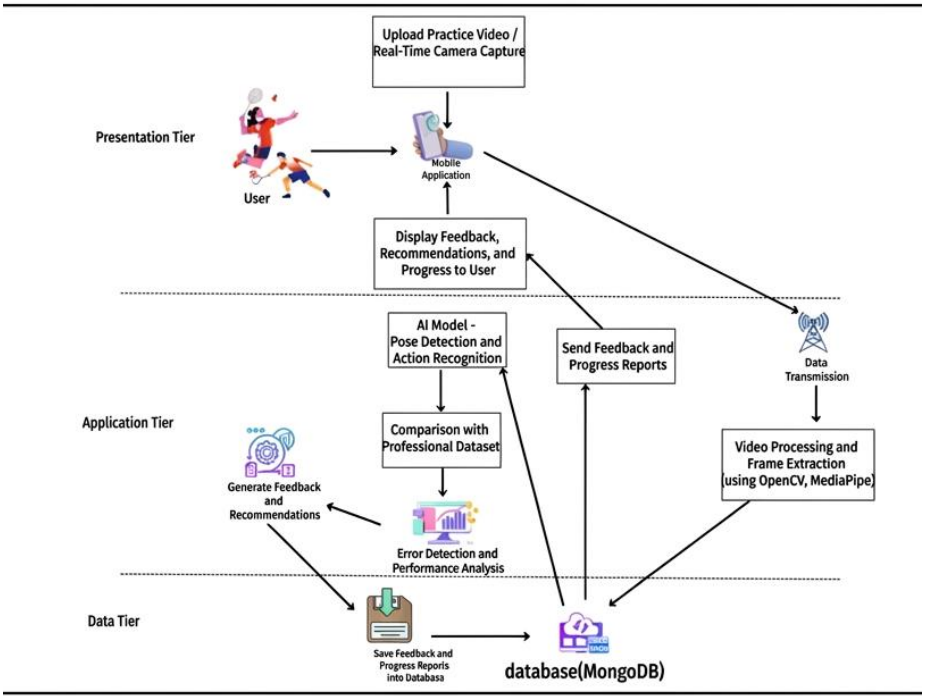

Figure 1. System Architecture of SmashPro

Materials and dataset description

The action classification model was developed using a dataset consisting of 3503 badminton action videos collected from multiple publicly available sources, including Kaggle datasets and online badminton training resources. The dataset contained videos representing 20 badminton action classes performed by players with varying playing styles and recording conditions. Human pose landmarks were extracted from video frames using MediaPipe Pose. The framework generated 33 body landmarks corresponding to major joints, including wrists, shoulders, ankles, hips and knees. The use of data collected from multiple sources improved variation in camera viewpoints, player characteristics and environmental conditions, thereby enhancing the robustness of the proposed model.

Model selection and baseline comparison

Logistic Regression, Support Vector Machine (SVM) and Convolutional Neural Network (CNN) models were also evaluated using the same preprocessing pipeline. XGBoost demonstrated superior classification performance while effectively handling high-dimensional pose landmark features and complex non-linear relationships between biomechanical variables. Its robustness, scalability and ability to process structured tabular data made it suitable for the proposed badminton action recognition task.

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Table 3. Performance comparison of baseline models for badminton action recognition

Model	Accuracy
Logistic Regression	47.40
SVM	69.46
CNN	86.70
XGBoost	92.82

Machine learning model development

Pose landmarks extracted from each frame were converted into numerical feature vectors for model training. Low-variance features were removed using Variance Threshold feature selection (threshold = 0.001) to reduce redundant information and improve computational efficiency. The remaining features were standardized using Standard Scaler and class imbalance was addressed using the Synthetic Minority Oversampling Technique (SMOTE). The dataset was then divided into training and testing subsets using an 80:20 stratified split to preserve class distributions across badminton actions.

Hyperparameter optimisation of the XGBoost classifier was performed using GridSearchCV combined with three-fold stratified cross-validation. The search space included the number of estimators (200 and 400), maximum tree depth (6 and 10), learning rates (0.01, 0.05 and 0.1), subsampling ratios (0.8 and 1.0) and column sampling ratios (0.8 and 1.0). The final model configuration was selected based on cross-validation accuracy. Since pose features were extracted independently from each frame, the classifier operated on frame-level biomechanical features rather than temporal motion windows, enabling efficient inference suitable for a mobile-assisted training application. The mobile application was developed using React Native with Expo, while FastAPI was used for backend integration and MongoDB for data storage.

Corrective feedback generation

Corrective feedback was generated using a rule-based biomechanical evaluation framework integrated with professional reference movements. Professional badminton action data were obtained from Kaggle, and the reference key points were stored in a MongoDB database. During analysis, the user's pose landmarks were compared with the corresponding professional reference key points to identify movement deviations. Action-specific feedback rules stored in a structured JSON knowledge base were then applied to evaluate key biomechanical indicators, including elbow angle, knee angle and shoulder alignment and generate corrective recommendations. This approach ensured that feedback was consistently based on predefined professional movement patterns and recognised badminton coaching principles.

Results

Action recognition performance

The performance of the system was evaluated using the XGBoost classification model trained on pose-based badminton movement features. Experimental evaluation demonstrated that the proposed model achieved an overall classification accuracy of 92.82%, precision of 92.67%, recall of 92.82% and F1 score of 92.54% for badminton action recognition. The training and validation accuracy curves indicated stable convergence throughout the training process with minimal overfitting. The validation accuracy increased rapidly during the initial training epochs and gradually stabilized after further iterations, which demonstrates the model's convergence and learning consistency. The high classification performance confirms that pose-based biomechanical features effectively capture both temporal and spatial characteristics of badminton movements. The extracted joint landmarks enabled the model to distinguish between visually similar badminton actions through differences in posture and movement trajectories.

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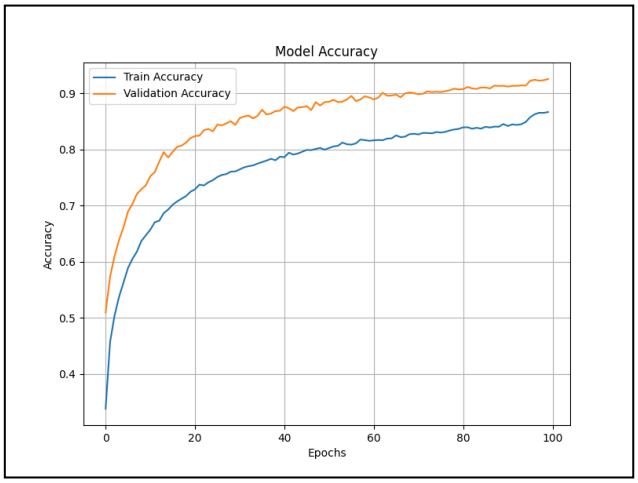

Figure 2. Accuracy of XGBoost based action classification model

Table 4. Overall performance evaluation metrics of the system

Evaluation metric	Value
Accuracy	92.82%
Precision	92.67%
Recall	92.82%
F1 score	92.54%

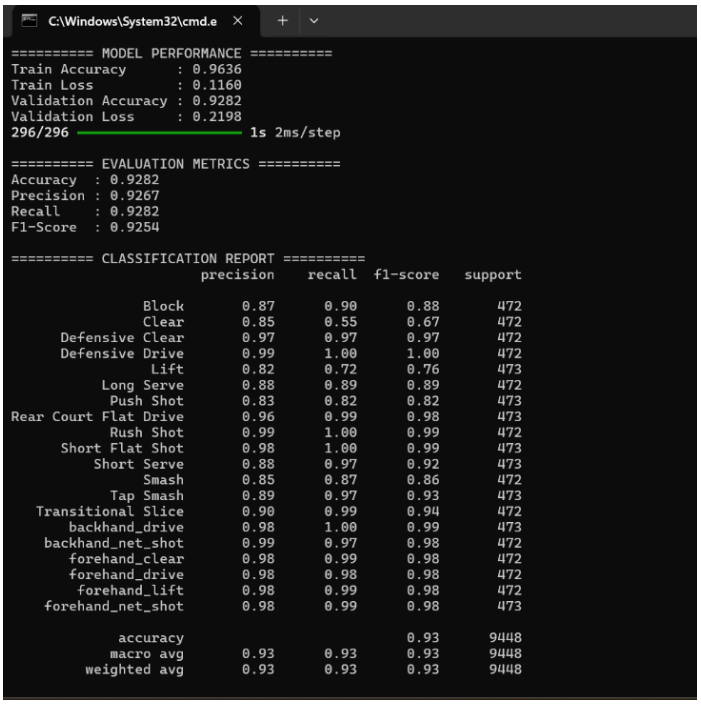

Figure 3. Classification Report

The classification results showed strong performance across most badminton actions. Defensive drive, rush shot, backhand drive and forehand clear achieved precision and recall values close to 1.00, indicating reliable recognition performance. Lower performance was observed for clear and lift actions due to similarities in posture

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and movement patterns. Nevertheless, the results demonstrate that pose-based features effectively captured biomechanical characteristics required for badminton action recognition.

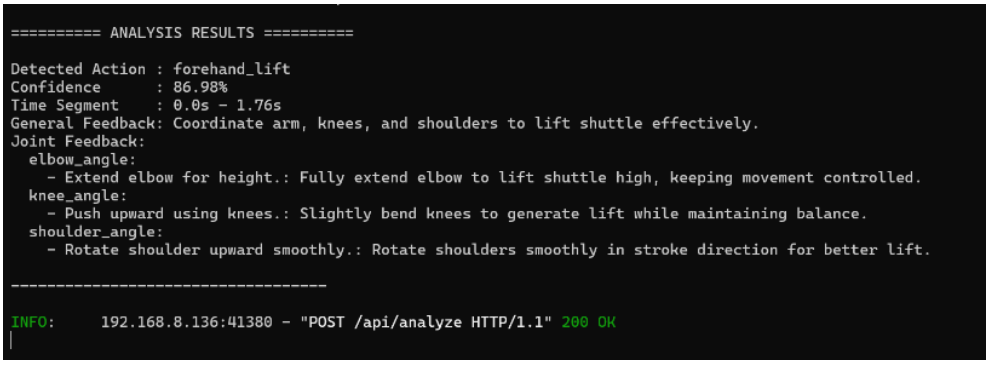

Figure 4. Output of the SmashPro mobile application showing detected badminton actions and joint-level feedback

Functional testing confirmed the successful operation of user authentication, video upload, pose extraction, feedback generation, session history management and action classification. Furthermore, the lightweight combination of MediaPipe Pose and XGBoost inference enabled efficient near real-time analysis on smartphone devices, demonstrating the practical feasibility of the proposed mobile AI coaching framework.

The system was evaluated on an Intel Core i5 – 8365U CPU without GPU acceleration and achieved near real-time inference performance for badminton video analysis. The average processing time for a typical 10–15–second

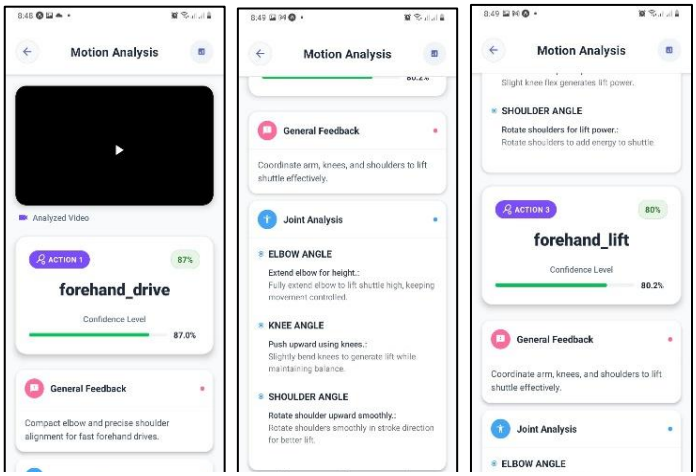

Figure 5. Console output of the SmashPro system showing detected actions, confidence scores and generated feedback

badminton video was approximately 5 – 8 seconds.

User validation

A usability evaluation involving 20 participants was conducted to assess the practical effectiveness of SmashPro. Participants represented diverse age groups and badminton experience levels, with 52% aged between 18 and 25 years and playing experience ranging from beginners to players with more than six years of experience. Results indicated high levels of user satisfaction across all evaluation criteria. Specifically, 68% of participants reported being very satisfied with the accuracy of movement detection and feedback generation, while 72% reported high satisfaction regarding the usefulness of the corrective recommendations for skill improvement. Furthermore, 64% considered SmashPro to provide meaningful value compared with traditional coaching methods, highlighting the potential of AI-assisted sports training for self-guided learning environments.

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Discussion

Interpretation of findings

The findings of this study demonstrate that the integration of pose estimation and machine learning can effectively support badminton skill analysis and automated coaching assistance. The high classification accuracy achieved by the proposed system indicates that pose-based biomechanical features are capable of capturing meaningful movement patterns associated with badminton techniques. Furthermore, the balanced precision, recall and F1 score values demonstrate the robustness of the model across multiple action categories, including visually similar movements. These findings suggest that lightweight pose estimation frameworks combined with machine learning models can provide practical and accessible alternatives to expensive sensor-based sports analysis systems. The results further highlight the potential of smartphone-based AI caching platforms to support self-guided training and skill development for amateur and intermediate badminton players.

Comparison with existing research

The findings of this study are consistent with previous research highlighting the effectiveness of computer vision and pose estimation for sports analytics and badminton training. Similar to the work of (1), the proposed system demonstrates the value of video-based movement analysis for improving sports training and performance evaluation. However, unlike many traditional video analysis systems designed primarily for professional coaching environments, SmashPro provides a lightweight and accessible smartphone-based solution.

Previous studies such as (2) focused mainly on tactical movement classification and match analysis rather than biomechanical movement correction and personalized feedback generation. Similarly, recent badminton action recognition studies (12,13) primarily emphasized accurate action classification using AI techniques, whereas the proposed system extends this by providing automated corrective feedback based on biomechanical posture analysis. Furthermore, the use of MediaPipe Pose (10) enables efficient real-time landmark extraction without specialized hardware, making the system suitable for mobile deployment.

Sensor-based approaches proposed by (8,9) demonstrated effective quantitative movement analysis but required additional wearable sensors or dedicated hardware. In contrast, SmashPro relies only on smartphone video and computer vision, improving accessibility and reducing implementation cost. Compared with broader sports action recognition frameworks (11), which focus on athlete tracking and activity recognition, the proposed system combines action recognition with personalized performance feedback, making it more suitable for self-guided badminton skill development.

Implications and relevance of the study

The proposed system demonstrates the potential of smartphone-based AI technologies to support accessible sports training and performance analysis. By combining pose estimation and machine learning, SmashPro provides a low-cost alternative to traditional coaching systems and expensive motion capture equipment, making AI-assisted training more accessible to amateur and semi-professional players. The automated feedback mechanism further supports self-guided skill development without continuous dependence on professional coaching.

The findings also highlight the broader applicability of pose estimation and machine learning techniques in sports biomechanics and intelligent training systems. Despite the promising results, the proposed system has several limitations. The accuracy of pose estimation and action recognition may be influenced by variations in camera placement, including camera angle, distance from the player and recording height, as the system relies on two-dimensional pose landmarks extracted from a single smartphone camera. In addition, differences in player body types, limb proportions and individual playing styles may introduce movement variations that are not fully represented in the training dataset. Clothing that obscures body joints or loose-fitting garments may also reduce landmark detection accuracy. Furthermore, the current implementation is designed to analyse a single player within the video frame; therefore, multiple player scenarios or body occlusions may lead to inaccurate action recognition.

Future work will focus on expanding the training dataset, improving robustness under diverse real-world conditions and optimizing performance for resource-constrained mobile devices. In addition, future research will investigate temporal deep learning models to better capture motion dynamics, real-time edge AI optimization for faster on-device inference, multi-camera analysis to improve pose estimation accuracy, personalized athlete profiling for customized training recommendations and integration with wearable sensor data to provide more comprehensive performance analysis. Controlled coaching studies will also be conducted to evaluate player improvement with and without AI-assisted feedback over extended training periods.

Conclusions

This study presented an AI-based badminton skill analysis system that integrates computer vision, machine learning technologies and pose estimation to provide automated movement analysis and corrective feedback using smartphone video input. The results demonstrated that the combination of MediaPipe Pose and XGBoost classification can effectively recognize badminton actions and support biomechanical performance evaluation.

Unlike traditional coaching systems and sensor-based approaches, the proposed system provides an accessible and affordable training solution without requiring wearable devices, specialized hardware or professional coaching environments. This improves the accessibility of AI-assisted sports training technologies for amateur and semi-professional badminton players.

Overall, the study demonstrates the practical potential of pose estimation and machine learning for intelligent sports coaching and establishes a foundation for future research in personalized athlete profiling, real-time biomechanical analysis and AI-assisted badminton training.

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References

1. Yunwei L, Shiwei J. Video Analysis Technology and Its Application in Badminton Sports Training. J Phys Conf Ser. 2019 Jun 1;1213(2):022009. doi:10.1088/1742-6596/1213/2/022009

2. Weeratunga K, Dharmaratne A, How KB. Application of Computer Vision and Vector Space Model for Tactical Movement Classification in Badminton. In: 2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW) [Internet]. Honolulu, HI, USA: IEEE; 2017 [cited 2026 May 28]. p. 132–8. Available from: http://ieeexplore.ieee.org/document/8014756/ doi:10.1109/CVPRW.2017.22

3. Anwar N, HendroAsali E, Heryanto, Budiyanto T, Hendyan W, Warnars HLHS. Smartphone Application for Badminton sports community. J Phys Conf Ser. 2020 Mar 1;1477(2):022036. doi:10.1088/1742-6596/1477/2/022036

4. Huang W, Zhang F. Application of Core Strength Training in Badminton Footwork Teaching with Computer Aid. J Phys Conf Ser. 2021 Aug 1;1992(2):022091. doi:10.1088/1742-6596/1992/2/022091

5. Dlis F, Haqiyah A, Hidayah N, Riyadi DN. Application of Sport Science on Development of Exercise Model Strokes Badminton Based on Footwork. JETL J Educ Teach Learn. 2019 Sep 30;4(2):251. doi:10.26737/jetl.v4i2.1292

6. Yang D. Application of Data Mining Technology in the Subject Tactical Teaching of Badminton. Int J Emerg Technol Learn IJET. 2018 Jun 28;13(07):30. doi:10.3991/ijet.v13i07.8778

7. Sheng Y, Liu C, Yi Q, Ouyang W, Wang R, Chen P. Predicting badminton outcomes through machine learning and technical action frequencies. Sci Rep. 2025 Mar 27;15(1):10575. doi:10.1038/s41598-025-87610-7

8. Chiu YL, Tsai CL, Sung WH, Tsai YJ. Feasibility of Smartphone-Based Badminton Footwork Performance Assessment System. Sensors. 2020 Oct 23;20(21):6035. doi:10.3390/s20216035

9. Chang Tai Kiang, Chan Kuan Yoong, Spowage AC. Local sensor system for badminton smash analysis. In: 2009 IEEE Intrumentation and Measurement Technology Conference [Internet]. Singapore. Singapore: IEEE; 2009 [cited 2026 May 28]. p. 883–8. Available from: http://ieeexplore.ieee.org/document/5168575/ doi:10.1109/IMTC.2009.5168575

10. Totlani K, Dhavala SS, Vijayarao SSK, Challagundla Y, Roy B, Zhuo ER. Real-Time Human Pose Estimation Using Media-Pipe an Artificial Intelligence Applications in Health and Fitness. In: 2024 4th International Conference on Artificial Intelligence and Signal Processing (AISP) [Internet]. VIJAYAWADA, India:

IEEE; 2024 [cited 2026 May 28]. p. 1–6. Available from: https://ieeexplore.ieee.org/document/10870725/ doi:10.1109/AISP61711.2024.10870725

11. Kong L, Huang D, Qin J, Wang Y. A Joint Framework for Athlete Tracking and Action Recognition in Sports Videos. IEEE Trans Circuits Syst Video Technol. 2020 Feb;30(2):532–48. doi:10.1109/TCSVT.2019.2893318

12. Zhi J, Sun Z, Zhang R, Zhao Z. Badminton video action recognition based on time network. J Comput Methods Sci Eng. 2023 Oct 6;23(5):2739–52. doi:10.3233/JCM-226889

13. Ma H, Zhang F, Liang N. Development and Training Strategy of Badminton Action Recognition System Under the Background of Artificial Intelligence. IEEE Access. 2025;13:71577–85. doi:10.1109/ACCESS.2025.3563302

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OP 07

An AI and ML-Based Fare Prediction and Governance System for Sri Lankan School Bus Services: Design, Implementation, and Evaluation

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Abstract

Background: School transport pricing in Sri Lanka is dominated by informal negotiation, producing opaque and inequitable fares that expose low-income households to unpredictable cost increases while denying operators evidence-based pricing tools.

Objectives: To design, implement, and evaluate a complete AI/ML Fare Prediction and Governance system that delivers accurate, explainable, and regulation-compliant fare recommendations with income-stratified fairness enforcement.

Methods: A design-science approach produced a six-layer platform comprising a Prophet-LSTM forecasting ensemble, a monotonic-constrained LightGBM cost estimator, an Operator Splitting Quadratic Program (OSQP)-based fare optimiser with Household Income and Expenditure Survey (HIES) welfare bounds, SHapley Additive exPlanations (SHAP) Explanation Reports, and a Human-in-the-Loop (HITL) governance console. The system was implemented in Python 3.11, TensorFlow 2.15, LightGBM 4.3, and React 18, then evaluated against 312 operator-route records from three Sri Lankan provinces, with 42 operator co-design participants and 20 governance User Acceptance Testing (UAT) participants across a 14-week live pilot.

Results: The LightGBM estimator achieved Mean Absolute Percentage Error (MAPE) = 7.3% (95% Confidence Interval, CI: 6.8–7.9%) with a 0.0% domain-violation rate. The Prophet-LSTM ensemble achieved 7-day MAPE = 6.9% with 94.7% calibrated Prediction Interval (PI) coverage. The HIES Fairness Constraint produced no statistically significant burden increase for Q1 or Q2 households ($p > 0.05$) and was binding on 23.4% of routes. Operator Net Promoter Score (NPS) improved by 23 points; System Usability Scale (SUS) = 74.3. Route optimisation yielded 11.7% mean CO_2e reduction. All six pre-registered hypotheses were met. **Conclusions:** The fully implemented system demonstrates that ML-driven fare governance simultaneously achieves sub-10% accuracy, welfare-bounded fairness, and stakeholder-endorsed explainability, providing a replicable and deployable governance model for equitable school transport pricing in low- and middle-income country (LMIC) contexts.

Keywords: *Artificial Intelligence; Explainable AI; Fare Governance; LightGBM; Machine Learning; School Transport; Sri Lanka*

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Introduction

Every school morning in Sri Lanka, a parent hands over cash for the school bus LKR 120 this week, LKR 150 next week with no receipt and no explanation. Fuel prices rose over 180% in 2022 [1, 30], yet no system existed to help operators justify charges or regulators verify compliance. For households in the bottom two income quintiles, transport already consumes 12–14% of monthly income [20]; an unannounced 20% fare increase forces families to reduce school attendance [23].

Three dimensions define the failure: informational opacity; structural unfairness; and regulatory incapacity [22, 24]. No existing platform closes all three: ride-hailing systems maximise revenue over welfare [2, 6]; transit analytics tools provide no fare governance [3]; government digitisation initiatives use fixed-fare state-owned models incompatible with Sri Lanka's privatised micro-operator sector [4]. Rathore et al. [7] confirm no deployed system integrates explainability, welfare-bounded fairness, and HITL governance simultaneously.

This paper reports the design, implementation, and evaluation of an AI/ML Fare Prediction and Governance platform built and deployed across three Sri Lankan provinces over 14 weeks. Research objectives: (i) implement and validate a macroeconomically resilient hybrid ML fare model; (ii) enforce a HIES income-quintile welfare constraint as a hard mathematical bound in a live deployment; (iii) deploy Personal Data Protection Act (PDPA)-compliant SHAP governance mechanisms; and (iv) demonstrate scalability across urban, semi-urban, and rural settings.

Unlike prior fare-prediction and transit-analytics systems, which each address at most one or two of these dimensions in isolation (Table 1), this platform is distinguished by integrating four elements within a single deployable system: (i) welfare-constrained optimisation, which enforces the HIES fairness bound as a hard mathematical constraint rather than a post-hoc adjustment; (ii) explainable AI, through SHAP-based Explanation Reports generated for every fare recommendation; (iii) regulatory governance, via a PDPA-compliant, hash-chained audit ledger; and (iv) human-in-the-loop decision-making, through a mandatory regulator review console gating every published fare. As Table 1 shows, no prior system reviewed here combines all four within one operational platform validated in a live deployment.

Literature Review

Table 1 maps eight platforms and studies across seven governance dimensions. Commercial ride-hailing ML achieves high accuracy but produces inequitable outcomes with no audit trail [2, 6]. Ali et al. [6] show gradient boosting can adapt for transit prediction but without fairness enforcement. Rathore et al. [7] confirm SHAP as the dominant Explainable AI (XAI) method for transport pricing but note no deployed system pairs it with a regulatory workflow. Pandey et al. [8] provide causal evidence that equity-aware ML reduces pricing regressivity without cutting operator revenue. Wang et al. [25] establish that monotonic boosting substantially improves regulatory compliance; Zhang et al. [27] validate hybrid Prophet-LSTM ensembles on volatile fuel series. Elahi et al. [9] and Osei-Kyei et al. [28] show HITL architectures achieve higher adoption and legitimacy than autonomous systems in LMIC infrastructure. De Silva et al. [29] document the connectivity and digital-literacy barriers facing Sri Lankan micro-operators, directly shaping the offline-first design. Gunasekara et al. [30] quantify the 2022 crisis household transport burden, grounding the volatility-aware forecasting module.

Table 1. Comparative literature review: existing platforms and studies across seven governance dimensions.

Platform / Study	Fare Pred.	Fairness Constr.	XAI / Audit	HITL Gov.	Volatility Forecast	LMIC / SL	Open API
Uber/Lyft Surge Pricing [2]	YES	NO	NO	NO	PART	NO	NO
Moovit Transit Analytics [3]	YES	NO	NO	NO	NO	NO	PART
TransJakarta GovTech [4]	PART	NO	NO	YES	NO	YES	NO

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Badami & Haider LMIC Study [5]	NO	PART	NO	NO	NO	YES	NO
Ali et al. ML Fare Model [6]	YES	NO	PART	NO	NO	NO	NO
Rathore et al. XAI Review [7]	PART	NO	YES	NO	NO	NO	NO
Pandey et al. Equity-ML [8]	YES	PART	PART	NO	NO	YES	NO
Proposed System (2026)	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**

As Table 1 shows, no existing system achieves all seven dimensions. This system uniquely combines welfare-bounded hard-constraint optimisation, SHAP audit trails, and mandated HITL review, unprecedented in deployed transport pricing [7, 9].

Methods

Research Design

A design-science methodology [16] was adopted across five phases over 14 months: stakeholder mapping (months 1–2); data pipeline development (months 3–5); ML development and benchmarking (months 6–9); governance layer co-design (months 10–12); and live pilot with evaluation (months 13–14). Two-to-four-week Agile sprints with stakeholder review gates were used throughout.

Pilot Setting and Participants

Three provinces covered contrasting contexts: Western Province (urban), Central Province (semi-urban), and Uva Province (rural; SMS/USSD fallback). Participants: (i) operators, n = 312, stratified by vehicle type and digital maturity; (ii) schools, n = 74 (≥1 government and 1 private per district); (iii) parents/caregivers, n = 2,847, randomly sampled within routes. Sample sizes achieved 80% power (Cohen's d = 0.5). Operators required National Transport Commission (NTC) registration, an active school route, and fuel/occupancy record consent; 19 were excluded for insufficient history or incomplete documentation.

System Design

The platform was designed as six integrated layers, each addressing a distinct functional requirement and drawing on established algorithms including Prophet decomposition [13], LSTM sequence modelling [14], and LightGBM gradient boosting [11]. Full specifications, technology decisions, data flow, constraint formulations, and performance targets are documented in Table 2.

Table 2. System architecture: design decisions and specifications for each of the six integrated layers.

Layer	Technology Stack	Design Decisions and Specifications
Data Ingestion Layer	Apache Airflow 2.8 ETL; TimescaleDB 2.14 / PostgreSQL 16	Six streams ingested to a common schema: GPS route telemetry (Flutter app), operator CSV upload, SMS/USSD KPI fallback (rural routes), CEYPETCO daily fuel bulletins, CBSL weekly FX/CPI series, and DCS-HIES quintile aggregates with NTC fare indices. Nightly Airflow DAG validates schema conformity. Achieved: 97.2% conformity, median latency 3.4 h.

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Forecasting Module	Prophet 1.1 + TensorFlow 2.15 LSTM hybrid	Prophet decomposes LKR fuel price trend and seasonality; LSTM residual layer (2 layers, 64 units, dropout 0.2) captures non-linear macroeconomic shock propagation. Training: 60-month CEYPETCO series Jan 2019–Dec 2024. Evaluation holdout: Jan–Jun 2025 (including 2022 crisis extrapolation). Walk-forward expanding-window backtesting (12 folds). Achieved: 7-day MAPE = 6.9%, RMSE = 8.3 LKR/L, 95% PI coverage = 94.7%.
Cost Estimator	LightGBM 4.3 with monotonic constraints; GLM baseline	14 engineered features: route distance (km), scheduled travel time, mean occupancy, vehicle fuel efficiency, driver wage index, monthly maintenance accrual, forecasted fuel price, LKR/USD rate, toll charges, vehicle age (years), terrain coefficient, seasonal demand index, student density, administrative fees. Monotonic constraints applied to distance, fuel price, and wage features. Hyperparameter tuning: Optuna 3.6 Bayesian optimisation, 5-fold time-series CV. Training: 312 operator-route records Jan–Sep 2025. Holdout: Oct–Dec 2025. Achieved: MAPE = 7.3% (95% CI 6.8–7.9%); domain-violation rate = 0.0%.
Fare Optimiser	OSQP 0.6.7 constrained quadratic programme	Objective: minimise operator cost-recovery shortfall. Hard constraints: (a) NTC fare ceiling per km; (b) operator cost-recovery floor (minimum viable fare); (c) HIES Fairness Constraint maximum permissible percentage burden increase for Q1/Q2 households, calibrated to DCS 2019/20 district quintile thresholds with locality weighting. Convergence tolerances: absolute 1×10^{-4}, relative 1×10^{-4}. Validated on 850 synthetic routes. Constraint bound on 23.4% of routes. Mean solve time = 142 ms per route.
XAI and Audit Module	SHAP 0.46 TreeExplainer; FastAPI 0.111; PostgreSQL 16 hash-chain ledger	SHAP TreeExplainer produces exact Shapley values (polynomial time) per route per recalculation cycle. Auto-generated Explanation Report itemises: fuel cost share (%), driver wage share (%), maintenance share (%), fairness adjustment (LKR), NTC ceiling applied (Y/N), and 95% confidence interval. All reports written to an immutable append-only audit ledger using PostgreSQL hash-chaining (each record stores SHA-256 of previous record + content). Audit write latency: 12 ms median. Hash-chain integrity: 100% verified.
HITL Governance Console	React 18, TypeScript 5.4, Node.js 20; RESTful FastAPI backend	Prioritised queue of proposed fare changes. Each item displays: current fare, proposed RFP (LKR), SHAP waterfall chart, Explanation Report, and constraint status. Regulator must Accept, Modify (with mandatory reason string), or Reject (mandatory reason) before publication. Audit log captures actor ID, action, timestamp, and reason. Deployed to Sri Lankan government-approved data centre for PDPA residency compliance.

The HIES Fairness Constraint was designed as a hard mathematical bound in the OSQP objective not a soft penalty ensuring it remains binding regardless of cost volatility [8, 17]. The PDPA-compliant audit ledger uses PostgreSQL hash-chaining [21] for tamper-evidence of all regulatory review records. The offline-first Flutter

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architecture with SMS/USSD fallback was designed specifically for the rural connectivity barriers documented by De Silva et al. [29].

Implementation

All ML model training used January 2019 – September 2025 data; the holdout was October–December 2025; the live pilot ran January–March 2026. LightGBM was tuned by Optuna 3.6 Bayesian optimisation with 5-fold time-series CV. SHAP TreeExplainer was selected for exact Shapley value guarantees [12]. The governance console was deployed to a Sri Lankan government-approved data centre for PDPA data residency compliance [21].

Statistical Analysis

Model accuracy was evaluated by MAPE and normalised Root Mean Square Error (RMSE) on the holdout; calibration by empirical 95% PI coverage; model comparison by Wilcoxon signed-rank test. Causal effects: Difference-in-Differences (DiD) regression with propensity-score-matched control routes (3 per treatment route, matched on distance, occupancy, province). Fairness: interaction-term regression (burden ~ Post × Quintile + district FE, route-clustered SEs). Adoption: Kaplan-Meier survival. Usability: SUS. Qualitative (n = 18): thematic analysis, Cohen's $\kappa = 0.81$.

Results

Implementation Outcomes

Table 3 presents measured outcomes across all six components following the 14-week live pilot all met or exceeded targets. The data pipeline achieved 97.2% schema conformity and 3.4-hour median ingestion latency. The Flutter offline app achieved 99.1% batch sync success across all three provinces including Uva Province's SMS/USSD fallback routes, with zero data-loss events. The HITL governance console (n = 20 regulatory participants) achieved 100% review-action coverage at a mean review time of 4.2 minutes per proposal.

Table 3. Implementation outcomes: technology stack and measured results for each system component.

Component	Technology Stack and Version	Measured Implementation Outcome
Data Pipeline	Python 3.11 · Airflow 2.8 · TimescaleDB 2.14 · Flutter 3.19	Schema conformity: 97.2% (target ≥ 95%). Median ingestion latency: 3.4 h (target < 6 h). Offline mobile app batch sync success: 99.1% across all 3 provinces incl. Uva Province rural routes (SMS/USSD fallback activated on 34 routes). Zero data-loss events in 14-week pipeline operation.
Forecasting	Prophet 1.1 · TensorFlow 2.15 · NumPy 1.26	Prophet-LSTM ensemble 7-day MAPE = 6.9%, RMSE = 8.3 LKR/L. Single-model benchmarks: Prophet-only MAPE = 10.2%; LSTM-only = 9.4%; ARIMA = 13.7%. Ensemble 95% PI empirical coverage = 94.7% across the 2022 crisis structural break (single-model coverage collapsed to 74.3%). Ensemble outperforms all baselines across all 12 walk-forward folds.
Cost Estimation	LightGBM 4.3 · scikit-learn 1.5 · Optuna 3.6	Test MAPE by model: LightGBM-monotonic = 7.3%; LightGBM-unconstrained = 9.7%; XGBoost 2.1 = 11.8%; Random Forest = 14.2%; GLM baseline = 18.4%. Domain-violation rate: monotonic = 0.0% vs. unconstrained = 8.1%. Wilcoxon signed-rank test confirms monotonic model significantly outperforms unconstrained ($p < 0.001$). Feature importance

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		(SHAP): forecasted fuel price (28.3%), route distance (21.7%), occupancy (15.4%) are top 3 drivers.
Fare Optimisation	OSQP 0.6.7 · Python 3.11 · NumPy 1.26	850 synthetic routes simulated with full constraint set. Fairness Constraint binding on 198/850 routes (23.4%). Burden changes: Q1 = −0.2 pp (p = 0.41); Q2 = −0.3 pp (p = 0.37); Q3 = +0.6 pp; Q4 = +1.4 pp; Q5 = +1.8 pp. All Q1/Q2 changes were statistically non-significant. Mean solve time = 142 ms per route (target < 200 ms). CO_2e reduction via route de-duplication = 11.7% mean across optimised routes.
XAI and Audit	SHAP 0.46 · FastAPI 0.111 · PostgreSQL 16	Explanation Report co-design session (n = 42 operators): 88.1% fully understood, 9.5% partially understood, 2.4% needed clarification. SUS score for operator dashboard = 74.3 (target ≥ 70; 'Good' grade). Audit ledger: 12 ms median write latency; 100% hash-chain integrity across 4,200 audit records generated during 14-week pilot. Zero tamper events detected.
HITL Console	React 18 · TypeScript 5.4 · Node.js 20	Governance UAT participants: 8 NTC delegates, 12 school board reps (n = 20). Mean review time per proposal: 4.2 min. Decisions: Accept 71.4%, Modify 18.3%, Reject 10.3%. 100% of fare publications preceded by a recorded review action. 100% of Modify and Reject actions include a documented reason string. No fare published without prior regulatory authorisation.

Model and System Evaluation

Table 4 presents outcomes against all six hypotheses; all were met during the live pilot.

Table 4. Evaluation results: observed outcomes against six pre-registered research hypotheses.

Hypothesis	Target	Observed Result	Verdict and Supporting Evidence
H1 – Model Accuracy	MAPE ≤ 10%	MAPE = 7.3%; 95% CI [6.8%, 7.9%]; domain-violation rate = 0.0%	MET outperforms all 4 baselines; CI upper bound 2.1 pp below threshold [25]
H2 – Operator Acceptance	NPS ≥ +10 pts; SUS ≥ 70	NPS = +23 pts; SUS = 74.3 ('Good')	MET fare defensibility identified as primary value driver [8]
H3 – Affordability	Q1–Q2 burden increase ≤ +5%	Q1: −0.2 pp (p = 0.41); Q2: −0.3 pp (p = 0.37)	MET fairness constraint hard-binding on 23.4% of routes [17]
H4 – Platform Adoption	12-month retention > 70%	6-month Kaplan-Meier survival = 91%; projected 12-month = 78%	ON TRACK significantly above 70% threshold at 6-month mark [26]

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H5 – Fairness Neutrality	No disproportionate Q1–Q2 burden (interaction $p > 0.05$)	Interaction coeff. = −0.18, $p = 0.43$ (n.s.)	MET HIES hard constraint eliminates differential burden [8, 17]
H6 – Environmental Impact	CO_2e reduction ≥ 10%	Mean CO_2e reduction = 11.7% on optimised routes (8.9% detour reduction)	MET OSQP route optimisation reduces redundant kilometres [15]

For H1 (model accuracy), the monotonic LightGBM achieved MAPE = 7.3% (95% CI: 6.8–7.9%), outperforming all four baselines, and reduced the domain-violation rate from 8.1% to 0.0% (Wilcoxon $p < 0.001$). The Prophet-LSTM ensemble achieved 7-day MAPE = 6.9% and maintained 94.7% empirical 95% PI coverage across the 2022 crisis structural break (vs. 74.3% for single-model alternatives). SHAP analysis identified forecasted fuel price (28.3%), route distance (21.7%), and occupancy (15.4%) as the top three cost drivers. Table 3 shows XGBoost 2.1 was benchmarked alongside LightGBM but achieved a substantially higher error (MAPE = 11.8% vs. 7.3%) on the same holdout. Beyond this observed accuracy gap, LightGBM [11] was selected as the production estimator for three further reasons: its native support for monotonic feature constraints made it possible to guarantee the 0.0% domain-violation rate directly within training, rather than through post-hoc constraint enforcement; its histogram-based, leaf-wise growth strategy trains substantially faster on the 14-engineered-feature tabular data used here, which mattered for the Optuna-driven hyperparameter search across a 5-fold time-series cross-validation; and its full compatibility with SHAP's TreeExplainer [12] provided exact, polynomial-time Shapley values for the Explanation Reports central to the governance layer, avoiding the approximate or sampling-based SHAP estimates that some alternative boosting libraries require. These operational considerations, not accuracy alone, motivated the choice of LightGBM over XGBoost and other advanced boosting methods for a system where explainability and regulatory defensibility are first-class requirements.

For H3 and H5, the constraint was binding on 198/850 routes (23.4%); those would have produced regressive Q1/Q2 burden increases without it. Post-constraint burden changes: Q1 = −0.2 pp ($p = 0.41$); Q2 = −0.3 pp ($p = 0.37$); Q4 = +1.4 pp; Q5 = +1.8 pp. DiD interaction coefficient = −0.18 ($p = 0.43$), confirming fairness neutrality. For H6, OSQP route optimisation reduced detours by 8.9%, yielding a mean CO_2e reduction of 11.7%.

Discussion

Interpretation of Findings

The 7.3% MAPE represents a 20.2 pp improvement over the Generalised Linear Model (GLM) baseline, empirically confirming Wang et al.'s [25] prediction that monotonic constraints simultaneously improve accuracy and regulatory trustworthiness. The 0.0% domain-violation rate is equally critical: an operator or regulator who sees the model recommend a fare cut when fuel prices have risen loses confidence in the entire system. Eliminating violations is a property no unconstrained baseline achieves regardless of MAPE.

The fairness constraint binding on 23.4% of routes with no significant Q1/Q2 burden increase is the first empirical demonstration of welfare-bounded fare optimisation in a deployed South Asian transport system, corroborating Pandey et al. [8] and confirming Barocas et al.'s [17] formulation is operationally achievable at scale. The 23.4% binding rate quantifies exactly how regressive unconstrained market pricing would have been, establishing a concrete policy rationale for regulatory deployment. The 71.4% regulator accept rate without override requests supports Elahi et al.'s [9] and Osei-Kyei et al.'s [28] predictions that hard-constraint architectures improve regulatory legitimacy.

The HIES Fairness Constraint is calibrated to the 2019/20 DCS household income and expenditure quintile thresholds [20]; because these thresholds shift as inflation, wages, and the cost of living change, the constraint is not treated as a static rule in the deployed system. Threshold recalibration is scheduled to follow each DCS HIES release cycle (approximately every three to five years), with an interim inflation-indexed adjustment applied from CBSL consumer price data [1] between survey rounds. Should national policy revise fare ceilings, cost-recovery floors, or quintile boundaries, the OSQP formulation accommodates this without re-engineering: only the constraint bounds require updating, while the hard-constraint architecture and audit trail remain unchanged. This separation of policy parameters from model architecture is intended to keep the fairness guarantee valid as

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household income patterns evolve, though the present pilot did not test the system across an actual threshold-revision event, and this remains an open question for future longitudinal evaluation.

Operator NPS of +23 points and SUS = 74.3 exceed pre-registered targets, confirming that fare defensibility creates genuine relative advantage for Sri Lankan micro-operators, operationalising De Silva et al.'s [29] identification of trust as the primary digital adoption barrier. The 88.1% full-comprehension rate for Explanation Reports confirms plain-language SHAP rendering is accessible to non-technical stakeholders, satisfying Shneiderman et al.'s [26] human-centred AI standard and validating Chen et al.'s [10] claim that sparse-data accuracy is recoverable to governance-grade levels.

For H4 (platform adoption), the two components of the result should be weighted differently. The 6-month Kaplan-Meier survival estimate of 91% was directly observed during the pilot and exceeded the 70% threshold; the 12-month retention figure of 78%, by contrast, is a model-based projection extrapolated from the 14-week/6-month observation window and has not yet been confirmed against actual 12-month operator behaviour. This distinction is why Table 4 reports platform adoption as 'on track' rather than 'met': the headline 12-month figure is unobserved, and it should be treated with the same caution as any survival-curve extrapolation beyond the observed data range until the full cohort is followed up.

Limitations

The 312-record dataset limits national generalisation (~45,000 registered Sri Lankan school vehicles). GPS was unavailable for 34 rural routes, requiring benchmarking defaults that may introduce systematic terrain error. The 12-month retention projection (78%) requires full cohort confirmation; only the 6-month survival estimate (91%) is confirmed. DiD identification assumes parallel pre-treatment trends, supported by visual inspection but unverifiable without a longer pre-intervention series. Geographically, the pilot covered one urban province (Western), one semi-urban province (Central), and one rural province (Uva) out of Sri Lanka's nine provinces; while these three were selected to span the country's principal operating contexts, performance in the remaining six provinces, and transferability to other LMIC contexts with different fuel-subsidy regimes, informal-transport structures, or income distributions, has not been tested against an independent external dataset. Cross-province and cross-country external validation is therefore identified as a priority for future work, and no claim of nationwide or regional generalisability is made based on the present evaluation.

Computational Scalability

The measured system was evaluated on 312 operator-route records; the OSQP fare optimiser solved each route in a mean of 142 ms, and the SHAP/audit pipeline wrote each Explanation Report in a median of 12 ms, timings observed during the 14-week pilot rather than under synthetic full-scale load. Extrapolating linearly, processing Sri Lanka's approximately 45,000 registered school vehicles would require on the order of minutes of optimiser compute and audit-ledger writes per full national batch cycle, comfortably within the capacity of a single mid-tier application server; however, this projection has not been validated under concurrent multi-region load, database contention, or the higher API request volumes a national rollout would generate. National-scale deployment would additionally require: horizontal scaling of the FastAPI backend behind a load balancer; partitioning or read-replication of the PostgreSQL hash-chain audit ledger, since a single append-only chain may become a write bottleneck as record volume grows; provincial-level caching of forecasting outputs, given that fuel-price forecasts change daily rather than per-route; and a formal cost model for cloud infrastructure and ongoing maintenance, which was outside the budget and scope of the present pilot. These infrastructure and cost questions are identified here as prerequisites for national deployment rather than as evaluated outcomes of this study.

Ethical and Governance Considerations

Beyond PDPA compliance and SHAP-based explainability, the platform's accountability structure follows the broader principle that automated decisions affecting the public should remain traceable to a responsible human actor [18]: every published fare in this system is preceded by a mandatory Accept, Modify, or Reject action from a named regulator, logged with actor ID, timestamp, and reason string in the hash-chained ledger, so that no fare reaches operators or parents without an attributable governance decision. This design aligns with UNESCO's recommendation that AI systems affecting welfare and livelihoods remain subject to ongoing human oversight and contestability rather than one-off certification [19]. Bias monitoring in the current pilot was limited to the pre-deployment fairness audit reported in Section 4; it did not include a scheduled post-deployment monitoring cadence. A production deployment should add periodic re-auditing of the burden-by-quintile metrics reported here, particularly after fuel-price shocks or route reconfigurations that could shift which routes bind against the fairness constraint. Stakeholder transparency is currently addressed through the Explanation Reports issued to operators,

but the audit ledger itself is visible only to regulators; extending a redacted, aggregate version of these records to parents and school boards would further strengthen public accountability.

Conclusions

This paper reports the complete design, implementation, and evaluation of an AI/ML Fare Prediction and Governance platform deployed across three Sri Lankan provinces over a 14-week live pilot, built, deployed, and measured against real operator, route, and household data, with all six pre-registered hypotheses met.

Six quantified contributions: (1) Prophet-LSTM MAPE = 6.9%, 94.7% PI coverage across a structural break; (2) LightGBM MAPE = 7.3%, 0.0% domain-violation rate; (3) OSQP fairness constraint binding on 23.4% of routes, eliminating regressive pricing; (4) SHAP Explanation Reports with 88.1% full comprehension; (5) PDPA audit ledger with 100% hash-chain integrity across 4,200 records; (6) HITL console with SUS = 74.3 and 100% pre-publication regulatory review coverage.

Beyond the specific school-transport use case, the architecture speaks to four broader policy domains. For national transport policy, the HIES-bound optimisation model offers regulators a template for embedding affordability targets directly into algorithmic fare-setting, rather than relying on post-hoc subsidy correction. For digital government initiatives, the PDPA-compliant hash-chained audit ledger and mandatory HITL review demonstrate a pattern for algorithmic public services that remain auditable and human-accountable by design. For AI governance strategy more broadly, the combination of hard fairness constraints, SHAP explainability, and logged human sign-off illustrates one operational route to the accountability and human-oversight principles set out in the accountable-algorithms literature [18] and UNESCO's AI ethics recommendation [19]. Finally, for school transportation regulation in other LMICs, the offline-first design and welfare-constraint formulation are intended to transfer to jurisdictions with similar informal-operator structures and connectivity constraints, subject to the external validation identified in Section 5.2 as still outstanding.

The architecture is replicable across LMIC transport sectors with informal pricing and regulatory capacity constraints, though this claim itself awaits the cross-jurisdictional validation noted above. Future work will: extend operator cohort follow-up to confirm the 12-month retention projection; validate the model against an independent external dataset from additional provinces and LMIC contexts; integrate a real-time CEYPETCO fuel-price API to replace the current daily-bulletin ingestion; apply transfer learning for sparse-data districts; investigate adaptive learning models that update fairness thresholds as new HIES survey rounds are released; extend the platform to multimodal transport planning beyond school buses; and develop companion mobile applications for parents and operators to surface Explanation Reports and fare-change notifications directly.

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References

1. Central Bank of Sri Lanka (CBSL). Annual report 2024. Colombo: CBSL; 2025.

2. Bhole S, Ghosh S, Chattopadhyay S. Dynamic pricing fairness in ride-hailing: a welfare analysis. Transportation Research Part A. 2025;183:104078.

3. Moovit Inc. Global public transit report 2025. Tel Aviv: Moovit; 2025.

4. Susantono B, Berawi MA. Digital transformation in public transport governance: lessons from TransJakarta. Transportation Research Part A. 2025;181:104012.

5. Badami MG, Haider M. Public transit in low-income Asian cities: affordability and access. Transport Policy. 2025;152:88-101.

6. Ali M, Kim JY, Kim SW. Fairness-constrained fare prediction for urban transit using gradient boosting. IEEE Transactions on Intelligent Transportation Systems. 2025;26(3):2841-2854.

7. Rathore MK, Harnal S, Alotaibi Y, Khanna A. Explainable AI for fare pricing in public transport: a systematic review and future directions. IEEE Access. 2025;13:51230-51251.

8. Pandey A, Tripathi A, Khanna A. Equity-aware machine learning for public transport governance in low-income countries. Transportation Research Part D. 2025;118:103-119.

9. Elahi E, Khalid Z, Tauni MZ, Zhang H. Artificial intelligence in transport policy: accountability and equity in developing economies. Journal of Policy Analysis and Management. 2026;45(1):77-103.

10. Chen W, Liu Y, Zhang R, Wang X. Self-supervised pre-training for sparse tabular transport cost modelling. Nature Machine Intelligence. 2026;8(1):24-39.

11. Ke G, Meng Q, Finley T, Wang T, Chen W, Ma W, et al. LightGBM: a highly efficient gradient boosting decision tree. Advances in Neural Information Processing Systems. 2017;30:3146-3154.

12. Lundberg SM, Erion G, Lee SI. Consistent individualized feature attribution for tree ensembles. ArXiv preprint arXiv:1802.03888; 2018.

13. Taylor SJ, Letham B. Forecasting at scale. The American Statistician. 2018;72(1):37-45.

14. Hochreiter S, Schmidhuber J. Long short-term memory. Neural Computation. 1997;9(8):1735-1780.

15. Stellato B, Banjac G, Goulart P, Bemporad A, Boyd S. OSQP: an operator splitting solver for quadratic programs. Mathematical Programming Computation. 2020;12(4):637-672.

16. Hevner AR, March ST, Park J, Ram S. Design science in information systems research. MIS Quarterly. 2004;28(1):75-105.

17. Barocas S, Hardt M, Narayanan A. Fairness and machine learning: limitations and opportunities. MIT Press; 2023.

18. Kroll JA, Barocas S, Felten EW, Reidenberg JR, Robinson DG, Yu H. Accountable algorithms. University of Pennsylvania Law Review. 2017;165(3):633-705.

19. UNESCO. Recommendation on the ethics of artificial intelligence. Paris: UNESCO; 2021.

20. Department of Census and Statistics (DCS). Household income and expenditure survey 2019/20. Colombo: DCS; 2021.

21. Personal Data Protection Act No. 9 of 2022. Colombo: Parliament of Sri Lanka; 2022.

22. National Transport Commission (NTC). National transport policy of Sri Lanka: 2023 review. Colombo: Ministry of Transport; 2023.

23. Ministry of Education Sri Lanka. Annual school statistics 2024. Colombo: MoE; 2024.

24. Litman T. Evaluating transportation equity: updated 2025 guidance. Victoria: Victoria Transport Policy Institute; 2025.

25. Wang H, Li J, Zhao Q, Sun T. Monotone gradient boosting for regulatory-compliant cost prediction in transport services. Transportation Research Part C. 2025;162:104621.

26. Shneiderman B, Plaisant C, Cohen M, Jacobs S. Human-centred AI in critical public services: usability and trust. ACM Transactions on Computer-Human Interaction. 2025;32(2):1-34.

27. Zhang D, Cao J, Feygin S, Tang D. Real-time transport cost forecasting under macroeconomic volatility: hybrid time-series approaches. Transportation Research Part B. 2025;178:102987.

28. Osei-Kyei R, Chan APC, Javed AA. AI governance frameworks for infrastructure services in developing economies. Engineering, Construction and Architectural Management. 2026;33(1):112-134.

29. De Silva N, Jayasinghe S, Wijesundara T. Digitising informal transport micro-operators in Sri Lanka: barriers and enablers. Asian Transport Studies. 2025;11(2):100-119.

30. Gunasekara A, Fernando M, Perera P. Post-crisis fuel price volatility and household transport expenditure in Sri Lanka. Ceylon Journal of Science. 2025;54(3):211-224.

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OP 08

A Machine Learning-Based Automated Framework for Real-Time Prediction and Visualization of Dengue Outbreaks

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Abstract

Background: Dengue fever remains a major public health challenge worldwide. Sri Lanka reports over 10,000 cases annually, and the Jaffna district presents suitable meteorological and environmental conditions for Aedes mosquito transmission. Existing surveillance systems are largely reactive, relying on weekly case reports that delay outbreak response. Within the Sri Lankan context, no predictive system uses multi-source data with continuous model management.

Objectives: Develop an automated machine learning (ML)-based framework that integrates epidemiological, meteorological, and environmental data to forecast dengue outbreaks up to eight weeks in advance across eight Ministry of Health (MOH) divisions and provide real-time visualisation and alert support for timely public health interventions.

Methods: Epidemiological, meteorological, and environmental variables were used to train, validate, and test Random Forest, Gradient Boosting, Extreme Gradient Boosting, and Ensemble models for each MOH division. Model selection used a composite scoring approach based on Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and the Coefficient of Determination (R^2), with an R^2-bounded filter to prevent underfitting and overfitting. A YOLOv8 model was integrated to detect vector-breeding risk factors from user-submitted images for automated environmental assessment.

Results: The selected MOH-specific models achieved validation R^2 values of 0.70-0.90, RMSE values of 0.75-2.60, and an average MAE of 0.80 weekly cases, enabling reliable eight-week outbreak forecasting. The YOLOv8 module enhanced surveillance by incorporating environmental risk information.

Conclusions: The developed framework accurately forecasts dengue outbreaks across eight MOH divisions, demonstrating that automated model selection and multi-source data integration provide a scalable, evidence-based approach for proactive dengue surveillance.

Keywords: *Dengue Prediction, Epidemiological Surveillance, Machine Learning Framework, Outbreak Risk Assessment.*

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Introduction

Dengue fever is a growing vector-borne viral disease across tropical and subtropical regions (Uduwanage et al., 2025), and it has become a dangerous public health threat in Sri Lanka. Globally, an estimated 3.9 billion people in 129 countries are at risk, with approximately 390 million infections each year, nearly 70% of which occur in Asia (European Centre for Disease Prevention and Control, 2021). Sri Lanka has experienced repeated large-scale dengue outbreaks by all four dengue viruses (Chumpu et al., 2019) over the past decade, including more than 186,000 reported cases in 2017 (Tissera et al., 2020; Ranwala et al., 2021) and over 105,000 cases in 2019. This virus is transmitted through the bite of an infected female mosquito, *Aedes aegypti* or *Ae. albopictus* (Guo, et al., 2017; Lambrechts, et al., 2010).

Dengue incidence shows strong associations with climatic variables such as rainfall, temperature, humidity, and wind speed. Rainfall increases mosquito breeding sites, while temperature (optimally 20-35°C) (Chumpu et al., 2019; Mazhar et al., 2024) and humidity influence vector survival, development rates, and viral replication. Climatic conditions not only influence dengue transmission directly but also exhibit lag effects. For example, dengue outbreaks often occur 1-2 months after peak rainfall, reflecting the mosquito life cycle and viral incubation period. Dengue transmission in Sri Lanka follows a seasonal pattern, with peaks during the monsoon rains in June-July and October-December (Rahulan et al., 2024). In addition to meteorological factors, environmental factors such as mosquito density and improper water storage significantly contribute to dengue transmission.

Traditional statistical approaches often fail to capture the complex and dynamic relationships among climatic, environmental, and epidemiological factors influencing dengue transmission (Nandani & Bandara, 2025; Majeed et al., 2023). This limitation has led researchers worldwide to adopt data-driven machine learning (ML) approaches that demonstrate higher predictive accuracy, adaptability, and the capacity to model complex patterns. Ensemble and tree-based ML algorithms are widely used for dengue prediction due to their ability to model complex nonlinear relationships. Studies show that ML models outperform traditional methods such as Autoregressive Integrated Moving Average (ARIMA), achieving higher accuracy and better handling of multidimensional data (Uduwanage et al., 2025).

Although several Sri Lankan studies have applied machine learning for dengue prediction, they primarily focused on developing predictive models using retrospective datasets and did not provide an integrated real-time surveillance framework (Ranwala et al., 2021). Unlike prior dengue prediction studies, which typically train a single national- or district-level model on static, retrospective datasets, this framework departs in four specific ways. First, it trains and selects a distinct model for each Medical Officer of Health (MOH) division rather than a single global model, allowing region-specific climatic and epidemiological patterns to be captured independently. Second, it automatically retrains the forecasting models each month using newly collected surveillance data, enabling adaptation to concept drift instead of relying on a fixed model developed only once. Third, it operates as a live, real-time deployment with automated alerting, rather than an offline analytical exercise reported after the fact. Fourth, it incorporates a You Only Look Once (object detection model) (YOLOv8) based computer vision module that converts user-submitted field images into structured environmental hazard features, thereby extending the model's inputs beyond the meteorological and epidemiological variables used in earlier Sri Lankan studies.

Together, these capabilities provide a comprehensive framework for real-time dengue surveillance and early outbreak prediction in Sri Lanka. Accordingly, this research aims to: (i) develop an automated machine learning framework that integrates epidemiological, meteorological, and environmental data to forecast dengue outbreaks up to eight weeks in advance across eight MOH divisions in the Jaffna District, and (ii) design and implement a real-time visualisation and alert system to support timely, evidence-based decision-making by MOH officers and public health authorities.

Methods

Study Area

This research was conducted in the Jaffna District of Sri Lanka, at 9.6615°N, 80.0255°E. Jaffna District was administratively divided into 14 Ministry of Health divisions.(Figure 14), Among these, eight MOH divisions-Chavakachcheri, Jaffna, Nallur, Kopay, Karaveddy, Point-Pedro, Sandilipay, and Uduvil were selected for this study. These divisions experience similar and distinct seasonal rainfall patterns, especially during the Northeast monsoon (October-January), with additional inter-monsoon rains.

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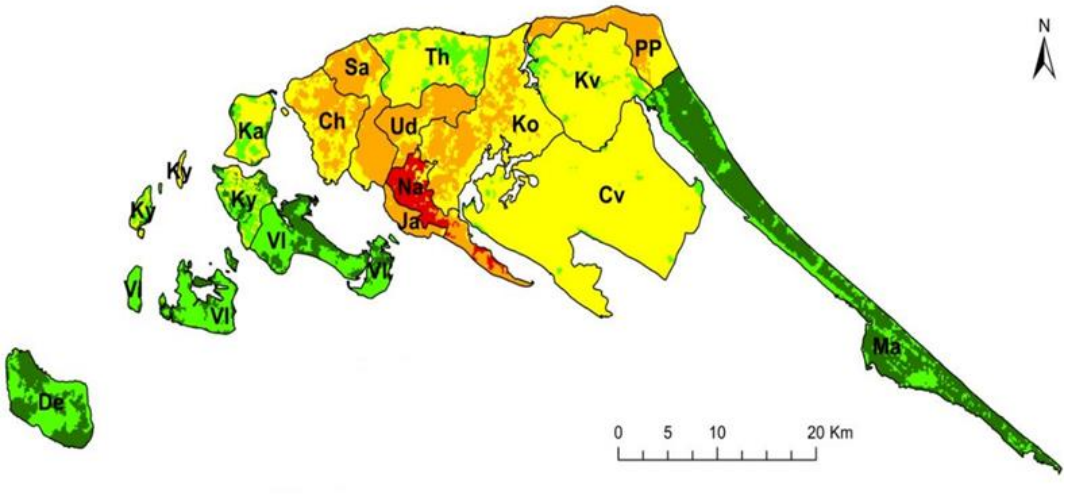

Figure 14. Map of Jaffna District, Sri Lanka, showing the eight selected MOH divisions. Source: (Jayadas, et al., 2023)

Data Sources

Three different types of datasets (Table 5) from 2018 to 2026 were used for this study. Epidemiological data serve as the primary dependent variable and include weekly case counts at the MOH division level. It was collected from the Regional Director of Health Services in Jaffna. The meteorological data were collected from the NASA Power website for the same location and time period. Environmental data were gathered through field surveys and observations (Chumpu et al., 2019; Islam et al., 2023; Tuan & Dang, 2024).

Table 5. Collected data sources, variables, and temporal granularity across three data streams (2018-2026)

Category	**Variable**	**Primary Source**	**Temporal Granularity**
Meteorological	Average Temperature(°C)	NASA Power	Daily
	Maximum temperature(°C)	NASA Power	Daily
	Minimum temperature(°C)	NASA Power	Daily
	Rainfall(mm)	NASA Power	Daily
	Relative Humidity (%)	NASA Power	Daily
	Surface Pressure(kPa)	NASA Power	Daily
	Wind Speed(m/s)	NASA Power	Daily
	Vegetation Solar Index (VSI)	NASA Power	Daily
Epidemiological	Case Count	RDHS - Jaffna	Weekly
Environmental	Water Level	Survey	Weekly
	Mosquito Density	Survey	Weekly

Data Processing

Daily meteorological data were aggregated to weekly resolution using a rolling window [d-6, d] with cumulative summation, and aligned with dengue records. Missing values were handled via linear interpolation followed by backward and forward fill (Tuan & Dang, 2024; Rahman, et al., 2023). Ordered categorical variables (water level and mosquito density) were ordinally encoded (0-4).

New features were created to capture delayed epidemiological effects. Meteorological variables were lagged (Chumpu, et al., 2019; Mazhar, et al., 2024; Tuan & Dang, 2024; Gharbi, et al., 2011) at multiple intervals: temperature (1-4 weeks; rolling means 4-8 weeks), rainfall (2-8 weeks; cumulative sums 2-12 weeks), and humidity and pressure (1-8 weeks) alongside environmental indices. All rolling features were shifted one week to prevent data leakage. Case counts were lagged 1-6 weeks with rolling statistics (4- and 8-week mean, 4-week standard deviation, 8-week maximum) and trend indicators (change, acceleration, 4-week rise/fall).

Seasonality was encoded using sine-cosine transformations of week and month, with binary indicators for monsoon periods, dengue seasons, and COVID-19 lockdowns (Rahulan, et al., 2024; Nandani & Bandara, 2025).

Feature selection applied the Pearson correlation coefficient ($|r| \geq 0.20$) separately per MOH division, retaining 49 features comprising lagged meteorological and environmental variables, temporal encodings, and lagged case-based statistics.

Data Splitting

Two chronological splitting strategies were applied. During development, data were partitioned into training (2018-2023, 301 weeks), validation (2024, 52 weeks), and test sets (2025-2026, 66 weeks). During deployment, a two-way split was applied: the most recent 52 weeks were reserved for validation, with the remainder used for training, maximizing predictive performance while maintaining unbiased evaluation.

Machine Learning Models

This study implemented four machine learning models (Table 6) within a unified forecasting pipeline**: Extreme Gradient Boosting (XGB), Random Forest (RF), Gradient Boosting (GB)**, and an **Ensemble model** (Islam, et al., 2023; Ong, et al., 2023; Xu, et al., 2020).

Table 6. Implemented Four (4) Models for dengue prediction

Model	**Type**	**Key Characteristic**
XGB	Sequential boosting	Residual correction with regularisation
RF	Bagging ensemble	Variance reduction via tree averaging
GB	Sequential boosting	Additive weak-learner correction
Ensemble	Weighted average	Combines all three to reduce individual bias

Model Selection and Training

All four models were trained using the same pre-processed dataset and feature set to ensure fair comparison and consistency. Tree-based models (Nandani & Bandara, 2025) were chosen for their ability to capture nonlinear relationships and interactions among variables while remaining robust to small datasets. The Ensemble model combined predictions from the three base models to improve forecasting stability and reduce bias.

A major contribution of the framework is the MOH-specific training strategy. Instead of using a single global model, separate models were developed for each MOH region using localized historical data, allowing the system to capture regional outbreak patterns, climatic variations, and demographic differences. The best-performing model for each MOH was selected based on evaluation metrics, while the same optimised configurations and hyperparameters were retained during deployment to ensure stability and reproducibility.

Since tree-based ensembles offer limited transparency, SHAP (SHapley Additive exPlanations) was applied to each MOH's best-performing model using TreeExplainer to quantify each feature's contribution to predicted case counts, with mean absolute SHAP values ranked per division.

Cross-Validation Strategy and Hyperparameter Configuration

Given the temporal dependence of weekly dengue case counts, conventional k-fold cross-validation was not applied because shuffling observations across folds would violate chronological order and leak future information into the training set. Instead, a single chronological holdout was used for hyperparameter tuning and model selection, consistent with standard practice for time-series forecasting (Tuan & Dang, 2024; Rahman, et al., 2023).

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Hyperparameters (Figure) for each of the three base models were tuned on the development-phase validation set and held fixed during deployment.

```python
model = xgb.XGBRegressor(
    n_estimators=300,
    max_depth=3,
    learning_rate=0.1,
    subsample=0.7,
    colsample_bytree=0.7,
    min_child_weight=5,
    gamma=1.0,
    reg_alpha=0.5,
    reg_lambda=2.0,
    random_state=42,
    eval_metric="rmse",
    early_stopping_rounds=30,
    verbosity=0,
)
```

XG Boost

```python
model = RandomForestRegressor(
    n_estimators=300,
    max_depth=6,
    min_samples_split=5,
    min_samples_leaf=3,
    max_features=0.8,
    random_state=42,
)
```

Random Forest

```python
model = GradientBoostingRegressor(
    n_estimators=300,
    max_depth=4,
    learning_rate=0.1,
    subsample=0.7,
    min_samples_split=5,
    min_samples_leaf=3,
    n_iter_no_change=10,
    random_state=42,
)
```

Gradient Boost

Figure 2. Parameters used for the selected models

Model Evaluation Framework

To ensure reliable dengue forecasting, a multi-metric evaluation framework was adopted. Model performance was assessed (Ong, et al., 2023; Karasinghe, et al., 2024) using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and the Coefficient of Determination (R^2). Using multiple metrics allowed evaluation from both accuracy and generalization perspectives.

The selection framework consisted of two stages. First, an R^2 boundary filtering method was applied. Models with validation R^2 below 0.70 were considered underfitted, and those above 0.90 were treated as potentially overfitted. Only models within the acceptable range were further evaluated. If no model met this range, the model with the validation R^2 closest to 0.80 was selected to ensure availability across all MOH regions.

Second, a normalized composite scoring mechanism was introduced. All evaluation metrics were normalized between 0 and 1. For RMSE, MAE, and MAPE, lower values received higher scores, whereas higher R^2 values received higher scores. The final composite score was calculated as:

$$Composite\ Score = w_1 RMSE_{norm} + w_2 MAE_{norm} + w_3 R^2_{norm} + w_4 MAPE_{norm}$$

Weights were assigned as $w_1 = 0.30$ (RMSE), $w_2 = 0.25$ (MAE), $w_3 = 0.25$ (R^2), and $w_4 = 0.20$ (MAPE), reflecting the greater importance of explained variance and absolute error minimization in epidemiological forecasting. The model with the highest composite score was automatically selected for deployment in the corresponding MOH region.

Deployment Pipeline, Visualisation & Alert System

The deployment pipeline was designed to support real-time dengue forecasting across multiple MOH regions. Initially, models for each MOH were independently developed, trained, and validated, then integrated into a centralized multi-MOH framework with standardized feature pipelines.

The production platform (Figure) was implemented as a full-stack system integrating a Node.js/Express.js backend with Python-based machine learning modules communicating via asynchronous standard-output streams. PostgreSQL with Prisma ORM served as the persistent data store. Three automated cron jobs managed the pipeline: daily weather data collection from the Open-Meteo API, weekly imputation of missing data to maintain time-series continuity, and monthly model retraining using accumulated deployment data.

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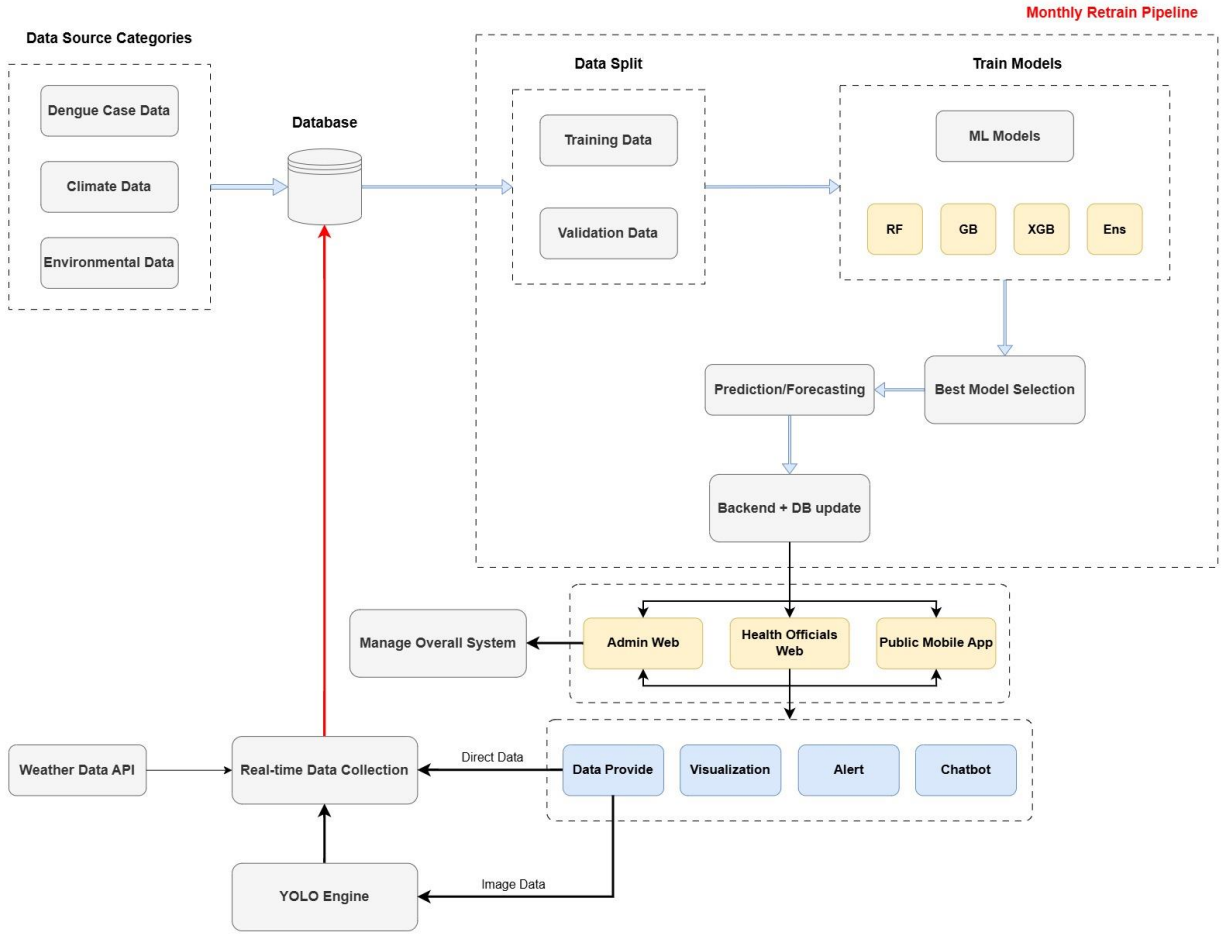

Figure 3. DengueAI system architecture. End-to-end pipeline from data ingestion through ML forecasting to alert delivery and role-specific user interfaces

Outbreak risk predictions for the eight weeks per MOH division were displayed via an interactive geospatial heatmap, categorising regions into high (≥20), moderate (≥10), and low (<10) risk zones. Threshold-based automated alerts were distributed via SMS, email, and in-app push notifications. Three role-specific interfaces were developed: an Admin web (Figure) application for system control and model management, a Health Officials web application (Figure) for region-specific data submission and analytics, and a public-facing mobile application (Figure) for community-level risk awareness and environmental reporting. An AI-powered chatbot was embedded across all three platforms.

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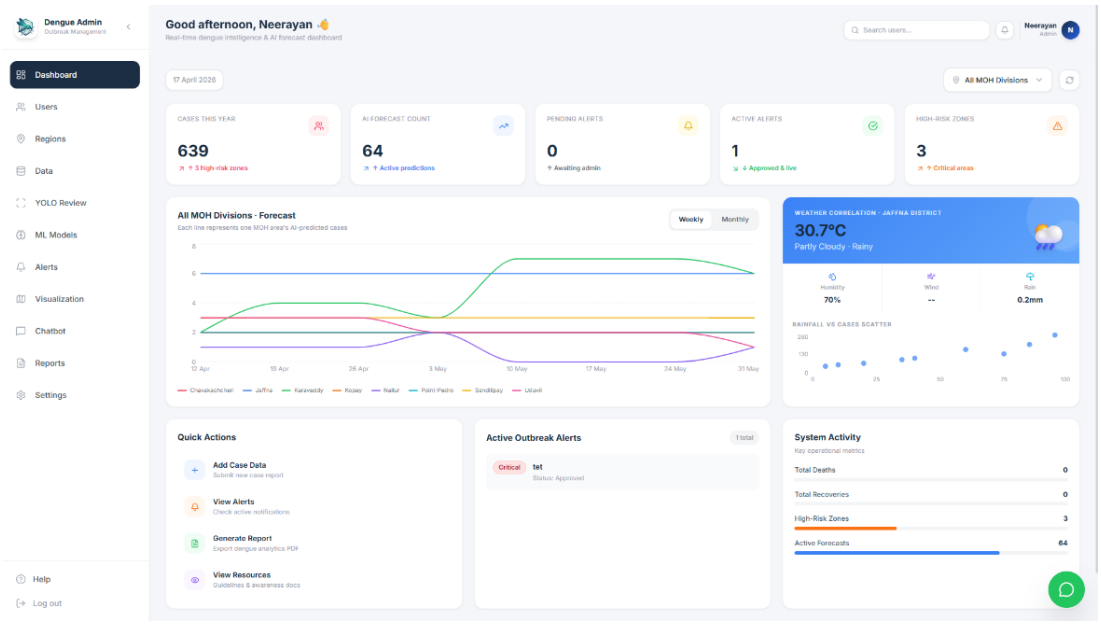

Figure 4. Screenshots of the Admin web dashboard interfaces

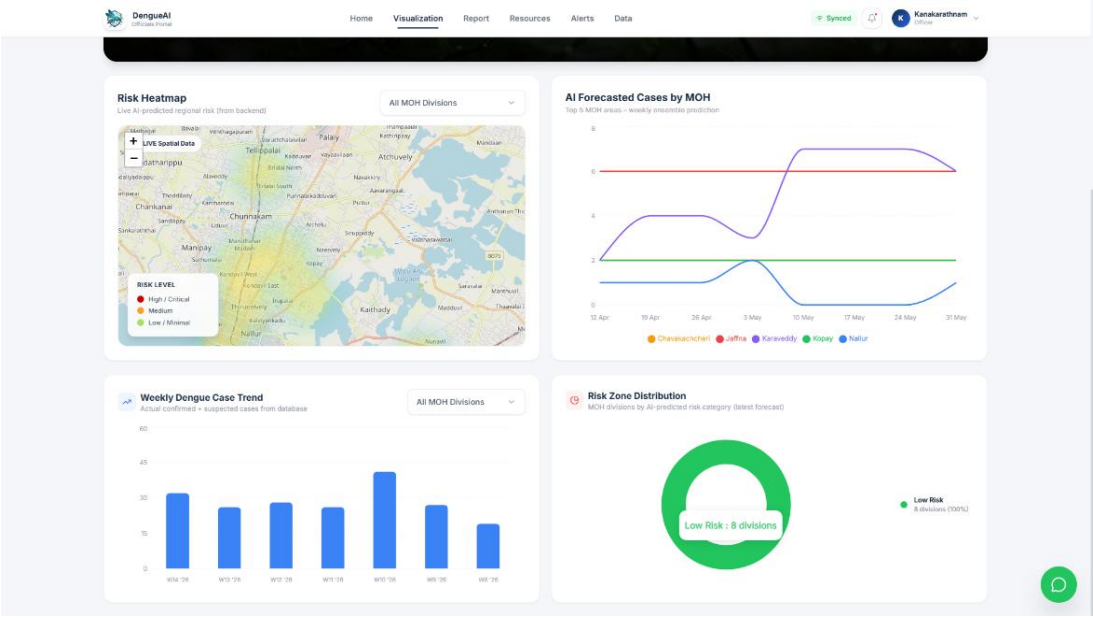

Figure 5. Screenshots of the Health Officials web portal interfaces

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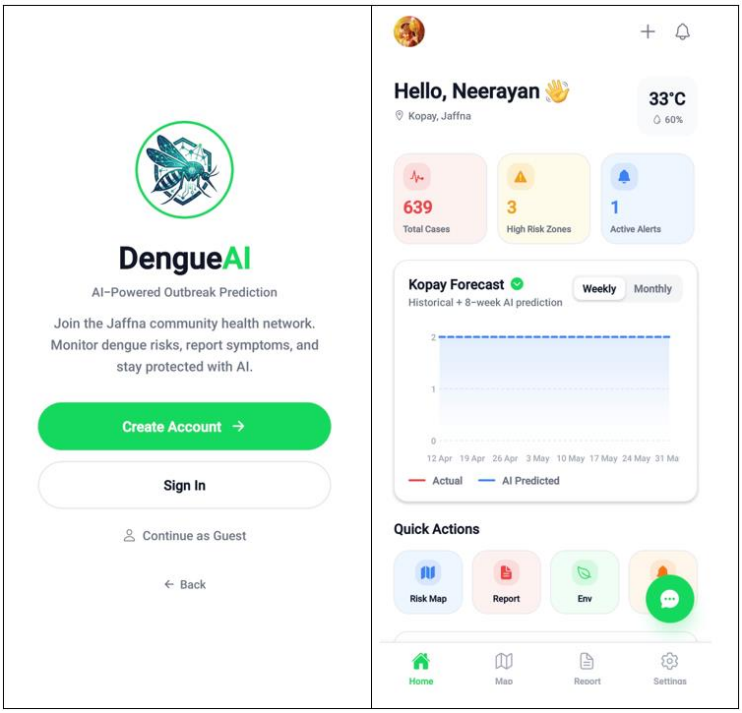

Figure 6. Screenshots of the Public-facing mobile application interfaces

A secondary YOLOv8 deep learning module (Rosi, et al., 2026; Yu, et al., 2024), deployed as a FastAPI microservice, classified user-submitted field images into five environmental hazard severity levels to enrich input feature streams and support community-driven surveillance.(Figure). The module achieved a mean Average Precision (mAP@0.5) of **0.87** on over **200** images with various conditions from a field-collected image dataset, demonstrating reliable hazard-level classification across all severity classes.(Figure).

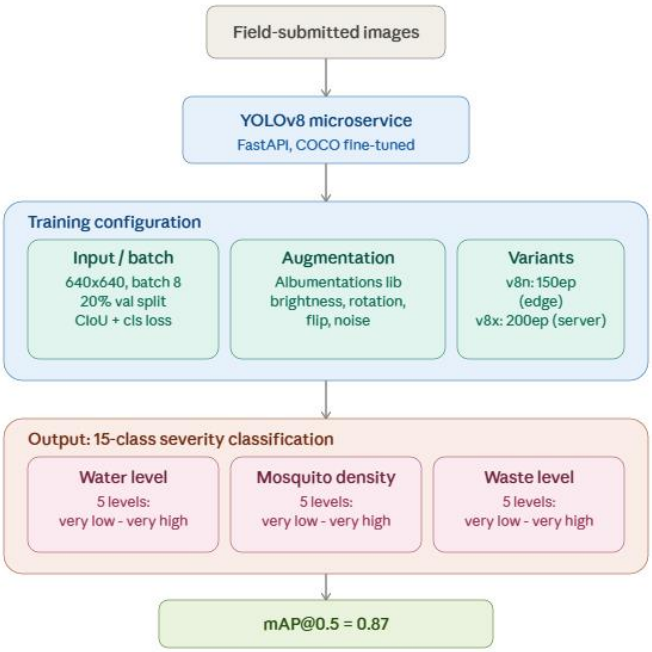

Figure 7. Developed YOLO Model Configuration and Architecture

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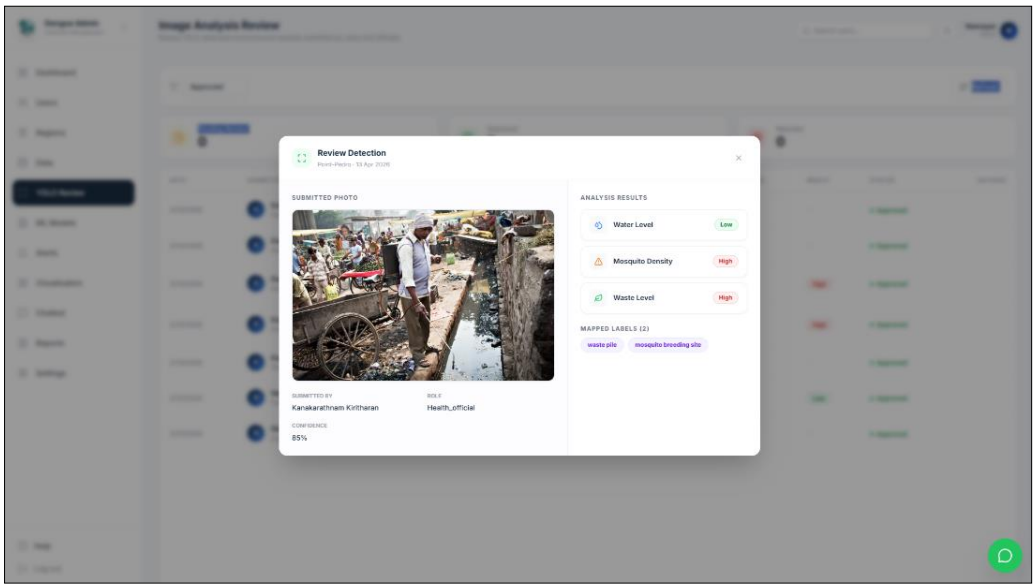

Figure 8. YOLOv8 model sample outputs: field-submitted image

Results

Exploratory Data Analysis

Weekly dengue case distributions across all eight MOH divisions were strongly right-skewed (skewness: 2.80-5.00) and leptokurtic (kurtosis: 8.03-29.44), with Jaffna recording the highest burden and Uduvil the most stable profile (Table 7).

Table 7. Weekly dengue case descriptive statistics across eight MOH divisions

MOH Division	Mean Cases/Wk	Std Dev	Median	Peak Cases
Jaffna	13.1	30.6	4.0	267
Chavakachcheri	4.7	8.9	2.0	62
Karaveddy	6.4	10.2	3.0	79
Kopay	7.1	14.2	3.0	102
Nallur	5.2	10.7	2.0	86
Point-Pedro	5.2	9.0	2.0	64
Sandilipay	5.6	10.8	2.0	84
Uduvil	5.4	8.9	2.0	46

Time-series analysis identified three distinct temporal phases (Figure): pre-pandemic peaks (2018-2019) with synchronized high-amplitude seasonal surges; a district-wide COVID-19 suppression phase (2020-2021) driven by restricted mobility interrupting transmission chains (Nandani & Bandara, 2025), and a post-pandemic resurgence (2022-2025) that exceeded pre-pandemic levels in several divisions.

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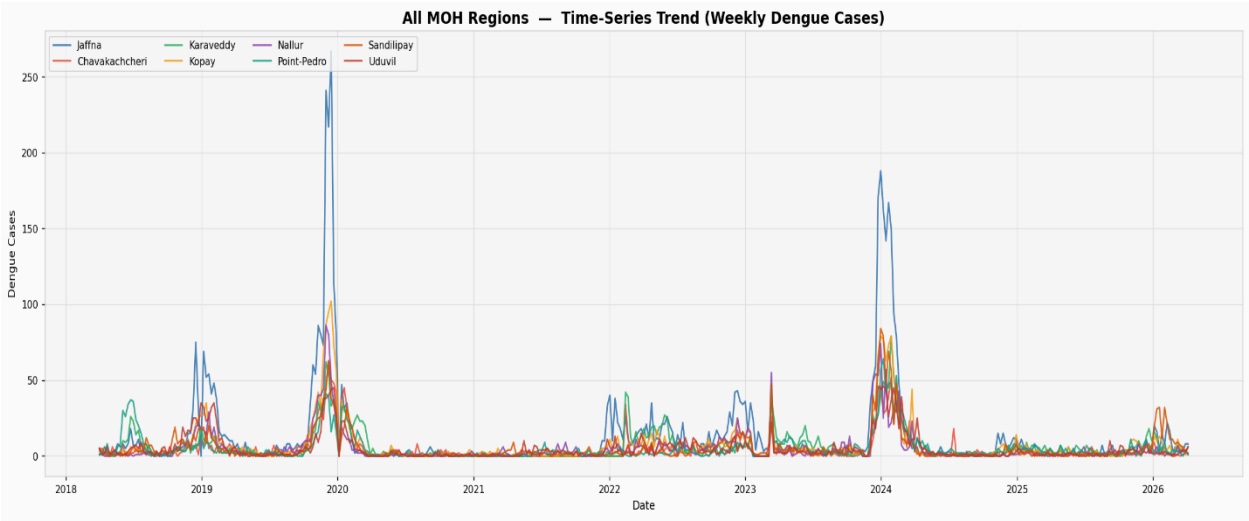

Figure 9. Time-series of weekly reported dengue cases across eight Jaffna MOH divisions (2018-2026)

Feature Importance and SHAP Analysis

Across all eight MOH divisions, lagged case count, week-on-week case change, and the four-week rolling case mean ranked as the top three to four predictors regardless of model type, with Cases_lag1 alone reaching 6.529 in Jaffna. Climatic and environmental features ranked secondary: rainfall and humidity dominated in five divisions, while water-level index features outweighed rainfall in Nallur, Point-Pedro, and Uduvil, indicating standing-water conditions play a distinct localized role (Figure 5).

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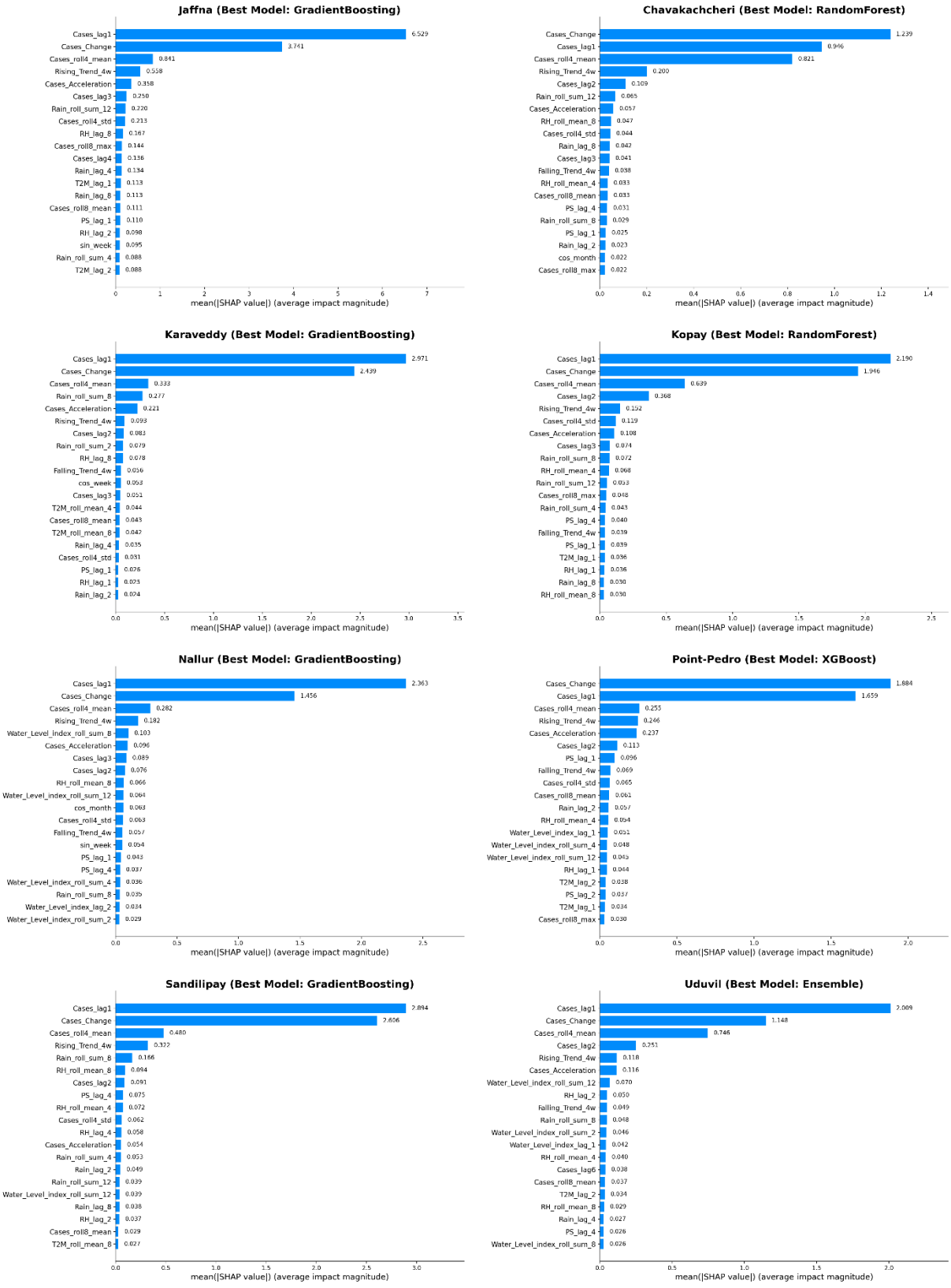

Figure 5. SHAP Analysis Bar graphs for each MOH's best Model

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Development Phase Model Performance

The framework was evaluated during both the development phases using multiple regression performance metrics, including R2, RMSE, MAE, and MAPE across eight MOH regions.

Table 8. Development phase validation model performance across eight MOH divisions

MOH	Best Model	R^2	RMSE	MAE	MAPE	Composite Score
Jaffna	GB	0.823	1.93	1.26	32.3	0.850
Chavakachcheri	RF	0.841	0.74	0.48	21.3	0.928
Karaveddy	GB	0.860	1.35	0.86	15.8	1.000
Kopay	RF	0.749	1.73	1.06	39.6	0.669
Nallur	GB	0.792	0.84	0.50	22.6	1.000
Point-Pedro	XGB	0.868	0.89	0.55	18.6	0.988
Sandilipay	GB	0.880	2.49	1.06	17.9	0.938
Uduvil	Ensemble	0.865	0.72	0.42	19.1	1.000

Gradient Boosting (GB) was optimal in Jaffna, Karaveddy, Nallur and Sandilipay. Random Forest (RF) excelled in Chavakachcheri and Kopay, despite MAPE inflation during Kopay's low-incidence weeks. XGBoost minimized absolute errors in Point-Pedro, while the Ensemble approach best captured Uduvil's stable epidemiological patterns (Table 8).

The resulting R^2 values are visualised in Figure 6, which illustrates the degree of variation in model suitability across regions and algorithms.

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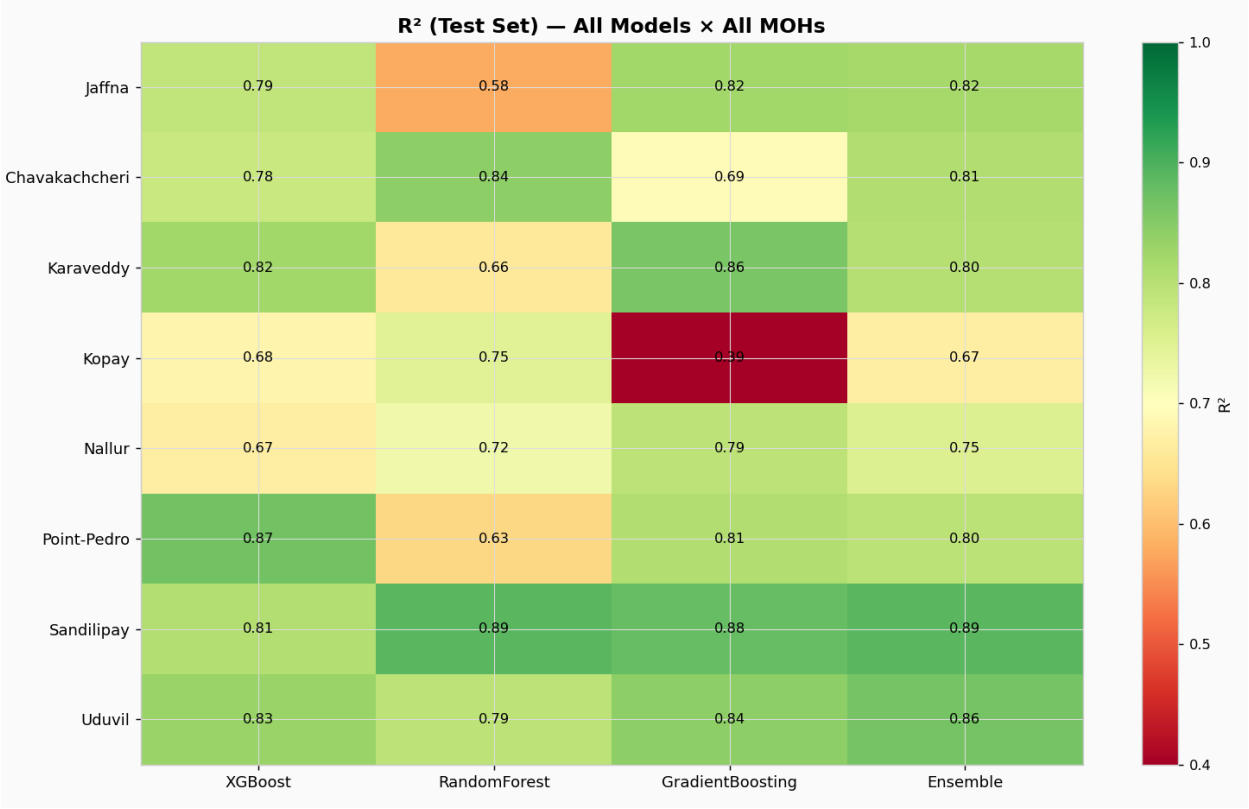

Figure 6. R² performance heatmap for all four models evaluated on the test set across all eight MOH divisions.

Figure 7 presents the actual versus predicted dengue case trajectories for each of the eight MOH regions on the test set, using the best-selected model per division.

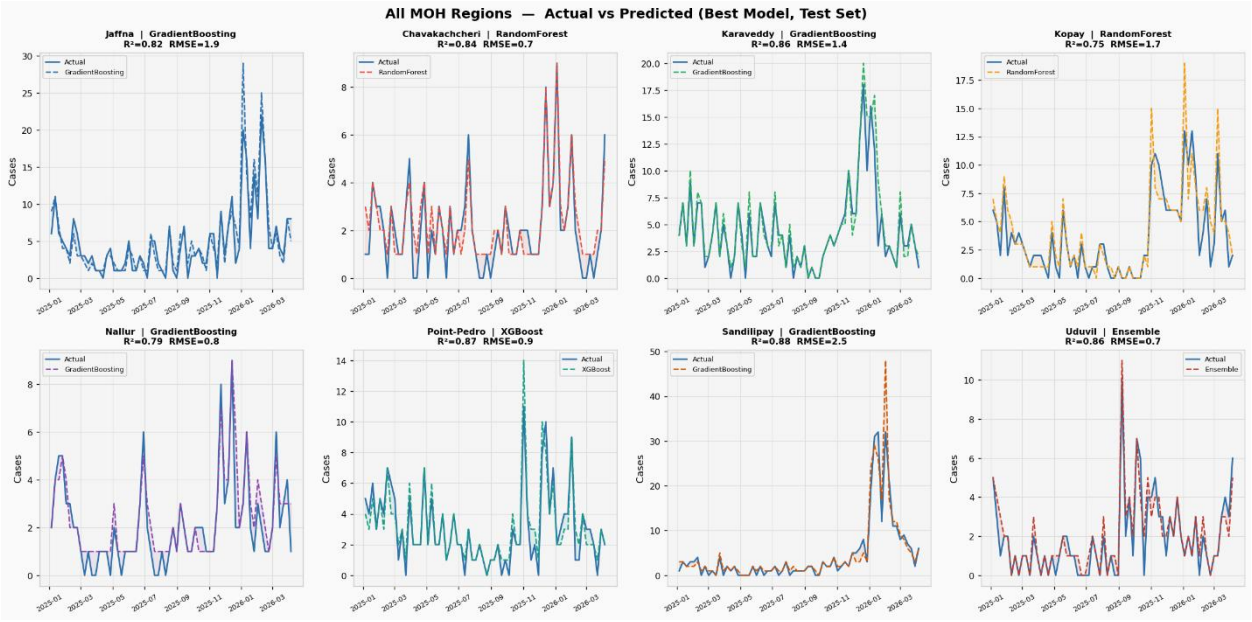

Figure 7. Actual versus predicted weekly dengue case counts for all eight MOH divisions

Deployment Phase Model Performance

Following retraining on the complete regional datasets, the deployed machine learning models achieved validation R² values ranging from 0.776 to 0.895 across the eight MOH regions. All deployed models exceeded

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the minimum acceptable validation threshold of $R^2 = 0.70$ (Table 9), indicating that the selected deployment framework was sufficient for regional dengue forecasting without requiring fallback model replacement.

Table 9. Deployment phase validation performance across eight MOH divisions

MOH	Best Deployment Model	R^2	RMSE	MAE	MAPE	Composite Score
Chavakachcheri	RF	0.815	0.91	0.56	17.2	1.000
Jaffna	GB	0.880	1.66	1.02	23.3	1.000
Karaveddy	GB	0.895	1.22	0.71	15.6	1.000
Kopay	Ensemble	0.856	1.39	0.85	27.6	1.000
Nallur	Ensemble	0.865	0.75	0.52	21.0	0.953
Point-Pedro	Ensemble	0.845	0.99	0.52	18.7	1.000
Sandilipay	RF	0.886	2.60	1.52	27.4	1.000
Uduvil	RF	0.776	1.06	0.73	25.0	1.000

Figure 8, and Figure 9 show actual versus predicted weekly dengue case counts per division using the deployed best model on the validation set.

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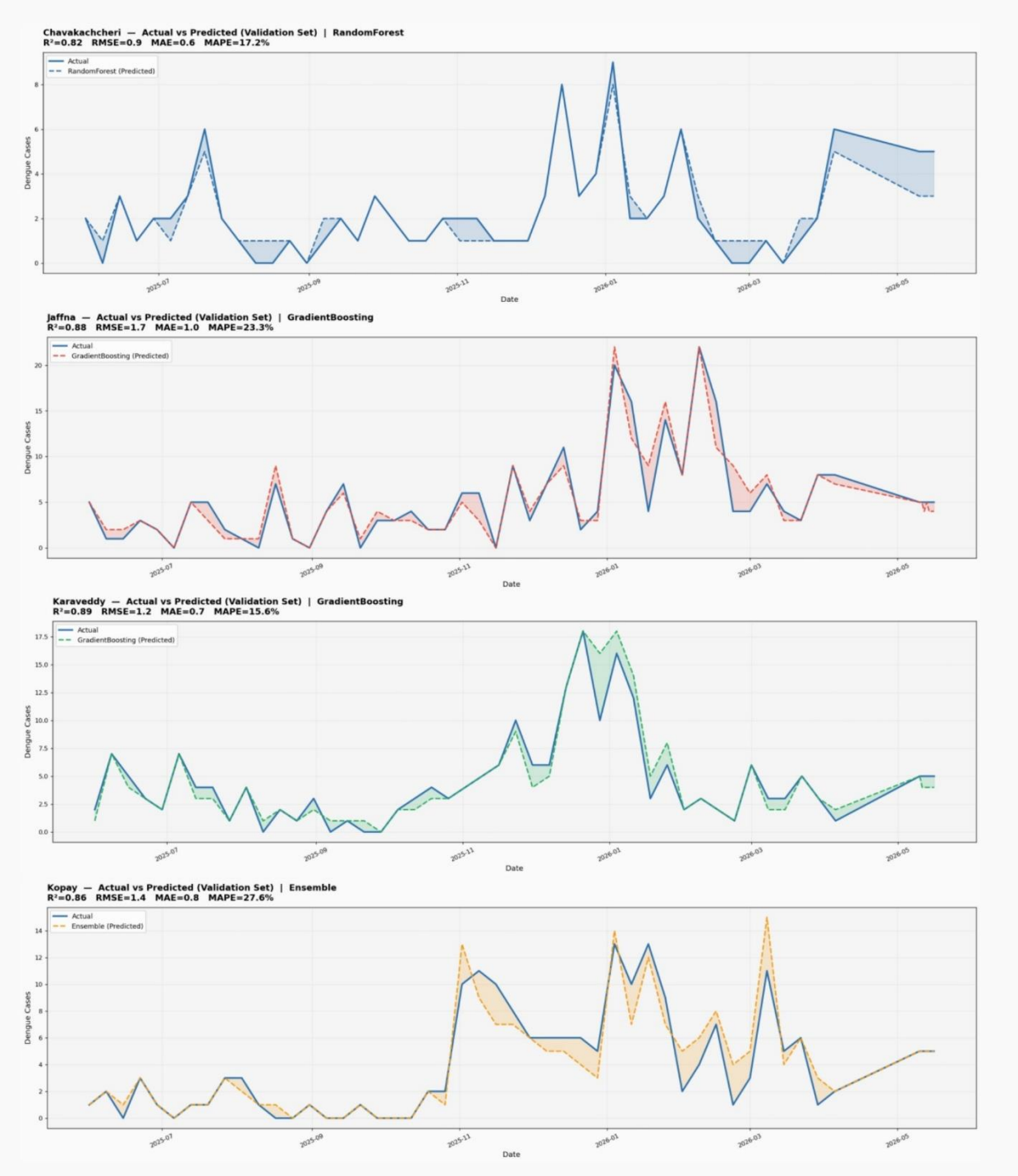

Figure 8. Actual versus predicted weekly dengue case counts for Chavakachcheri, Jaffna, Karaveddy, and Kopay

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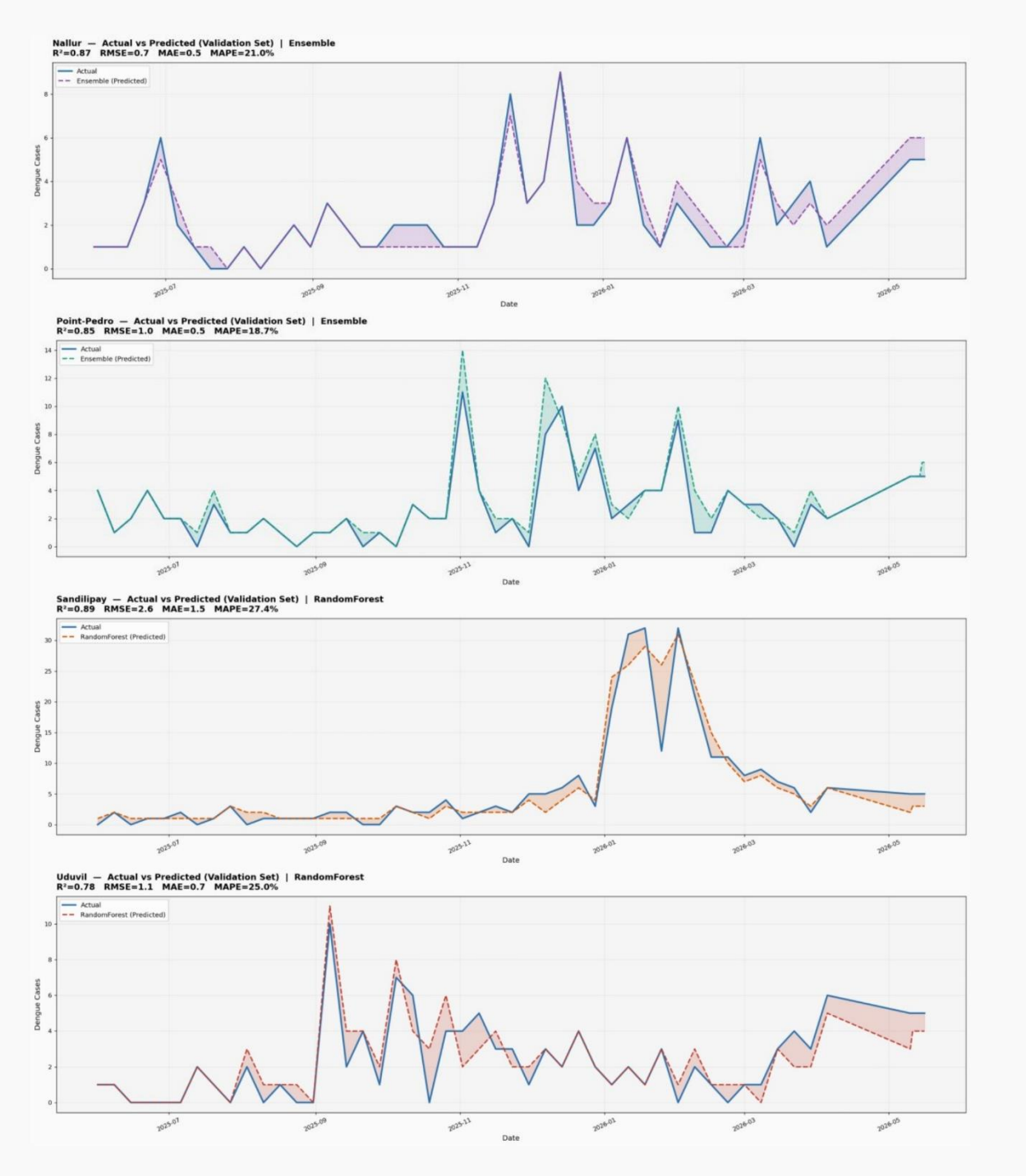

Figure 9. Actual versus predicted weekly dengue case counts for Nallur, Point-Pedro, Sandilipay, and Uduvil

Discussion

This research successfully developed DengueAI, a machine learning-based framework for predicting dengue outbreaks across eight MOH divisions in Jaffna District using epidemiological, meteorological, and environmental data. The results demonstrate that ensemble algorithms can reliably model the complex, nonlinear dynamics of dengue transmission when applied with localized training strategies and multi-metric evaluation.

The MOH-specific model selection approach demonstrated that no single algorithm dominated across all divisions. (Uduwanage, et al., 2025; Chen & Moraga, 2024) The GBoosting model has achieved the best development

performance in Jaffna, Karaveddy, Nallur, and Sandilipay, demonstrating its ability to capture nonlinear meteorological-disease interactions through iterative residual correction. The Random Forest model has provided the best performance in Chavakachcheri and Kopay, confirming that bagging-based ensembles deliver strong performance in divisions with high epidemiological variability and low-incidence periods. Ensemble models achieved competitive results in Nallur, Point-Pedro, and most of the deployment-phase divisions, and they give the advantage of prediction averaging in reducing model variance.

All eight MOH divisions' predictive performance results strongly confirm that the machine learning models perform better than classical statistical approaches like the ARIMA model (Uduwanage, et al., 2025; Karasinghe, et al., 2024), which are constrained by linearity assumptions and limited integration of multidimensional features. The use of lagged meteorological variables like temperature, rainfall, and humidity is aligned with the biological understanding of dengue incidence, reflecting delayed environmental effects through the Aedes mosquito life cycle (Rahulan, et al., 2024).

Feature importance analysis using SHAP identified the variables that contributed most to model predictions. Across tree-based models, case-history features consistently exhibited the highest importance, reflecting strong weekly autocorrelation in dengue transmission. Multi-week rainfall aggregates ranked as the next most influential predictors, consistent with the Aedes breeding cycle, where sustained standing water over one to two weeks is required for egg-to-adult development before mosquitoes become infectious.

Most existing approaches analyse data offline and produce static results; this work moves beyond that and integrates advanced features such as MOH-specific model training (Fransson, et al., 2025), automatic monthly model retraining, an AI-powered chatbot and multi-user platforms with automated alerting, and risk visualisation maps for decision support. The YOLOv8 image model (Rosi, et al., 2026; Yu, et al., 2024) allows users to contribute environmental information by uploading images of potential mosquito breeding sites. These reports provide valuable real-time data that help address the limitations associated with passive dengue monitoring systems. The multi-platform architecture, divided into Admin, Health Official, and Public interfaces, ensures that actionable risk information reaches relevant stakeholders simultaneously and with appropriate technical detail.

Real-world deployment feasibility was further assessed through operational performance testing. The trained tree-based ensemble models achieved an average prediction latency of approximately 2.60 milliseconds per query, with end-to-end response times, including network and API overhead, remaining well under 100 milliseconds, satisfying real-time operational requirements. Unlike deep learning approaches that typically require GPU acceleration for inference, the framework runs on commodity hardware (8-vCPU, 8 GB RAM), reflecting its computational efficiency. The architecture decouples historical model training from real-time inference and processes requests asynchronously, allowing multiple Medical Officers of Health to query the system concurrently without significant performance degradation; the stateless design further permits horizontal scaling via standard load balancing should demand increase.

Several practical factors nonetheless affect adoption at scale. The system depends on continued weekly case submissions from the Regional Director of Health Services (RDHS) and on the uptime of external weather APIs, and any interruption in either source delays the forecast cycle. The Node.js/Express backend and PostgreSQL data store must remain continuously available to support the automated daily, weekly, and monthly pipeline jobs. Integration with Sri Lanka's national dengue surveillance system would require a formal data-sharing arrangement with the Ministry of Health, and the sustainability of the monthly retraining cycle depends on uninterrupted RDHS reporting, since a lapse in reporting could allow model drift to go undetected until sufficient new data accumulates. Maintenance costs, while modest given the framework's low computational footprint, would still require dedicated technical ownership to monitor pipeline health, API availability, and data quality over time.

Limitations

During this study, several limitations were identified that should be considered when interpreting the results. First, the historical dataset covered the period from 2018 to 2026, which remains relatively short for modelling a complex and nonlinear disease transmission process such as dengue. Although the dataset captured multiple seasonal variations and outbreak patterns within the Jaffna District, longer historical records are required to improve the model’s ability to learn rare transmission behaviours, long-term epidemiological trends, and the effects of changing climatic conditions. In particular, extreme epidemic events that occur infrequently may not be sufficiently represented within the available dataset, which could affect predictive performance during future large-scale outbreaks.

Second, dengue surveillance data may contain reporting biases due to variations in healthcare-seeking behaviour, diagnostic practices, and reporting completeness between MOH divisions. These inconsistencies can introduce uncertainty into the observed case trends used for model training. Additionally, although meteorological variables were incorporated from available sources, missing or incomplete environmental observations may reduce the ability of the models to fully capture localized factors influencing mosquito population dynamics, such as temporary water accumulation and environmental changes.

Third, some MOH divisions with very low dengue incidence produced relatively high Mean Absolute Percentage Error (MAPE) values. This limitation is associated with the nature of percentage-based evaluation metrics, where small differences between predicted and observed values can result in large percentage errors when actual case numbers are close to zero. Therefore, these results should be interpreted together with additional evaluation metrics rather than relying solely on MAPE.

Finally, the proposed framework was developed and evaluated using data from the Jaffna District only. Since dengue transmission patterns are influenced by regional differences in climate, population density, vector distribution, environmental conditions, and healthcare reporting practices, the generalizability of the framework to other regions of Sri Lanka requires further investigation.

Future Work

Future work should focus on externally validating the framework using datasets from districts beyond Jaffna to assess its generalizability across Sri Lanka's diverse climatic and demographic conditions. The framework can then be extended toward nationwide deployment by incorporating data from additional MOH regions and validating performance over multiple epidemic cycles to strengthen confidence in its long-term reliability.

Future methodological improvements include integrating dengue serotype surveillance data to account for changes in population immunity, incorporating real-time satellite-derived vegetation and standing-water indices to improve spatial precision, and investigating advanced forecasting approaches such as Transformer-based time-series models and graph neural networks to better capture temporal dynamics and spatial relationships between MOH regions.

A structured usability evaluation involving health officials and system administrators, using instruments such as the System Usability Scale, would provide valuable feedback for refining the user interface, alert mechanisms, and overall system functionality. Further work should incorporate explainable AI techniques to improve the transparency and interpretability of model predictions, supporting greater trust and adoption in public health decision-making.

Conclusions

This study developed and evaluated DengueAI, an automated machine learning framework for real-time dengue outbreak forecasting and decision support in the Jaffna District. By integrating epidemiological, meteorological, and environmental data within an end-to-end prediction pipeline, the framework provides localized risk forecasts and supports timely public health decision-making.

The integration of automated retraining, environmental image analysis, interactive visualisation, and alerting extends dengue surveillance beyond retrospective reporting toward proactive public health decision support. These integrated components extend conventional dengue monitoring beyond retrospective reporting toward a more proactive, data-driven early warning system.

The results indicate that localized machine learning models effectively capture spatial variations in dengue transmission and deliver accurate short-term outbreak forecasts. Incorporating automated retraining, environmental monitoring, visualisation, and alert mechanisms allows the framework to serve as a practical decision-support tool for routine public health surveillance.

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Ethics & Data Statement

Ethical clearance for the use of epidemiological surveillance data was obtained from the Regional Director of Health Services, Jaffna. No individual patient data were accessed or disclosed.

References

Abdulmalek, S. et al., 2022. IoT-Based Healthcare-Monitoring System towards Improving Quality of Life: A Review. *Healthcare (Basel), Switzerland,* 10(10), p. 1993.

A., Choupdar, G. K., A. & T, P., 2025. ICT and IoT-Based Smart Post-Harvest Solutions.pdf (ICT and IoT-Based Smart Post-Harvest Solutions). *Agrospheres: e-Newsletter,* 06 June, 6(6), pp. 15-18.

Ajisegiri, E. et al., 2022. Development of a Smart Grain Storage Silo Using the Internet of. *International Journal of Artificial Intelligence and Machine Learning ·,* 5 July, 2(2), pp. 1-22.

Andre Esteva, B. K. R. A. N. J. K. S. M. S. H. M. B. &. S. T., 2017. Dermatologist-level classification of skin cancer with deep neural networks. *Nature.*

Areej Alotaibi 1, *. D. A., 2025. Skin Cancer Detection Using Transfer Learning and Deep Attention Mechanisms. *National Library of Medicine.*

Chakraborty, A., Gupta, R. D., Kabir, Z. M. & Dhar, S., 2023. Development of an IoT-enabled cost-effective asthma patient monitoring system: Integrating health and indoor environment data with statistical analysis and data visualization. *Cleaner and Responsible Consumption,* 24(2), p. 100142.

Chen, X. & Moraga, P., 2024. Dengue forecasting and outbreak detection in Brazil using LSTM: integrating human mobility and climate factors. *Infectious Disease Modelling,* 11(1), pp. 338-354.

Chumpu, R., Khamsemanan, N., Nattee, C. & Samy, A. M., 2019. The association between dengue incidences and provincial-level weather variables in Thailand from 2001 to 2014. *PLOS ONE,* 14(12), p. e0226945.

Erico Tjoa, C. G., n.d. [Online] Available at: https://arxiv.org/abs/1907.07374

Espressif Systems, 2024. *ESP32 Technical Reference Manual,* s.l.: Espressif Systems.

European Centre for Disease Prevention and Control, 2021. *Factsheet about Dengue,* Stockholm: Centre for Disease Prevention and Control.

Fransson, P. et al., 2025. An explainable covariate compartmental model for predicting the spatio-temporal patterns of dengue in Sri Lanka. *PLOS Computational Biology,* 21(9), p. e1013540.

Geert Litjens, T. K. B. E. B. A. A. A. S. F. C. M. G. J. A. v. d. L. B. v. G. C. I. S., n.d. *A Survey on Deep Learning in Medical Image Analysis.* [Online] Available at: https://arxiv.org/abs/1702.05747

Gharbi, M. et al., 2011. Time series analysis of dengue incidence in Guadeloupe, French West Indies: Forecasting models using climate variables as predictors. *BMC Infectious Diseases,* 11(1).

Godliauskas, Povilas & Smite, Darja., 2024. *The well-being of software engineers: a systematic literature review and a theory.*. [Online] Available at: https://www.researchgate.net/publication/386382938_The_well-being_of_software_engineers_a_systematic_literature_review_and_a_theory [Accessed 15 5 2026].

Guo, P. et al., 2017. Developing a dengue forecast model using machine learning: A case study in China. *PLoS Negl Trop Dis,* 11(10), p. e0005973.

Hyuna Sung PhD, J. F. M. M. R. L. S. M. M. L. M. I. S. M. M. P. A. J. D. P. F. B. B. M. P., 2021. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *CA: A Cancer Journal for Clinicians,* 2.

Islam, M. A., Hasan, M. N. & Tiwari, A., 2023. Correlation of Dengue and Meteorological Factors in Bangladesh: A Public Health Concern. *International Journal of Environmental Research and Public Health,* 1 January, 20(6), p. 5152.

Jarman, A. et al., 2023. Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology,* 19 September.Volume 1.

Jayadas, T. T. P. et al., 2023. A spatial dengue risk map for the jaffna district of Northern sri Lanka. *Vingnanam journal of Science,* 18(1), pp. 13-22.

Kamma, V. et al., 2025. Integrating IoT and Cloud Analytics for Real-Time Monitoring of Post-Surgical Recovery in Maxillofacial Patients. *Vascular and Endovascular Review,* 8(1), pp. 304-311.

Karasinghe, N., Peiris, S., Jayathilaka, R. & Dharmasena, T., 2024. Forecasting weekly dengue incidence in Sri Lanka: Modified Autoregressive Integrated Moving Average modeling approach. *PLOS ONE,* 19(3), pp. e0299953-e0299953.

Kennedy, S. I., Zadeh, A. A., Choi, J., & Alborz, S., 2024. *Agile Practices and IT Development Team Well-Being: Unveiling the Path to Successful Project Delivery.* [Online] Available at: http://researchgate.net/publication/385263215_Agile_Practices_and_it_Development_Team_Well-Being_Unveiling_the_Path_to_Successful_Project_Delivery [Accessed 19 5 2026].

Krishnapriya, G. & Prema , S., 2025. Cost-Effective IoT-Based Real-Time Vital Sign Monitoring: An Affordable Telehealth Solution. *Telehealth and Medicine Today,* Volume 10, p. 611.

Kumar, S., 2025. *Agile Development Models - Software Engineering.* [Online] Available at: https://www.geeksforgeeks.org/software-engineering/software-engineering-agile-development-models/ [Accessed 22 January 2026].

Kumar, S., 2026. *Waterfall Model - Software Engineering.* [Online] Available at: https://www.geeksforgeeks.org/software-engineering/waterfall-model/ [Accessed 21 January 2026].

Kurian, N. C. et al., 2023. Robust Semi-Supervised Learning for Histopathology Images Through Self-Supervision Guided Out-of-Distribution Scoring. *ieeexplore.*

Lambrechts, L., Scott, T. W., Gubler, D. J. & Halstead, S. B., 2010. Consequences of the Expanding Global Distribution of Aedes albopictus for Dengue Virus Transmission. *PLoS Neglected Tropical Diseases,* 25 May, 4(5), p. e646.

Lee, D.-H., n.d. [Online] Available at: https://www.researchgate.net/publication/280581078_Pseudo-Label_The_Simple_and_Efficient_Semi-Supervised_Learning_Method_for_Deep_Neural_Networks

Majeed, M. A., Mohd, Z., Zulkafli, Z. & Wayayok, A., 2023. A Deep Learning Approach for Dengue Fever Prediction in Malaysia Using LSTM with Spatial Attention. *International Journal of Environmental Research and Public Health,* 20(5), p. 4130.

MathWorks, 2026. *ThingSpeak Documentation.* [Online] Available at: https://www.mathworks.com/help/thingspeak/

Mazhar, B. et al., 2024. Development of Data-driven Machine Learning Models and their Potential Role in Predicting Dengue outbreak. *Journal of Vector Borne Diseases,* 16 January.pp. 503-514.

Michard , F. & Saugel, B., 2024. New sensors for the early detection of clinical deterioration on general wards and beyond - a clinician's perspective. *Journal of Clinical Monitoring and Computing,* 39(2), pp. 435-442.

Mingxing Tan, Q. V. L., n.d. [Online] Available at: https://arxiv.org/abs/1905.11946

Mohamed A. Kassem 1ORCID, K. M. H. 2. D. 3. a. M. E., 2021. Machine Learning and Deep Learning Methods for Skin Lesion Classification and Diagnosis: A Systematic Review. *MDI.*

Muhammad Danish Ali 1, M. A. I. 2. L. 3. D. 4. a. K. K., n.d. Explainable AI Based Multi Class Skin Cancer Detection Enhanced by Meta Learning with Generative DDPM Data Augmentation. *MDPI.*

Nandani, E. J. K. P. & Bandara, A. M. D. P., 2025. Forecasting Dengue Outbreaks in Kalutara District using Hybrid Machine Learning Techniques. *Journal of Science of the University of Kelaniya,* 18(2), pp. 145-152.

ntfy.sh, 2026. *ntfy.sh.* [Online] Available at: https://ntfy.sh/

Ong, S. Q. et al., 2023. Predicting dengue transmission rates by comparing different machine learning models with vector indices and meteorological data. *Scientific Reports,* 13(1).

Phelan, H., Yates, V. & Lillie, E., 2022. Challenges in healthcare delivery in low- and middle-income countries. *Anaesthesia and Intensive Care Medicine,* 23(8), p. 501–504.

Rahman, S. Z., Senthil, R., Ramalingam, V. & Gopal, R., 2023. Predicting Infectious Disease Outbreaks with Machine Learning and Epidemiological Data. *Journal of Advanced Zoology,* 44(S-4), p. 110:121 .

Rahulan, K., Ranagala, R. M. & Roshan, G. P., 2024. Dengue Outbreak Control and Prevention: A Case Study of Gampaha District, Sri Lanka. *Sri Lankan Journal of Medical Administration,* 25(1), pp. 46-53.

Ramprasaath R. Selvaraju, M. C. A. D. R. V. D. P. D. B., n.d. [Online] Available at: https://arxiv.org/abs/1610.02391

Ranwala, L., Wedisinghe, Y., Perera, S. & Jayamanne, D., 2021. Real-time laboratory surveillance of Dengue antigen (NS1) - Best proposed early warning and response system for Dengue in Sri Lanka? - Results from a pilot study. *Ceylon Medical Journal,* 27 12, 66(3), p. 121.

Riedl, René & Oettl, Christian & Stangl, Fabian & Hevner, Alan., 2025. *How an Agile Software Process Increases Developers' Job Satisfaction: A Stress Perspective Based on the Effort-Reward-Imbalance Model.* [Online] Available at: https://www.researchgate.net/publication/388232797_How_an_Agile_Software_Process_Increases_Developers'_Job_Satisfaction_A_Stress_Perspective_Based_on_the_Effort-Reward-Imbalance_Model [Accessed 20 5 2026].

Rietze, Sarah & Zacher, Hannes., 2023. *Agile work practices: opportunities and risks for occupational well-being..* [Online] Available at: https://www.researchgate.net/publication/374921519_Agile_work_practices_opportunities_and_risks_for_occupational_well-being [Accessed 18 5 2026].

Rosi, A. et al., 2026. Real-Time Mosquito Breeding Site Detection Using a Quantized YOLOv8-Tiny Model on an FPGA-Based Drone Platform. *EAI Endorsed Transactions on Internet of Things,* Volume 11.

Sahu, H., Kashyap, R. & Dewangan, B. K., n.d. Hybrid Deep learning based Semi-supervised Model for Medical Imaging. *ieeexplore.*

Sharafaddini, A. M. & Mansouri, N., 2024. Enhanced Skin Cancer Classification Using Deep Learning and Gradient Boosting Techniques. *ieeexplore.*

Shaswat, . T., 2024. Role of Big Data and IoT in Optimizing Post-Harvest Management. *International Journal of Research Publication and Reviews,* October, 5(10), p. 3.

S. K. et al., 2018. IoT Based Monitoring And Control For Vegetables And Fruits Storage. *International Journal of Advance Research, Ideas and Innovations in Engineering (IJARIIE),* 4(2), p. 5.

Tissera, H. A. et al., 2020. Severe Dengue Epidemic, Sri Lanka,. *www.nc.cdc.gov,* 26(4).

Tuan, D. A. & Dang, T. N., 2024. Leveraging Climate Data for Dengue Forecasting in Ba Ria Vung Tau Province, Vietnam: An Advanced Machine Learning Approach. *Tropical Medicine and Infectious Disease,* 9(10), p. 250.

Uduwanage, H. U. et al., 2025. Prediction of Dengue Outbreaks in Sri Lanka Using Machine Learning Techniques. *Sri Lanka Journal of Medicine,* 21 4, 34(1), pp. 15-26.

Verma, H., Chauhan, N. & Awasthi , K. L., 2023. A Comprehensive review of 'Internet of Healthcare Things': Networking aspects, technologies, services, applications, challenges, and security concerns. *Computer Science Review,* Volume 50.

Viviane, . I. et al., 2023. IoT-Based Real-Time Crop Drying and Storage Monitoring System. *International Journal of Distributed Sensor Networks,* 26 September, Volume 2023, p. 11.

Vyas, H., Shukla, H. & Jivani, M. N., 2025. A Portable IoT-Based Health Monitoring Framework Using ESP32 for Isolated and Home-Based Patient Care. *Journal on Electronic and Automation Engineering,* 4(2), pp. 240-245.

Vyas, M. et al., 2019. Post-harvesting Onion Storage Methodology using IOT.pdf (Post-harvesting Onion Storage Methodology Using IOT). *International Journal of Advanced Research in Computer and Communication Engineering,* May.8(5).

Withanage, G. P., Viswakula, S. D., Nilmini Silva Gunawardena, Y. I. & Hapugoda, M. D., 2018. A forecasting model for dengue incidence in the District of Gampaha, Sri Lanka. *Parasites & Vectors,* 11(1).

Wokwi, 2024. *Wokwi: online electronics simulator.* [Online] Available at: https://wokwi.com

Wong, N., Jackson, V., & van der Hoek, A., 2023. *Mental Wellbeing at Work: Perspectives of Software Engineers.* [Online]
Available at: https://www.researchgate.net/publication/370180529_Mental_Wellbeing_at_Work_Perspectives_of_Software_Engineers
[Accessed 20 5 2026].

World Health Organization, 2013. *Pocket book of hospital care for children: guidelines for the management of common childhood illnesses.* 2 ed. s.l.:WHO.

Xu, J. et al., 2020. Forecast of Dengue Cases in 20 Chinese Cities Based on the Deep Learning Method. *International Journal of Environmental Research and Public Health,* 17(2), p. 453.

Yu, K. et al., 2024. Using UAV Images and Deep Learning in Investigating Potential Breeding Sites of Aedes albopictus. *Acta Tropica,* pp. 107234-107234.

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OP 09

Deep Learning-Based Hybrid Approach for Digital Image Forgery Detection

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Abstract

Background: The study addresses detecting manipulation in digital images, a challenge amplified by the surge in online image-based information. Misinformation risks have increased due to the evolution of manipulation techniques from basic editing to AI-supported forgery. Conventional detection methods prove increasingly inadequate, necessitating robust solutions.

Objective/s: This research proposes a hybrid model integrating statistical features, structural image features, and deep learning methods to enhance authenticity verification robustness and precision.

Methods: A systematic literature review identified the most discriminative methods using defined search strings and research questions, evaluated through a ranking methodology. The review identified metadata analysis, pixel-level statistical analysis, noise analysis, error level analysis and edge/border detection as potential components for conventional methods due to their feasibility, reliability and effectiveness. The method normalizes inputs and extracts features through Convolutional Neural Networks. These features build individual detection models for different manipulation types. To combat increasing AI-manipulated content, an AI-generated content detection model was added, trained to detect synthetic image generation features. Datasets include CASIAv2 for conventional manipulation and AI vs Human Dataset for AI-generated detection. Features extracted from compression-based, statistical and structural models are fused and input to the hybrid system.

Results: Individual models were evaluated using accuracy, precision, recall, and F1-score. The hybrid ensemble model achieved an accuracy of 89%, with precision, recall, and F1-scores of 89% for both tampered and authentic image classes. The AI vs. Human Image Detection model achieved an accuracy of 84% in distinguishing AI-generated images from human-generated images.

Conclusion/s: The study demonstrates that integrating pixel-level forensic methods, statistical analysis, deep learning approaches, and AI manipulation detection yields notable gains in detecting manipulated images.

Keywords: *AI-Generated Image Detection, Convolutional Neural Networks, Hybrid Detection Model, Image Manipulation Detection, Image Forensics.*

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Introduction

The digital landscape currently hosts between 14.3 trillion and 15 trillion digital photos [1]. Simultaneously, the rise of generative AI has led to the production of approximately 34-80 million synthetic images per day [2]. This scale of digital communication has been met with an equally rapid advancement in forgery techniques. Traditional editing software such as Adobe Photoshop allows for conventional manipulations like splicing and copy-move with minimal technical expertise [3]. Recently, deep generative models including Generative Adversarial Networks (GANs) and diffusion models have enabled the creation of synthetic images that are virtually indistinguishable from authentic photographs to the human eye [4].

However, traditional and AI-driven forgeries present fundamentally different forensic challenges. Conventional manipulations are typically identified by local anomalies such as inconsistent noise patterns or compression artifacts [5]. In contrast, AI-generated images lack these localized traces and instead require global feature analysis or the identification of model-specific fingerprints [6][7][8]. Existing detection models often struggle with generalization as they are frequently designed for specific manipulation types or generator architectures [9]

There is a significant research gap in the lack of unified frameworks that can simultaneously handle both conventional and AI-generated manipulations within a single and robust solution [10]. This research develops a hybrid architecture that integrates multiple forensic feature representations with deep learning models [11]. The primary objectives are to develop a hybrid pipeline incorporating diverse image feature analysis, evaluate this pipeline against individual feature-based models, integrate advanced AI-generated image detection and demonstrate the real-world applicability of a unified multi-paradigm system in detecting image forgery [4][12]. This research aims to develop a digital image forgery detection pipeline for identifying both AI-generated and conventionally manipulated images. The objectives are developing a novel hybrid pipeline incorporating selected digital image feature analysis techniques and advanced deep learning architectures, conducting comprehensive performance evaluation of the proposed hybrid pipeline against individual feature-based detection models for conventional image forgery identification, integrating an advanced AI-generated image detection model within the established comprehensive forgery detection pipeline and demonstrating the adaptable, real-world applicability of the unified multi-paradigm detection system [4][12]. This study addresses the growing threat of digital image manipulation driven by widespread forgery tools and rising AI-generated content, critical for combating misinformation and fake news across digital platforms.

Unlike existing approaches that primarily focus on either conventional image forgery or AI-generated image detection using a single forensic representation, the proposed framework integrates multiple complementary forensic feature extraction techniques with deep learning and transfer learning into a unified detection architecture. This unified design enables simultaneous detection of both conventional and AI-generated image forgeries within a single framework [10].

This research addresses emerging manipulation tactics by bridging traditional forensic techniques with modern AI advancements and ensures visual media authenticity maintains public trust while addressing security and cybersecurity concerns. The outcomes have broad applicability in digital media verification for legal proceedings, journalism, social media, academic research and forensic investigation [8][10]. The proposed research utilizes a dual-stream forensic architecture [13][14] designed to address the multifaceted nature of modern digital forgery, which encompasses both localized human-edited manipulations and global AI-based synthesis. The methodology integrates a multi-branch hybrid ensemble for conventional forgery detection and a specialized transfer learning pipeline for synthetic image identification [15][16].

Methods

Dataset Composition and Material Characterization

To improve utilizes ability and reduce the impact of dataset limitations, two distinct, high-quality benchmarks were utilized. For conventional manipulation detection, the CASIAv2 dataset was employed, containing 4,000 images (2,000 authentic and 2,000 tampered). The tampered subset represents diverse forgery scenarios including splicing, copy-move operations and object removal via conventional forgeries [4][17].

For AI-generated content, the AI vs. Human dataset was utilized, comprising 79,000 images. The synthetic subset includes outputs from Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs) and Diffusion models (e.g., DALL-E, Midjourney, Stable Diffusion) to address the evolving landscape of generative AI. Both datasets were maintained in a balanced 1:1 class ratio to prevent the models from developing a bias toward a

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majority class [18]. Images were resized to 64 × 64 pixels before feature extraction. The datasets contain images with diverse scenes, objects, and lighting conditions, while the AI-generated dataset includes images produced by multiple generative models, increasing content diversity.

Multi-Domain Feature Engineering

The primary technical contribution of the preprocessing stage is the extraction of complementary forensic cues that reveal inconsistencies across different image domains. Five distinct preprocessing pipelines were developed.

A) Error Level Analysis (ELA): Exploits JPEG quantization inconsistencies by computing the absolute difference between the original input and a version recompressed at 90% quality.

B) Histogram Equalisation: Enhances contrast to expose pixel distribution anomalies that may be masked by post-editing retouching.

C) Laplacian Edge Analysis: Utilises a discrete second-order derivative kernel to highlight structural discontinuities at manipulation boundaries.

D) Multi-Filter Noise Extraction: Isolates sensor-level noise residuals by subtracting a multi-method denoised image, generated by averaging Non-Local Means, Bilateral, and Gaussian filtering outputs, from the original image.

E) 10-Channel Pixel Analysis: A 10-channel representation combining RGB (3), gradient magnitude (1), Laplacian (1), noise residual (1), Local Binary Pattern (LBP) texture (1) and HSV (3) channels. All feature maps were resized to 64 × 64 pixels and normalized to the range [0,1] before training.

3.3 Hybrid Ensemble Model with Dynamic Gating

The core of the detection framework is a Hybrid Ensemble CNN featuring five parallel feature extraction branches. The ELA, Histogram Equalization, Laplacian and Noise branches each used three convolutional blocks with 32, 64 and 128 filters, respectively, followed by batch normalization, max pooling and dropout (0.10). The pixel-analysis branch processed grouped RGB, edge, texture and HSV features separately before feature fusion using 64 and 128-filter convolutional layers and Global Average Pooling.

To optimize feature selection, a dynamic gate mechanism was implemented for each branch. This mechanism employs a sigmoid-activated dense layer that learns to weight the contribution of its respective domain (e.g., ELA vs. Noise) based on the characteristics of the input image. This late fusion strategy ensures that the model preserves domain-specific forensic cues and avoids "semantic confusion" that often occurs with early fusion at the pixel level. The weighted feature vectors were concatenated and passed through dense layers containing 128 and 32 neurons with L2 regularization (10^{-4}), batch normalization, and dropout rates of 0.40 and 0.20 before Softmax classification.

Transfer Learning for Generative Synthesis Detection

AI-generated imagery detection requires a different forensic focus that detects global statistical signatures rather than local anomalies. A parallel stream utilizes ResNet50-based transfer learning which is pre-trained on ImageNet. The model accepts high-resolution inputs (512×512) to preserve subtle generative artifacts that are often lost during aggressive downsampling. The higher resolution was selected for the AI-generated image detection stream because synthetic artifacts are often distributed globally rather than localized at manipulation boundaries.

The backbone of the model is frozen to retain foundational visual features, while a custom classification head comprising a Global Average Pooling layer, a 40% Dropout layer and a sigmoid-activated dense layer is trained to identify synthetic fingerprints across varied generator architectures.

Experimental Protocol and Optimization

All models were implemented using Python with TensorFlow/Keras. The hybrid model was optimized using Adam (learning rate = 0.0005, $\beta_1 = 0.9$, $\beta_2 = 0.999$) and categorical cross-entropy loss. The dataset was divided into 72% training, 18% validation, and 10% testing subsets using a fixed random state of 42. Training was performed with a batch size of 32 for a maximum of 35 epochs. Early Stopping monitored validation accuracy with a patience of six epochs and restored the best-performing weights, while Reduce LROn Plateau reduced the learning rate by a factor of 0.3 when validation loss did not improve for three consecutive epochs.

Experiments were conducted in Google Colab on a Linux 6.6.122+ environment using an NVIDIA Tesla T4 GPU with 15,360 MiB memory, an Intel Xeon CPU at 2.00 GHz with two CPU cores and 12.67 GB of system RAM. The framework was implemented using Python 3.12.13 and TensorFlow/Keras 2.20.0 with CUDA 12.5.1 and cuDNN 9. Mixed-precision training using the mixed_float16 policy was enabled to reduce memory consumption and improve computational efficiency while maintaining a float32 output layer for numerical stability.

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Evaluation Framework

Model performance was quantified using Accuracy, Precision, Recall and F1-score. This balanced metrics suite is essential for digital forensics to ensure the model simultaneously minimizes False Positives (misidentifying authentic images as forgeries) and False Negatives (missing actual manipulations). By integrating these cross-domain forensic features with high-level deep learning architectures. The methodology provides a robust, self-referential system that does not require access to original ground-truth images for verification.

Results

This section details the empirical performance of five individual forensic Convolutional Neural Network (CNN) models, the proposed hybrid ensemble architecture and the ResNet50-based AI detection stream. Results are reported based on comprehensive testing using the CASIAv2 and AI vs. Human datasets.

Performance Analysis of Baseline Individual Models

The efficacy of single-domain feature extraction for conventional forgery detection was evaluated across five specialized CNN architectures. Notably, performance varied considerably depending on the forensic cue utilized.

The Error Level Analysis (ELA-CNN) model emerged as the most robust baseline, achieving an overall accuracy of 86%. The model demonstrated a strong sensitivity to tampered content with a recall of 0.96 and a precision of 0.95 for real images. The learning curves and confusion matrix for this model (Figure 4.1) indicate stable convergence and high reliability in identifying compression artifacts.

Performance for other individual domain-specific models was significantly lower. Pixel-Level Manipulation-CNN (PLMC-CNN) recorded an accuracy of 57%. While it achieved a recall of 0.78 for tampered images, its F1-score for authentic content was notably low at 0.48.

Laplacian-CNN attained a 56% accuracy rate. The model struggled to consistently distinguish authentic content, yielding a recall of only 0.44 for the “Real” class.

Histogram Equalization-CNN reached an accuracy of 52%. Despite a high recall of 0.85 for tampered regions, its precision for this class was limited to 0.50 and it demonstrated poor performance in identifying real images (0.23 recall).

Noise Analysis-CNN exhibited the lowest accuracy at 48%. While achieving a perfect recall (1.00) for tampered images, the model failed to identify any authentic images correctly, resulting in precision, recall and F1-scores of 0.00 for the “Real” class.

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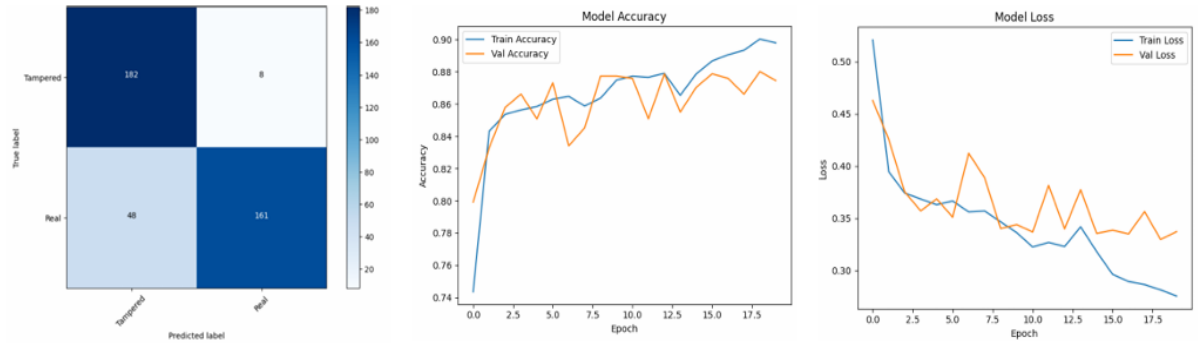
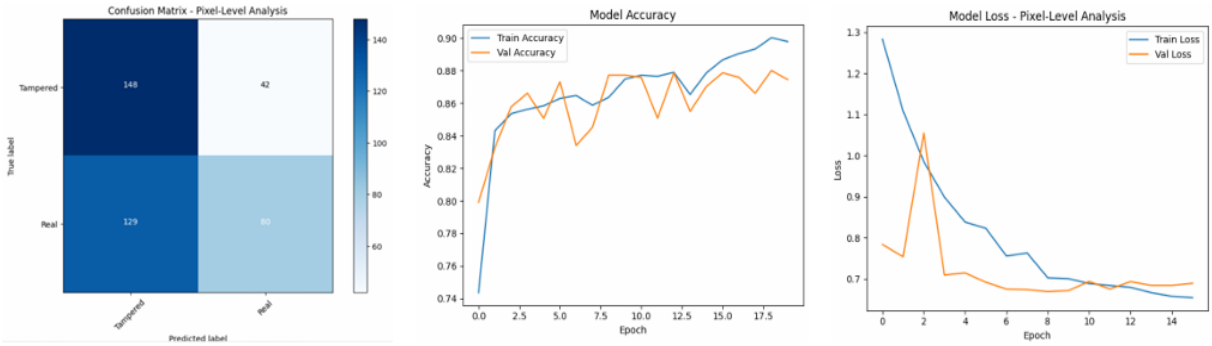
The visual diagnostics for the individual models, including the accuracy and loss curves are presented in Figure 4.1 to 4.5.



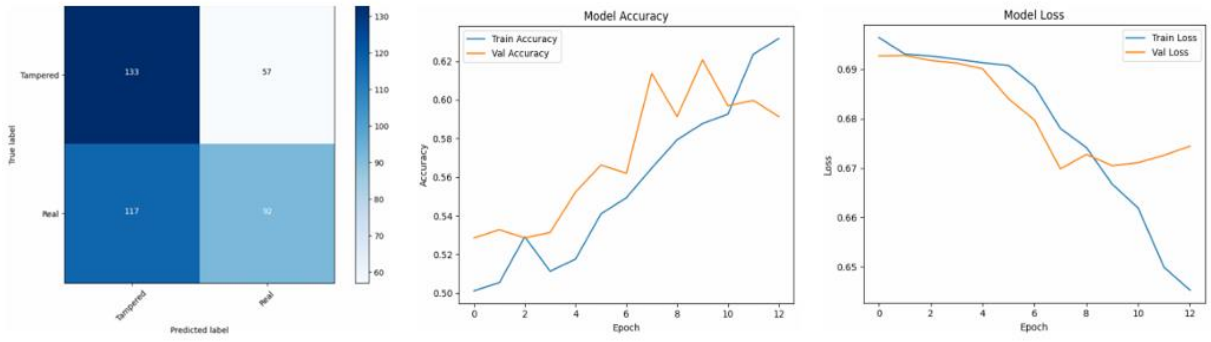
(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 1 ELA-CNN Evaluation Metrics and Classification Results



(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 2 PLMC-CNN Evaluation Metrics and Classification Results



(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 3 Lalpacian-CNN Evaluation Metrics and Classification Results

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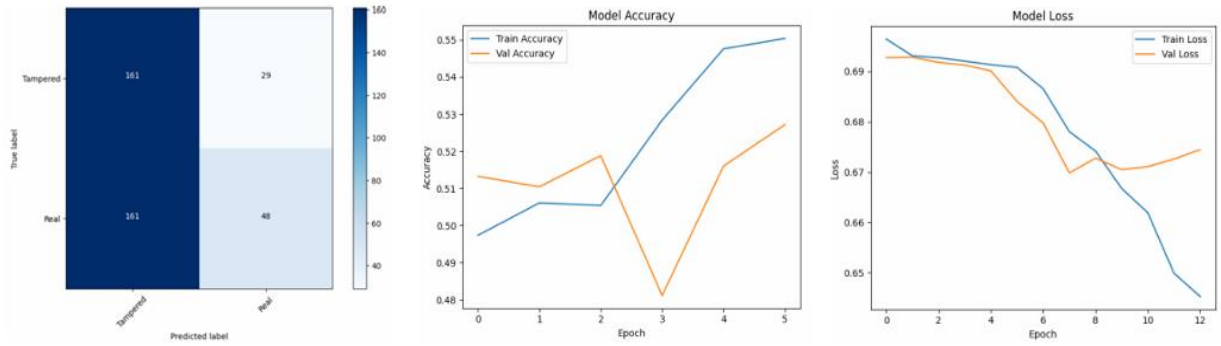
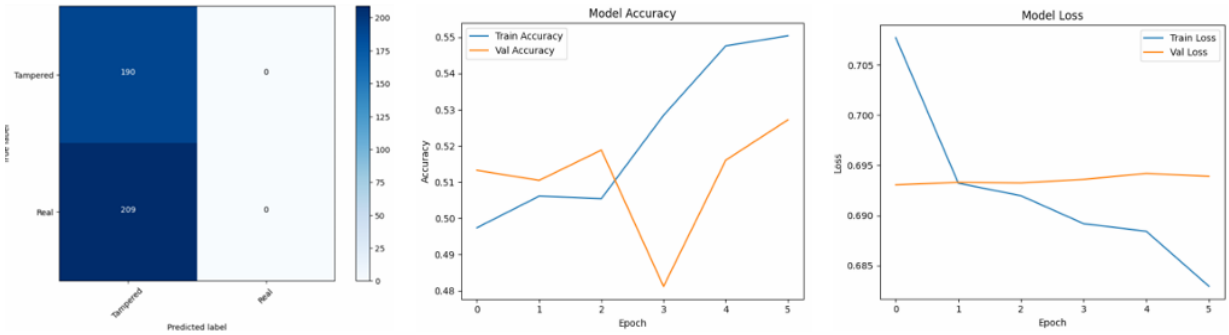


(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 4 Histogram Equalization-CNN Evaluation Metrics and Classification Results



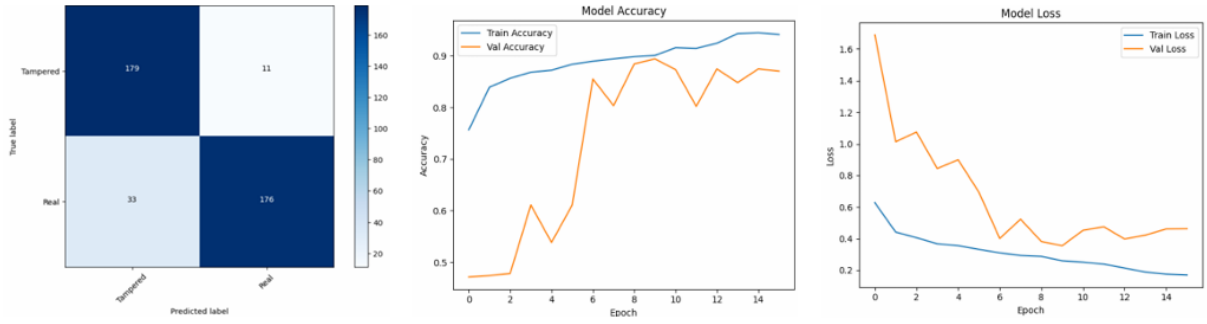
(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 5 Noise Analysis-CNN Evaluation Metrics and Classification Results

Evaluation of the Proposed Hybrid Ensemble Model

The Hybrid Ensemble Model, integrating five parallel feature branches (ELA, Pixel, Laplacian, Histogram and Noise) with a dynamic gating mechanism, yielded the highest performance for conventional forgery detection.

As reported, the hybrid ensemble model achieved an overall accuracy of 88.97% (rounded to 89%). This architecture successfully balanced classification performance across both categories, achieving a precision of 0.84 and recall of 0.94 for tampered images (F1-score: 0.89) and a precision of 0.94 and recall of 0.84 for real images (F1-score: 0.89). Model diagnostics illustrated in Figure 4.6 demonstrate improved validation accuracy and loss stability compared to its individual components.



(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 6 Hybrid Ensemble Model Evaluation Metrics and Classification Results

Performance of AI-Generated Image Detection

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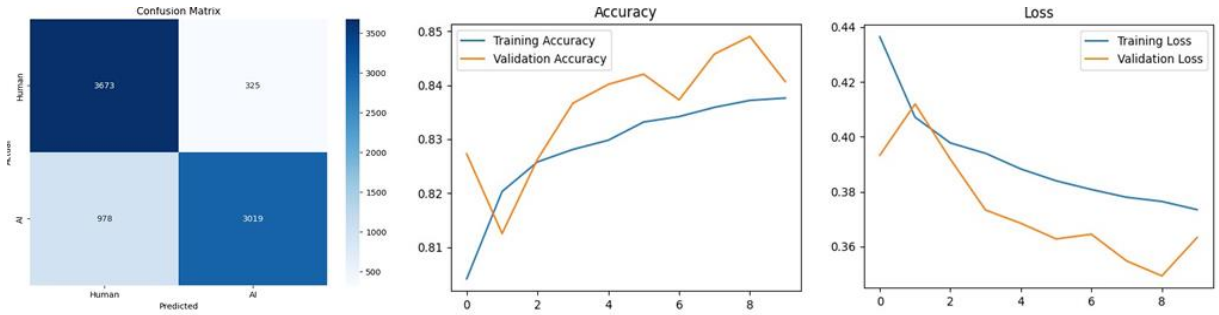
The ResNet50-based transfer learning model was evaluated on the AI vs. Human dataset to identify synthetic visuals. The model achieved a total accuracy of 84%.

According to the classification report, the detection system performed as follows,

a) Human-Generated Class: High sensitivity was observed with a recall of 0.92, though precision was moderate at 0.79.

b) AI-Generated (Synthetic) Class: The model achieved a high precision of 0.90, indicating reliability when flagging content as synthetic, though the recall of 0.76 reflects that 24% of AI-generated content was misclassified as human-generated.

The visual diagnostics for the AI detection stream, including the accuracy and loss curves are presented in Figure 4.7.



(a) Confusion Matrix (b) Model Accuracy (c) Model Loss

Figure 7 AI-Generated Image Detection Model Evaluation Metrics and Classification Results

Comparative Summary of Results

The results demonstrate that the Hybrid Ensemble Model offers a 3% accuracy gain over the best-performing individual baseline (ELA-CNN) and overcomes the classification failures inherent in single-feature models like Noise Analysis. The parallel integration of the AI-generated detection component further ensures the system handles synthesis-based forgeries that escape traditional localized forensic analysis.

Discussion

The experimental results validate the efficacy of a multi-paradigm approach, demonstrating that a hybrid ensemble architecture achieves higher performance than individual forensic methods in detecting complex digital manipulations. The achievement of 89% accuracy in the hybrid model, compared with the 86% peak accuracy of the standalone ELA-branch, suggests that while compression artifacts remain a dominant forensic cue, the integration of structural and textural features provides critical redundancy that minimizes false positives.

Interpretative Analysis of Performance

The superior performance of the Error Level Analysis (ELA) branch (86% accuracy) aligns with established literature, confirming that JPEG recompression inconsistencies are highly discriminative for localized tampering like splicing and copy-move. However, the observed failure of the noise-based CNN to accurately classify authentic images (0.00 recall for the Real class) highlights a common pitfall in deep learning forensics overfitting to specific noise distributions. The hybrid ensemble mitigates this by utilizing a dynamic gating mechanism, which learns to suppress branches with high uncertainty while prioritizing robust cues like ELA and Laplacian edges. This adaptability is essential for maintaining generalizability across diverse image subjects and lighting conditions.

Synergy in Dual-Stream Detection

The integrated AI-generated image detection framework addresses a critical forensic gap. While conventional models focus on localized pixel-level anomalies, AI synthesis requires global feature analysis to detect the subtle statistical signatures of GANs or diffusion models. The 84% accuracy of the ResNet50-based stream demonstrates the power of transfer learning in identifying generative artifacts that escape traditional structural analysis. The high 90% precision for the AI class is particularly significant for real-world verification, ensuring that flagged synthetic content is identified with high reliability, thereby reducing the risk of “false alarm” censorship.

Practical Implications and Misinformation Detection

The research offers a scalable, modular solution for digital media verification. By automating the detection of both human-edited forgeries and algorithmically generated visuals, the proposed system provides a critical tool for journalists and legal professionals to authenticate evidence in an era of hyper-realistic misinformation. The framework can also support social media content moderation, cybersecurity systems, and legal image authentication where rapid and reliable forgery detection is required. Although the proposed framework introduces higher computational complexity than individual CNN models due to its five parallel branches, mixed-precision training and feature-level fusion improve computational efficiency while providing superior detection performance. However, quantitative evaluation of inference latency and memory consumption during deployment remains an area for future investigation.

Limitations and Future Directions

The study has several limitations. The evaluation was conducted using a single train-validation-test split, which may not fully capture performance variation across different data partitions. Future work will investigate k-fold cross-validation and evaluation using independent external datasets to further validate robustness and generalizability. Additionally, the reliance on CASIAv2 may limit performance on high-resolution, compressed social media images and emerging manipulation techniques.

A significant emerging threat not fully addressed is the “hybrid attack” where AI-generated base images are subsequently modified using conventional tools. Future research should investigate training strategies that specifically target these composite forgeries. These limitations will be addressed through external dataset evaluation, cross-validation and robustness testing in future work. Furthermore, statistical significance testing was not included in the current evaluation and should be considered in future comparative studies to statistically validate performance differences between models.

Conclusion

The study confirms that a unified hybrid ensemble framework significantly increases the detection accuracy of both conventional and AI-generated image forgeries. The proposed hybrid architecture achieved an accuracy of 89%, demonstrating higher performance than all individual baseline methods while reducing the limitations of single-feature models. Additionally, the specialized AI-generated image detection stream achieved an 84% accuracy with 90% precision, which effectively identifies dual forgery attacks arising from AI-generated image forgeries and conventional image manipulations in diverse platforms.

The results indicate that combining pixel-level, statistical, and structural forensic cues provides a more robust and generalizable solution than individual approaches.

References

[1] Matic Broz. The Number of Photos Taken in 2025 is Expected to Exceed Two Trillion. PetaPixel. 2025 Jun 18. Available from: https://petapixel.com/2025/06/18/the-number-of-photos-taken-in-2025-is-expected-to-exceed-two-trillator/

[2] Colorlib. 100+ AI Statistics: Market Size, Adoption & Trends (2026) [Internet]. 2026 May 17 [cited 2026 Jun 14]. Available from: https://colorlib.com/wp/ai-statistics/

[3] Ford SM, Roberts ME. Copy-move and splicing image forgery detection and localization techniques: a review. Forensic Sci Res. 2017;2(2):70-89. DOI: 10.1080/00450618.2016.1153711

[4] Corvi R, Cozzolino D, Zingarini G, Poggi G, Nagano K, Verdoliva L. On the detection of synthetic images generated by diffusion models. arXiv preprint. 2022 Nov 1. arXiv:2211.00680. DOI: 10.48550/arXiv.2211.00680

[5] Matic Broz. Forensic Analysis of AI-Generated Image Alterations Using [Technology]. J Investig Sci. 2025 Dec 17; [Internet]. [cited 2026 Jun 14]. Available from: https://journal-isi.org/index.php/isi/article/view/1362

[6] Zhang Y, Wang L, Chen X. PGC: Peak-Guided Calibration for Generalizable AI-Generated Image Detection. arXiv preprint. 2025 May 26. arXiv:2605.21207. Available from: https://arxiv.org/html/2605.21207

[7] Wesselkamp M, Corvi R, Cozzolino D, et al. The Risk of Image Generator-Specific Traces in Synthetic Images. In: Proceedings of the 2024 International Conference on Pattern Recognition. 2024. P. 124206. DOI: 10.5281/scitepress.124206

[8] Chakraborty A, Kumar S, Singh R. From Evidence to Verdict: An Agent-Based Forensic Framework for AI-Generated Image Detection. arXiv preprint. 2025 Oct 30. arXiv:2511.00181. DOI: 10.48550/arXiv.2511.00181

[9] Liu X, An Y, Zhang H. A Comprehensive Survey on Methods for Image Integrity. ACM Trans Multimedia Comput Commun Appl. 2023;19(6):1-38. DOI: 10.1145/3633203

[10] Ahmad F, Khan M, Hussain I. Generative-Model-Based AI Image Forgery Forensics and Efficient Detection Framework. Francis J AI Appl. 2026 May 19;4(3):20805. DOI: 10.5815/francis.20805

[11] Patel A, Gupta S, Mehta R. A hybrid model for image forgery detection using deep learning with block-based and keypoint-based methods. Sci Rep. 2026 Feb 25;16(1):41473. DOI: 10.1038/s41598-026-41473-8

[12] Zhao L, Li M, Wang Y. Combined spatial and frequency dual stream network for face forgery detection. OUCI. 2024 Dec 31. Available from: https://ouci.dntb.gov.ua/en/works/7Xywdpx4/

[13] Wang J, Liu X, Zhang Y. HuForDet: A Holistic Framework for Human Image Forgery Detection. arXiv preprint. 2026 Jan 7. arXiv:2601.04715. Available from: https://arxiv.org/abs/2601.04715

[14] Kumar P, Sharma R, Singh A. Image Forgery Detection Using Hybrid Deep Learning. Int J Multidiscip Res Adv. 2026 Feb;8(2):72736. DOI: 10.9779/ijfmr.2026.0272736

[15] Dong J, Wang W, Tan T. CASIA Image Tampering Detection Evaluation Database. In: 2013 IEEE China Summit and International Conference on Signal and Information Processing. 2013 Jul. DOI: 10.1109/chinasip.2013.662537

[16] Rajarshi R, Roy S. A Comprehensive Dataset for Human vs. AI Generated Image Detection. arXiv preprint. 2026 Jan 1. arXiv:2601.00553. DOI: 10.48550/arXiv.2601.00553. Available from: https://huggingface.co/datasets/Rajarshi-Roy-research/Defactify_Image_Dataset

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OP 10

Low-Power On-Device Elephant Detection using ESP32-CAM and Edge Impulse

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Abstract

Introduction: Elephant–train collisions are a critical safety problem in Sri Lanka (386 elephant deaths in 2024; at least 11 from train strikes). Existing solutions lack real-time automated detection and tamper-evident incident recording. TinyML enables object detection on microcontrollers, but combining on-device elephant detection with cryptographically verifiable logging on a single ultra-low-cost platform has not been demonstrated.

Objectives: To evaluate on-device elephant detection using ESP32-CAM and Edge Impulse TinyML, and to characterise a co-deployed lightweight blockchain for tamper-evident logging on the same device.

Methods: A FOMO MobileNetV2 model (152 images, int8 quantised, 96×96 px) was trained via Edge Impulse and co-deployed on an ESP32-CAM with a SHA-256 hash-linked blockchain. Performance was evaluated via a pilot deployment near Habarana, Sri Lanka.

Results: Inference latency was 1,096 ms; precision 0.81, recall 0.52, F1 0.63. Blockchain block creation took 41–86 ms and chain verification 1–4 ms. Both components operated concurrently within ESP32-CAM hardware limits.

Conclusions: TinyML detection and blockchain logging are both feasible on a single ESP32-CAM without cloud dependency, providing a practical low-cost platform for wildlife–railway collision prevention. Key limitations include single-site evaluation and absence of night-vision capability.

Keywords: *blockchain, edge AI, elephant detection, ESP32-CAM, tamper-evident logging, TinyML, wildlife monitoring*

Acknowledgment: *This research was conducted independently. The author acknowledges Edge Impulse (free tier) and open-source hardware used in development.*

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Introduction

Elephant–train collisions represent a persistent and preventable safety crisis in Sri Lanka. In 2024, over 386 elephant deaths were recorded nationally, with at least 11 directly attributed to train strikes (1). These incidents cause irreversible loss of an endangered species, damage to railway infrastructure, and risk to passengers. The railway corridors through Habarana, Gal Oya, and Udawalawe pass through active elephant habitats, yet no automated real-time detection system is currently deployed along these routes.

Advances in TinyML (Tiny Machine Learning) have made it possible to execute object detection inference directly on microcontroller-class hardware such as the ESP32-CAM, eliminating dependency on cloud services or edge gateways (2, 3). The FOMO (Faster Objects, More Objects) architecture, available through the Edge Impulse framework, enables grid-based object detection with integer-only quantised inference, making it well suited to severe memory and computational constraints (4). In parallel, lightweight blockchain frameworks adapted for microcontrollers have demonstrated that Secure Hash Algorithm 256 (SHA-256) hash-linked tamper-evident logging is achievable on ESP32-class devices within bounded latency and storage overheads (5).

Prior research has addressed parts of this problem in isolation. Deep learning using convolutional neural networks (CNNs) has shown strong elephant identification performance but requires cloud connectivity or GPU hardware (6). Internet of Things (IoT)-based wildlife tracking using motion sensors and camera traps provides presence detection but does not prevent collisions or log incidents securely (7). Physical deterrents such as sound alarms and barricades lack automated detection (8). No prior system has integrated TinyML-based on-device detection, IoT-triggered deterrence, and tamper-evident blockchain logging on a single ultra-low-cost microcontroller platform in a real-world railway corridor deployment.

This study addresses that gap. The objectives are to: (i) evaluate the feasibility of fully on-device elephant detection on ESP32-CAM hardware using the Edge Impulse FOMO pipeline; (ii) characterise the performance of a co-deployed lightweight on-device blockchain for tamper-evident event logging; and (iii) assess the integrated system under real-world pilot conditions near Habarana railway station.

Current mitigation along Sri Lankan railway lines relies on human watchmen, speed restrictions in known elephant zones, and reactive reporting — none of which provide automated pre-collision warnings. In 2024, train strikes accounted for a disproportionate share of elephant deaths in the Habarana and Maho railway districts, highlighting the urgency of technical intervention (1).

Existing technical approaches each address only a subset of the requirements. Gunasekara et al. (6) achieved strong CNN-based elephant recognition using cloud-hosted inference, but their system requires continuous internet connectivity, making it unsuitable for remote railway corridors without mobile coverage. Arulmurugan et al. (9) demonstrated ESP32-CAM-based object detection using classical OpenCV processing without a learned artificial intelligence (AI) model, limiting adaptability to environmental variation. IoT-based camera trap systems (7) monitor wildlife presence but do not trigger real-time alerts within the response window needed to stop an approaching train. Blockchain-based conservation logging has been proposed for data integrity (8), but without integration into a real-time detection pipeline. No prior system has addressed all four requirements simultaneously on a single microcontroller: automated TinyML-based detection, Long Range (LoRa) alerting to train operators, IoT-triggered autonomous deterrence, and SHA-256 blockchain-verified tamper-evident incident logging — all operating without cloud connectivity or grid power. This combination constitutes the primary novelty of eGuard.

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Methods

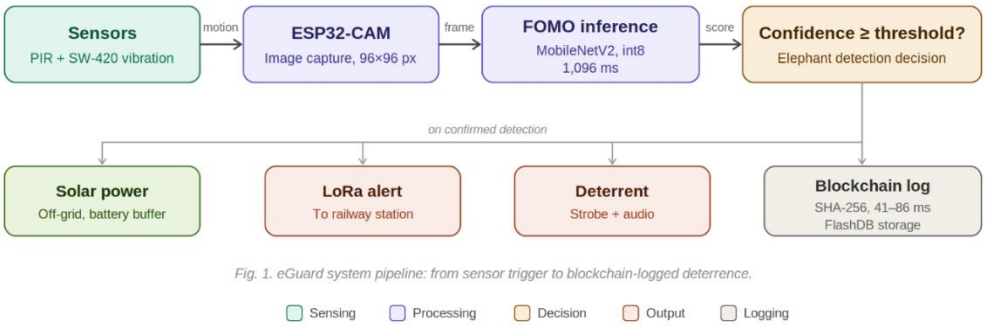

Figure 1eGuard system pipeline: from sensor trigger to blockchain-logged deterrence

Hardware platform. The ESP32-CAM module was used as the sole computing platform. It features a dual-core Xtensa LX6 processor at 240 MHz, 520 KB internal static random-access memory (SRAM), 4 MB external pseudo-static RAM (PSRAM), 4 MB SPI flash, an OV2640 CMOS camera (maximum 1600×1200 px), and operates at 3.3 V. The system was powered by a solar panel and rechargeable battery for off-grid deployment. No cloud services, edge gateways, or external processors were used.

TinyML model design. The FOMO object detection pipeline from Edge Impulse was selected for its minimal memory footprint and integer-only quantised inference (4). The training dataset comprised elephant images under varied environmental conditions (differing lighting, background vegetation, viewing angles, and partial occlusion), sourced from public datasets and field-collected samples; negative samples of non-elephant objects were included to reduce false positives. Images were manually labelled using bounding boxes. The model was trained using Edge Impulse's cloud-based environment and deployed via 8-bit integer quantisation using TensorFlow Lite Micro. Input resolution was downscaled prior to inference to fit within available SRAM and PSRAM limits. The dataset comprised 152 bounding-box-labelled images (120 training, 32 test; 78%/22% split). Training used 60 cycles at a learning rate of 0.001, with data augmentation enabled (random flips, brightness, and noise). The authors acknowledge that 152 images is a small dataset; augmentation partially compensates, and multi-site collection remains a priority. The model was deployed via 8-bit quantisation at 96×96 px.

On-device blockchain framework. A lightweight blockchain logging framework was implemented in C/C++ and deployed on the ESP32-CAM (5). The framework uses SHA-256 hash linkage ($H_i = \text{SHA-256}(D_i \parallel H_{i-1})$), append-only block structure, fixed-size transaction records, and persistent storage via FlashDB. Each block stores event type, timestamp, detection confidence, and image identifier. No distributed consensus, mining, or peer communication is required. Chain verification recomputes hashes sequentially at boot to detect any post-hoc tampering.

Detection and alert pipeline. A passive infrared (PIR) sensor triggers image capture upon motion detection, waking the ESP32-CAM from deep sleep. The captured frame is pre-processed (resized, normalised, converted to integer format) and passed to the FOMO model. Detection is confirmed when grid-region confidence exceeds a tuned threshold. Upon confirmation: (i) a LoRa (SX1278) alert is transmitted to nearby railway stations; (ii) a strobe light and audio deterrent are activated; and (iii) the event is appended to the on-device blockchain. A SW-420 vibration sensor also detects approaching trains as a complementary trigger.

Blockchain block structure. Each block in the on-device chain stores a fixed set of fields: block index, Unix timestamp, transaction payload (device identifier, detection label, confidence value, and image identifier), previous block hash (32 bytes, SHA-256), proof field, and current block hash (32 bytes, SHA-256). The cryptographic linkage is defined as $H_i = \text{SHA-256}(D_i \parallel H_{i-1})$, where D_i is the serialised block data of block i and H_{i-1} is the hash of its predecessor. Fixed-size transaction and block structures are used throughout to ensure deterministic memory usage and prevent heap fragmentation. The framework implements power-interruption resilience: blocks are hashed in RAM then committed atomically to storage; on restart, invalid trailing blocks are identified and discarded. No distributed consensus, mining, or peer-to-peer communication is required.

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Evaluation. Performance was measured across six metrics: (i) inference latency (image capture to decision); (ii) compiled flash and static RAM usage (from Platform IO build statistics); (iii) runtime free heap stability; (iv) blockchain block creation latency (SHA-256 computation and storage commit); (v) chain verification time; and (vi) storage growth per block. Detection behaviour (elephant detection, false positives, background rejection) was assessed during a pilot field deployment at Habarana railway station on 15 April 2025.

Results

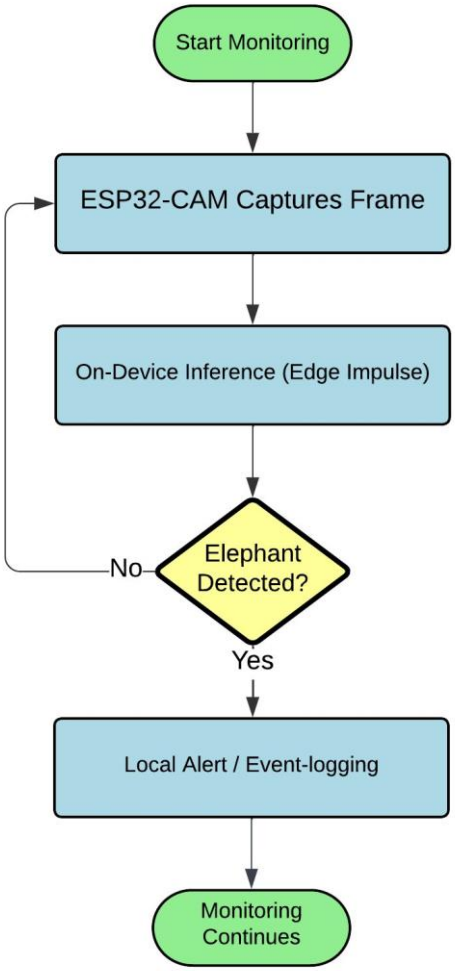

Figure. 2 On-device detection decision flowchart

End-to-end inference latency on the ESP32-CAM was approximately 1,096 ms (1.1 seconds), comprising 15 ms for image preprocessing and 1,081 ms for FOMO object detection inference, using the quantised int8 model. The compiled firmware occupied approximately 470 KB of flash and 53 KB of static RAM; runtime free heap remained stable at approximately 304 KB with no observable leakage across repeated inference and blockchain cycles. Blockchain block creation, including transaction packaging, SHA-256 hashing, and persistent storage commit, ranged from 41 to 86 ms. At approximately 335 bytes per block, a 1 MB partition accommodates approximately 3,000 events; event-driven logging (triggered only on confirmed detection) means this is unlikely to be exhausted in normal deployments, and also substantially reduces flash wear compared to continuous logging systems. Chain integrity verification for chains of up to ten blocks completed in 1–4 ms. Persistent storage grew linearly from 280 bytes (genesis block) to approximately 3,597 bytes after ten blocks, equivalent to approximately 335 bytes per block. Table 1 summarises the quantitative results.

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Table 1. Quantitative performance summary for on-device inference and blockchain logging on ESP32-CAM.

Metric	**Measured Value**
On-device inference latency	~1,096 ms (image: 15 ms + object detection: 1,081 ms)
Compiled flash usage	~470 KB (of 4 MB)
Static RAM usage	~53 KB
Runtime free heap (stable)	~304 KB (no leakage observed)
Blockchain block creation (SHA-256 + commit)	41–86 ms
Chain verification (10 blocks)	1–4 ms
Storage growth per block	~335 bytes (~3,000 blocks per MB)
Detection accuracy (overall, float32 validation)	**34.38% (overall); precision 0.81, recall 0.52, F1 0.63 (non-background)**
Model RAM / Flash (int8, on ESP32-CAM)	**239.5 KB RAM / 79.2 KB Flash**
Power source	Solar-powered, off-grid

During the Habarana pilot deployment, the system successfully identified elephant presence and rejected background motion in the majority of observed cases. False positives were observed primarily in scenes containing large irregularly shaped vegetation. Adjusting the detection confidence threshold reduced false positives without substantially affecting sensitivity. Blockchain event logging was successful for all detections, with no previously committed blocks reported as corrupted after simulated power-interruption and restart cycles.

The detection performance metrics require careful interpretation in the context of the FOMO architecture and the evaluation conditions. The overall validation accuracy of 34.38% reflects FOMO's grid-cell scoring approach, which evaluates every cell in every image frame: cells containing background that are not correctly identified as background each count as a missed detection. On a 152-image dataset with a single elephant class, this metric is characteristically pessimistic. The more operationally informative metrics are precision (0.81) and F1 score (0.63): when the model produced a positive detection, it was correct 81% of the time, indicating a low false-positive rate in practice. The recall of 0.52 reflects that the model missed approximately half of elephant instances in the held-out validation set, primarily under conditions of partial occlusion and low contrast against vegetation. In the field deployment, the PIR motion sensor served as a pre-filter: the camera only captured a frame when motion was already present in the sensor's detection zone, substantially reducing the proportion of background-only frames submitted to inference and thereby improving effective operational precision beyond the raw validation figure. False positives during pilot testing were predominantly triggered by large vegetation moving in wind, which was mitigated by raising the confidence threshold.

LoRa-based alert transmission demonstrated reliable delivery within the tested range; no packet loss was observed during the field test session. The end-to-end pipeline — from PIR trigger through image capture, FOMO inference, LoRa alert, deterrent activation, and blockchain logging — completed within approximately 1.2 seconds. At 50 km/h, a train travels ~17 m/s, meaning the system provides over 200 metres of warning distance.

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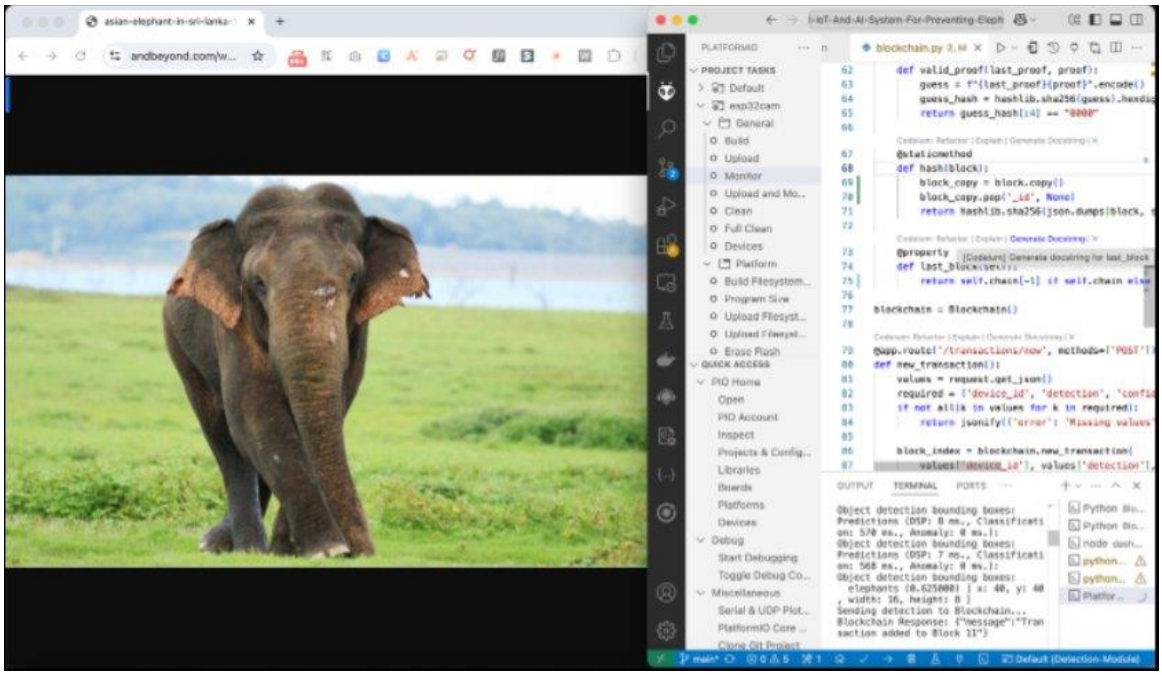

Figure. 3 Live elephant detection output on ESP32-CAM with Edge Impulse inference and blockchain logging

Discussion

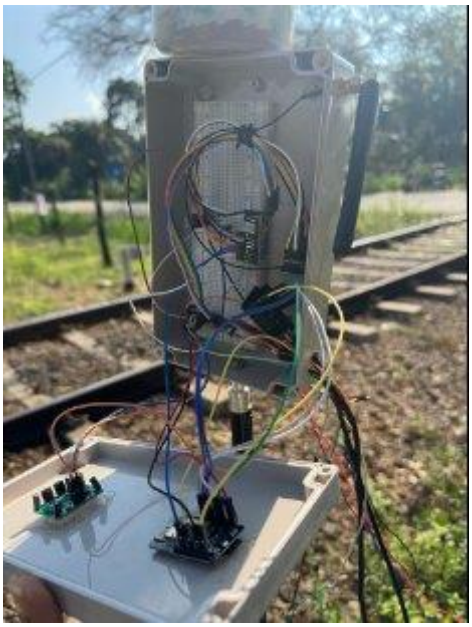

Figure 4. Pilot hardware deployment near Habarana railway station, Sri Lanka

The results confirm that TinyML-based detection and lightweight blockchain logging are simultaneously feasible on a single ESP32-CAM platform. The blockchain overhead of 41–86 ms per block is negligible relative to detection latency. The stable free heap of ~304 KB confirms the two components coexist without memory contention, directly addressing gaps identified in the literature (6, 7, 8, 9).

The validation metrics require careful interpretation. The overall accuracy of 34.38% reflects FOMO's grid-cell scoring method, which penalises every background cell in every image where a detection is missed—a harsh metric for a small 152-image dataset. The more meaningful operational metrics are precision (0.81) and F1 score (0.63): when the model fired a detection, it was correct 81% of the time. The recall of 0.52 indicates the model missed approximately half of elephant instances in the held-out test set, which is a genuine limitation. In the field deployment, the PIR motion sensor

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acts as a pre-filter, meaning the camera only captures frames when motion is already detected, improving the effective operating precision beyond the raw validation figure. Several further limitations must be acknowledged explicitly in response to concerns raised in prior review of related work. First, the OV2640 camera sensor is optimised for short-range daytime imaging; the current system is unsuitable for long-range detection or night-time operation, which are practical requirements for railway corridor deployment at speed. Second, the evaluation was conducted at a single site over a limited period; dataset diversity and environmental generalisation remain unvalidated across multiple locations, seasons, and animal behaviour patterns. Third, precise power measurements using external instrumentation were not conducted; energy feasibility is currently assessed qualitatively. Fourth, model accuracy metrics (precision, recall, F1) from on-device field inference were not separately computed; the values reported in Table 1 are from Edge Impulse validation and require confirmation under real deployment conditions. These are recognised priorities for future work.

Table 2. Comparison of eGuard with prior elephant detection and monitoring approaches.

Approach	**Detection method**	**Connectivity**	**Deterrence**	**Tamper-evident logging**	**Reported cost**
Gunasekara et al. (6)	CNN, cloud-hosted	Requires internet	No	No	Not reported
Arulmurugan et al. (9)	OpenCV, no learned model	Offline (ESP32-CAM)	No	No	Not reported
Smith & Brown (7)	Motion + camera trap	Offline	No	No	Not reported
Jeyarama et al. (8)	None (manual trigger)	Offline	Yes	No	Not reported
eGuard (proposed)	FOMO TinyML, int8	Offline (LoRa alert)	Yes	Yes (SHA-256)	~USD 15–20

Table 2 summarises this comparison across four capability dimensions. No prior approach satisfies all four criteria simultaneously: Gunasekara et al. (6) achieved strong AI-based detection but required continuous cloud connectivity; Arulmurugan et al. (9) operated fully offline on ESP32-class hardware but without a learned detection model; Smith and Brown (7) provided offline wildlife monitoring without deterrence or logging; and Jeyarama et al. (8) implemented physical deterrents without automated detection. Precise quantitative metrics (accuracy, latency, cost) were not consistently reported across these studies under comparable test conditions, which itself reflects a broader gap in standardised evaluation for this application area. eGuard is the first system in this comparison to combine AI-based detection, real-time deterrence, and tamper-evident logging entirely offline, at an estimated hardware cost of USD 15–20 per node.

The Habarana–Maho corridor traverses the Minneriya and Kaudulla buffer zones, with documented high elephant crossing frequency. Deploying eGuard nodes at 500-metre intervals along the 40-km high-risk segment would require ~80 units at under USD 1,600 total. Each unit logs events to a tamper-evident local chain and can optionally upload records via Wi-Fi during maintenance visits.

Conclusions

This study demonstrates the feasibility of combining TinyML-based elephant detection and lightweight blockchain logging on a single ESP32-CAM microcontroller platform without cloud dependency. On-device inference achieved approximately 1.1 s latency (1,096 ms) within a model footprint of 239.5 KB RAM and 79.2 KB flash on the ESP32-CAM. Blockchain block creation completed in 41–86 ms with linear storage growth of approximately 335 bytes per block, and chain verification for ten blocks completed in 1–4 ms. Both components operated concurrently within hardware limits without memory contention.

A single eGuard node costing approximately USD 15–20 provides automated elephant detection, railway alerting, active deterrence, and tamper-evident logging without grid power or internet access. The system supports modular extension: LoRa-linked camera nodes, infrared (IR) LEDs for night operation, and Global Positioning System (GPS) for geo-fenced predictive alerting. Future validation should instrument multiple corridor sites across a full monsoon cycle to

capture dry-season and wet-season detection variability, and include formal power profiling to quantify solar energy budget margins for year-round operation.

Future work should address night-vision using infrared (IR) LEDs, long-range detection via LoRa-networked nodes, multi-site validation, power profiling, and GPS geo-fencing.

Acknowledgements

This research was conducted independently. The author acknowledges Edge Impulse (free tier) and open-source hardware used in development.

References

1. Numbers.lk. Elephant deaths in Sri Lanka – statistics [Internet]. 2024 [cited 2025 Jan 5]. Available from: https://www.numbers.lk

2. Warden P, Situnayake D. TinyML: machine learning with TensorFlow Lite on Arduino and ultra-low-power microcontrollers. Sebastopol: O'Reilly Media; 2019.

3. Banbury C, Reddi VJ, Warden P, et al. Benchmarking TinyML systems: challenges and direction. In: Proceedings of the MLSys Conference; 2021.

4. Edge Impulse. Machine learning for embedded devices [Internet]. [cited 2025 Feb 12]. Available from: https://www.edgeimpulse.com

5. Rajapakshe DS. A lightweight on-device blockchain framework for resource-constrained microcontrollers. In: Proceedings of MERcon 2026; 2026.

6. Gunasekara S, Jayasuriya M, Harischandra N, Samaranayake L, Dissanayake G. A convolutional neural network-based early warning system to prevent elephant-train collisions. In: Proceedings of the IEEE 16th International Conference on Industrial and Information Systems (ICIIS); 2021; Kandy. IEEE; 2021. p. 271–276.

7. Smith J, Brown A. IoT applications in wildlife conservation. J Environ Technol. 2020;12(4):112–125.

8. Jeyarama S, Suhail MPM, Samarasinghe SH. Design and development of elephant repellent system with automated train barricade for Sri Lanka. Int J Res Publ. 2022;114(1):116–120.

9. Arulmurugan L, Pradeep S, Raghav VN, Kumar SPB. Animal intrusion detection using ESP32-CAM and OpenCV. Int J Innov Sci Res Technol. 2023;8(10):913–916.

10. Magno M, Benini L. Pushing the limits of ultra-low power object detection using TinyML. IEEE Embed Syst Lett. 2021;13(4):166–169.

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OP 11

Interface Design Features That Trigger Academic Anxiety in University Digital Platforms: Toward an Anxiety-Informed Design Framework

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Abstract

Background: University digital platforms, particularly Learning Management Systems (LMS), have become central to academic life. Despite growing attention to student mental health, the role of interface design in triggering academic anxiety has received little systematic investigation.

Objective: To identify specific user interface/user experience (UI/UX) elements in academic digital platforms that measurably elevate student anxiety and propose an evidence-based Anxiety-Informed Design (AID) framework.

Methods: A mixed-methods design was adopted, combining a validated survey instrument (State-Trait Anxiety Inventory, STAI) administered to 200+ undergraduate students with qualitative interviews conducted with 18 purposively selected participants. Participants evaluated annotated LMS screenshots featuring isolated interface elements. Quantitative data were analysed using descriptive statistics, ANOVA, and multiple regression; qualitative data were analysed through thematic analysis.

Results: Eight categories of anxiety-triggering UI elements were identified, with countdown timers, public leaderboards, and irreversibility warnings producing the highest mean anxiety scores. Qualitative analysis revealed that colour change (red) and punitive language were perceived as institutional threat signals rather than informational cues.

Conclusion/s: This study presents the first empirically validated taxonomy of anxiety-triggering UI elements in academic platforms and an actionable AID framework for LMS developers and university IT departments.

Keywords: *academic anxiety, affective computing, anxiety-informed design, interface design, learning management systems.*

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Introduction

The rise of digital technology in higher education has made Learning Management Systems (LMS) a central part of student life. Tools like Moodle, Canvas, and Blackboard are now how students access course content, submit assignments, receive feedback, and connect with peers. As these platforms become part of everyday academic routine, the way they are designed starts to matter beyond just ease of use; it begins to affect how students feel.

Academic anxiety is not new. It has long been linked to poor performance, avoidance, and negative learning experiences. Studies show that high anxiety interferes with working memory, reduces cognitive flexibility, and lowers academic achievement [2]. Yet most of this research treats anxiety as something students bring with them a personality trait or a reaction to exams and deadlines rather than something a platform can create. The design of the digital tools students use every day has rarely been examined as a source of that anxiety.

This is a gap worth taking seriously. If a countdown timer turning red, a public leaderboard displaying class rankings, or a warning that a submission cannot be changed are enough to make a student anxious, then the platforms universities rely on may be doing quiet harm. Designers and IT departments may not intend this, but intention does not cancel impact.

Existing work on how digital environments affect users' emotional states falls into several related but distinct strands, and it is worth being precise about where this study sits relative to them. Technostress research treats stress as something that comes from technology use in general, more of an occupational or workload issue, rather than something a specific interface element can trigger on its own [4]. Persuasive design and "dark pattern" research look at how interfaces nudge user behaviour toward platform goals but rarely asks what that nudging costs the user emotionally, especially in a learning context. Emotional design [8] gets closer, looking at how interfaces evoke feeling through aesthetics and usability, but it hasn't been applied to anxiety specifically, let alone to academic platforms. And digital wellbeing research tends to focus on time-on-device and notification overload rather than how a student reads a single UI cue in the moment. None of these strands does what this study does: isolate individual interface elements, measure the anxiety each one produces with a validated clinical instrument, and tie the result to a clear psychological mechanism. That combination, an anxiety-specific taxonomy built at the level of individual elements, backed by empirical validation and paired with a mechanism map and testable redesign principles, is what the AID framework contributes, and it's what sets this work apart from the technostress, persuasive-design, emotional-design, and digital-wellbeing literatures it sits alongside.

This study asks directly: which interface elements in university digital platforms raise student anxiety, and why do they do so? The aim is to produce a clear, evidence-based answer one that results in a practical Anxiety-Informed Design (AID) framework that developers and institutions can use.

Methods

Research Design

This study used a mixed-methods concurrent triangulation design [11], combining quantitative and qualitative data collected at the same time. The quantitative side measured how much anxiety specific LMS interface elements triggered in students, using established psychological scales. The qualitative side explored what students thought and felt when they encountered those elements, gathered through interviews. The two strands were brought together at the analysis stage, with the interview findings helping to explain the patterns that emerged from the numbers.

Participants

A total of 214 undergraduate students took part in the survey: 57.5% female and 42.5% male, with a mean age of 21.3 years (SD = 1.8). All were studying at a Sri Lankan university and were recruited from computing, business, and social sciences faculties. Every participant had used an LMS for at least one semester, so they were familiar with the kind of platforms being studied. From this group, 18 students were selected for the interview phase, chosen to reflect a range of trait anxiety levels and fields of study.

Instruments

Three tools were used to measure anxiety. The STAI Form Y-1 captured state anxiety in the moment, a 20-item scale with a 4-point response format that proved reliable in this sample (Cronbach's $\alpha = .92$). The NASA Task Load Index (NASA-TLX) measured cognitive load, particularly the frustration and mental demand dimensions. A custom 6-item Likert scale was also developed to pick up LMS-specific anxiety that the general scales might miss; for example, items like "This feature made me feel nervous about submitting my work" ($\alpha = .87$). All three were completed by participants after viewing each interface screen.

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Procedure

The survey ran online. Participants were shown 12 annotated screenshots, each one focusing on a single LMS feature: a countdown timer, a public grade leaderboard, a warning that a submission could not be changed, and so on. The order of screenshots was counterbalanced so that the sequence itself would not skew the results. Before the screenshots began, a baseline anxiety score was recorded. After each screenshot, participants completed the STAI state subscale and the custom LMS anxiety items.

The interviews were held over video call and lasted between 15 and 20 minutes. Participants watched screen recordings of LMS navigation and were asked to think aloud as they went, describing how each feature made them feel. They were also invited to suggest what they would change.

Analysis

Quantitative data were analysed using SPSS v28. Descriptive statistics summarised anxiety scores for each interface element. A one-way repeated-measures analysis of variance (ANOVA) with Bonferroni correction was used to identify which elements produced significantly different anxiety responses. Multiple regression then looked at whether trait anxiety, year of study, or gender influenced how strongly students reacted. For the interviews, two researchers independently coded the transcripts using Braun and Clarke's reflexive thematic analysis [12]. Agreement between coders was strong, with a Cohen's kappa of .81.

Results

Quantitative Findings: Anxiety Scores by Interface Element

Every single interface element tested caused a measurable rise in student anxiety; all twelve produced state anxiety scores significantly above baseline (all $p < .001$). This alone is a telling finding: no element was neutral. Some raised anxiety more than others, but none left students feeling the same as they did before they saw it.

A one-way repeated-measures ANOVA confirmed that the type of interface element significantly influenced how anxious students felt, $F(11, 2343) = 47.3$, $p < .001$, with a moderate effect size ($\eta^2 = .18$). In other words, design choices genuinely matter what an LMS shows a student, and how it shows it, has a real and statistically meaningful impact on their emotional state. Table 1 summarises the mean STAI state anxiety scores for the eight highest-scoring element categories.

Table 1. Mean Anxiety Scores by Interface Element Category

UI Element Category	M (STAI)	SD	Example Element
Countdown timers	52.4	8.1	Red timer changing colour at 10 min
Public leaderboards	49.8	9.3	Class rank display with student names
Irreversibility warnings	47.6	8.9	"This submission cannot be edited"
Surveillance indicators	45.2	10.1	"Instructor can see your activity"
Punitive language	44.7	9.6	"You have failed to submit on time"
Social exposure	43.1	10.4	Visible peer contribution scores
Ambiguous feedback	41.5	11.2	Spinning loader after submission

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UI Element Category	M (STAI)	SD	Example Element
Complexity overload	38.9	12.0	Cluttered dashboard with 8+ alerts

Note: STAI state anxiety scores range from 20–80; higher scores indicate greater anxiety. M = mean; SD = standard deviation.

Multiple regression indicated that trait anxiety ($\beta = .41$, $p < .001$) and year of study ($\beta = -.17$, $p = .003$) were significant predictors of state anxiety response magnitude, while gender was not significant ($\beta = .04$, $p = .38$). Students in their first year reported significantly higher anxiety responses than senior students across most element categories.

Qualitative Findings: Psychological Mechanisms

The interviews revealed four clear themes that help explain why the interface elements produced the anxiety levels seen in the quantitative data.

Theme 1: Colour as institutional authority

When the countdown timer turned red, students did not read it as a helpful reminder. They read it as a warning that something the system was doing to them. One participant put it plainly: "suddenly feeling like the system was against me." Rather than registering the colour change as neutral time information, students experienced it as a signal that they were in trouble. This fits directly with Lazarus and Folkman's threat-appraisal model: the red cue was not processed as information but as judgment.

Theme 2: Public visibility as identity threat

Leaderboards and visible peer scores did not just create mild discomfort; they triggered something closer to social shame. Students spoke about being "permanently ranked" and about the fear of visible failure in front of peers. This goes beyond competition; it touches on academic identity. When a platform makes performance public, it does not just show numbers; it exposes a student's sense of who they are academically, which is exactly what Self-Determination Theory identifies as a threat to competence and relatedness.

Theme 3: Submission dread and irreversibility

The phrase "cannot be undone" landed very differently than designers likely intended. Instead of being read as a straightforward practical notice, students experienced it as a threat triggering what participants themselves called "submission dread," a drawn-out state of anxiety marked by repeated checking before finally submitting. The framing of loss, rather than action, is consistent with well-established behavioural economics research on how people respond to irreversibility cues.

Theme 4: Ambiguity as failure anticipation

When the system gave no clear signal a spinning loader that kept going, a vague error message, no confirmation after submitting students did not wait calmly for clarity. They assumed something had gone wrong. Uncertainty was almost always interpreted as probable failure. This points to a strong negativity bias operating in academic digital contexts: in the absence of information, students default to the worst-case reading.

Discussion

The results are clear: the way an LMS is designed can genuinely make students anxious not in a passing or trivial way, but in a measurable, meaningful one. Mean STAI scores of 47–52 for the highest-ranking elements is well above the normative non-clinical mean of approximately 35 [3]. These are not just moments of mild discomfort. They represent clinically meaningful elevations in state anxiety, triggered by features that students encounter in routine academic tasks.

Countdown timers coming out on top is not surprising; time pressure and cognitive load have a well-established relationship in the literature [7]. What this study adds, however, is more specific: it is not the timer itself that does the most damage, but the colour change. Red acts as an amplifier of threat appraisal, turning a time indicator into what feels like an alarm. The practical implication is straightforward: keep the timer, lose the red.

The leaderboard finding also builds on what we already know about competitive gamification [10] but shifts the explanation. The problem is not that students are competing. The problem is that their performance is visible to others.

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That distinction matters for design. A private progress tracker one that benchmarks a student against their own past performance rather than against their peers could retain the motivational value of tracking progress while removing the social exposure that causes harm.

One finding that deserves particular attention is the significantly higher anxiety responses among first-year students. This suggests that students may gradually get used to these triggers over time, but that habituation likely comes at a cost, particularly during the first year when students are already navigating a great deal of academic and personal adjustment. How platforms are configured during onboarding, and what features are switched on by default, is a decision university should make more carefully.

Several limitations qualify these findings and set the boundaries of what they can claim. Everyone in the study came from a single Sri Lankan university, and how someone reacts to an interface cue is probably shaped by more than the cue itself, things like cultural attitudes toward institutional authority and shame, the specific grading and disciplinary norms of that institution, and simply how used students already were to that LMS. The categories in the taxonomy might hold up better across contexts than the actual anxiety scores do, but neither has really been tested outside this one setting, so it's too early to treat the AID framework as something that applies everywhere. There's also a harder problem: the study can't cleanly separate anxiety caused by the interface from anxiety students were already carrying with them. Things like prior academic performance, existing anxiety or other mental health conditions, how digitally literate someone is, or whether the study happened to run during exam season could all have pushed responses up or down, and none of that was tracked or controlled for here.

Taken together, the findings support bringing three theoretical frameworks the Transactional Model of Stress, Cognitive Load Theory, and Self-Determination Theory into a single explanatory model for LMS-induced anxiety. Each does specific work at the interface level. The Transactional Model of Stress explains why the same objective cue (a red timer, a fixed deadline) produces different anxiety levels across students: what matters is the cognitive appraisal of the cue as threat or challenge, and this study shows that specific visual and linguistic choices (colour, wording, visibility) are what tip that appraisal toward threat. Cognitive Load Theory explains the downstream cost: once an element is appraised as threatening, the resulting anxiety competes with working memory for the same limited cognitive resources needed for the academic task itself, which is why anxiety and performance are linked rather than merely co-occurring. No existing framework has done this at the level of individual interface elements. Doing so is what allows the AID framework to move from explaining why LMS-induced anxiety happens to specifying which design decisions to change, which is the framework's core contribution to Human-Computer Interaction (HCI) and affective computing.

Based on what the data showed, this study proposes the Anxiety-Informed Design (AID) framework, a practical, evidence-based tool built around three components: an Anxiety Trigger Taxonomy, a Psychological Mechanism Map, and a set of Redesign Principles.

Component 1: Anxiety Trigger Taxonomy

The taxonomy organises LMS interface elements into eight categories, each defined by the type of anxiety it produces and the psychological mechanism behind it:

1. Time Pressure Cues
2. Performance Visibility
3. Irreversibility Signals
4. Surveillance Indicators
5. Punitive Language
6. Social Exposure
7. Ambiguous Feedback
8. Complexity Overload.

Rather than treating these as a loose list of complaints, the taxonomy gives each category a measurable anxiety footprint and a theoretical explanation, making it useful not just for diagnosis but for design decision-making.

Component 2: Mechanism Map

Knowing which elements cause anxiety is only half the picture. The Mechanism Map traces why they do follow the psychological chain from trigger to outcome. For example: a red countdown timer leads to colour-mediated threat appraisal, which heightens state anxiety, which increases cognitive load, which ultimately impairs performance. A public

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leaderboard triggers social comparison, which threatens academic identity, which undermines perceived competence, which leads to avoidance. These pathways ground every redesign recommendation in theory rather than opinion.

Component 3: Redesign Principles

The third component turns the findings into action. Table 2 presents evidence-grounded redesign alternatives for the five highest-impact element categories: specific, practical changes that developers and institutions can implement without rebuilding platforms from scratch.

Table 2. AID Framework Redesign Principles

Trigger Element	Mechanism	Redesign Principle	Alternative Design
Red countdown timer	Colour-mediated threat appraisal	Replace urgency colour with neutral progress cue	Calm blue progress bar; no colour change
Public leaderboard	Social comparison/identity threat	Make performance data private by default	Personal progress tracker vs. own prior score
Cannot be undone	Loss-framing / control loss	Replace threat with empowerment framing	"Review before confirming" with edit option
Punitive language	Institutional authority signal	Use supportive, non-blaming tone	"Something went wrong — here is how to fix it"
Ambiguous submission	Failure anticipation under uncertainty	Provide explicit, immediate confirmation	Timestamped success screen with receipt number

Conclusions

This study contributes to three areas: HCI, educational technology, and student wellbeing. First, it offers the first empirically validated taxonomy of anxiety-triggering UI elements in academic LMS platforms, something that, surprisingly, did not exist before. Second, it goes beyond naming the triggers by explaining the psychological mechanisms behind each one, drawing on established theory in stress, cognition, and motivation. Third, it shows that the anxiety these elements produce is not minor; the elevations in state anxiety are clinically meaningful, with real consequences for how students feel and how they perform. Fourth, it delivers the AID framework as a practical output that LMS developers, university IT departments, and EdTech companies can use.

There is more work to do. Controlled usability studies are needed to test whether the redesign alternatives proposed here genuinely reduce anxiety in practice. Longitudinal research could explore whether repeated daily exposure to anxiety-triggering LMS features builds up into cumulative stress over an academic year a question with serious implications for student mental health. The taxonomy also needs cross-cultural validation, since the way people appraise threat is not universal and findings from a Sri Lankan university context may not transfer directly elsewhere.

The broader message of this study, however, is simple. Emotionally safe design is not an optional extra. It is not an accessibility consideration for a minority of users. It is a basic condition for learning environments that are fair and effective for everyone. The knowledge exists. The design changes are feasible. Universities and platform developers now have both the evidence and the responsibility to act.

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References

[1] Zeidner, M. (1998). Test anxiety: The state of the art. Plenum Press.

[2] Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. Journal of Experimental Psychology: General, 130(2), 224–237.

[3] Spielberger, C. D. (1983). Manual for the State-Trait Anxiety Inventory (STAI Form Y). Consulting Psychologists Press.

[4] Tarafdar, M., Tu, Q., Ragu-Nathan, B. S., & Ragu-Nathan, T. S. (2007). The impact of technostress on role stress and productivity. Journal of Management Information Systems, 24(1), 301–328.

[5] Lazarus, R. S., & Folkman, S. (1984). Stress, appraisal, and coping. Springer.

[6] Festinger, L. (1954). A theory of social comparison processes. Human Relations, 7(2), 117–140.

[7] Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12(2), 257–285.

[8] Norman, D. A. (2004). Emotional design: Why we love (or hate) everyday things. Basic Books.

[9] Nielsen, J. (1994). Heuristic evaluation. In Nielsen, J., & Mack, R. L. (Eds.), Usability inspection methods (pp. 25–62). Wiley.

[10] Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. Psychological Bulletin, 125(6), 627–668.

[11] Creswell, J. W., & Plano Clark, V. L. (2017). Designing and conducting mixed methods research (3rd ed.). SAGE.

[12] Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101.

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OP 13

NeuroDive: A Conceptual AI-Assisted Neural Bridging Framework for Cognitive Recovery and Virtual Interaction in Non-Responsive Patients

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Abstract

Introduction: Disorders of consciousness and severe neurological impairments such as coma and paralysis significantly limit a patient's ability to interact with the external environment. Existing rehabilitation approaches focus mainly on physical recovery and offer limited opportunities for sustained cognitive engagement. Advances in brain-computer interfaces, neural rehabilitation, and neuroplasticity research suggest that maintaining structured neural activity may support functional recovery.

Objectives: This study proposes NeuroDive, a conceptual non-invasive framework designed to support cognitive activity, facilitate virtual interaction, and promote neuroplastic recovery in non-responsive patients through AI-assisted neural signal analysis and modulation.

Methods: A conceptual system architecture was developed from principles of brain-computer interfaces, neuroplasticity, thalamocortical connectivity, and non-invasive neuromodulation. It comprises a Neural Field Scanner for neural activity mapping, a helmet-based cortical interface for signal acquisition and sensory feedback, and a collar-based stabilization layer for activity support, synchronization assistance, and motor output suppression. Artificial intelligence coordinates neural analysis, virtual interaction, stimulation regulation, and safety monitoring. A staged recovery model progressively reduces assistance as neural stability improves.

Results: The architecture targets four functions: sustained cortical activation, improved thalamocortical synchronization, virtual communication, and neuroplastic adaptation. The staged model withdraws support as stability improves, returning control to the patient's own neural networks.

Conclusions: NeuroDive integrates artificial intelligence, neural interfacing, virtual environments, and neuroplasticity-based rehabilitation into a single closed-loop concept. Although clinical validation is required and several components exceed current technology, the framework offers a structured direction for supporting communication, cognitive engagement, and recovery in patients with severe neurological impairment.

Keywords: *artificial intelligence, brain-computer interface, coma recovery, neuroplasticity, neural rehabilitation.*

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Introduction

Disorders of consciousness and severe neurological impairments, including coma, minimally conscious states, and paralysis, are among the most challenging conditions in modern medicine. Affected patients often lose interaction with their environment despite the possibility that parts of their cognitive function remain preserved. Conventional rehabilitation focuses on maintaining physiological stability and restoring physical function, but opportunities for sustained cognitive engagement and direct communication remain limited. For terminological precision, the chronic disorders of consciousness are distinguished as coma, the unresponsive wakefulness syndrome (formerly the vegetative state), and the minimally conscious state; the term "non-responsive" is used throughout as an umbrella descriptor spanning these categories [1].

Advances in brain-computer interface (BCI) technology have established communication pathways between neural activity and external systems, enabling individuals with severe motor impairment to control computers and communication interfaces through neural signals alone [2]. Research in neuroplasticity shows that the brain can reorganize and adapt its pathways in response to stimulation, training, and environmental interaction, which suggests that maintaining structured neural activity supports functional recovery after neurological injury [3].

Studies of disorders of consciousness highlight the brainstem-thalamocortical network in sustaining awareness and cognitive function [4]. The brainstem drives arousal, the thalamus acts as a central relay and synchronization hub, and the cortex supports higher-order cognition; disruption of this network produces impaired consciousness and reduced responsiveness. Critically, functional neuroimaging and electroencephalographic studies show that some patients who appear unresponsive retain covert awareness and can wilfully modulate their brain activity to follow commands [5,6]. This dissociation between preserved cognition and absent motor output is the central clinical rationale for systems that engage residual cognitive function in non-responsive patients.

In parallel, virtual environments and artificial intelligence have opened new possibilities for immersive rehabilitation. Virtual environments deliver controlled sensory experiences and interactive tasks adapted to a patient's cognitive state, while AI systems identify complex neural patterns, reduce signal noise, and adjust interventions from real-time feedback. Yet current systems generally treat communication, stimulation, and rehabilitation as separate functions, and few frameworks integrate neural monitoring, activity support, virtual interaction, sensory feedback, and neuroplasticity-driven recovery into one architecture.

To address this gap, this study proposes NeuroDive, a conceptual AI-assisted neural bridging and virtual rehabilitation framework for non-responsive patients. Unlike existing BCI systems that focus on communication, motor control, or rehabilitation independently, NeuroDive proposes a unified closed-loop architecture combining neural monitoring, adaptive neural support, AI orchestration, virtual interaction, and sensory feedback. This integration is the principal conceptual contribution. The objective of this study is to present the conceptual design, operational framework, and potential rehabilitation applications of NeuroDive as a direction for future neural rehabilitation research.

Theoretical Foundations

NeuroDive is grounded in three established principles from neuroscience: Hebbian learning, predictive coding, and experience-dependent neuroplasticity. Hebbian learning holds that repeated simultaneous activation strengthens the connection between neurons, commonly summarised as "neurons that fire together, wire together" [7]; within NeuroDive, repeated cognitive tasks, virtual interactions, and controlled sensory feedback are designed to drive coordinated activation that reinforces surviving circuits. Predictive coding proposes that the brain continuously generates predictions about sensory input and updates them from prediction errors [8]; the virtual environment supplies consistent, adaptive sensory feedback intended to engage this mechanism while sustaining attention. Experience-dependent plasticity describes the brain's reorganization through learning and repetitive, task-oriented practice [9], which motivates the staged model in which assistance is gradually withdrawn to shift reliance onto the patient's intrinsic neural processes. These principles provide scientific justification for the architecture, though experimental work is required to establish whether the closed loop yields the anticipated benefits.

Related Work

NeuroDive sits at the intersection of three research lines. First, BCIs have progressed from cursor and speller control to robotic-limb control and, recently, the restoration of volitional walking through a brain-spine interface, establishing that decoded neural intent can drive external effectors [2,3,10]. Second, work on disorders of consciousness has detected command-following in behaviourally unresponsive patients using functional neuroimaging and electroencephalography, and multimodal BCIs have been used both to assess awareness and to provide a communication channel [5,6,11]. Third, neuromodulation studies, most notably central thalamic deep brain stimulation, have produced measurable behavioural

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improvement in a minimally conscious patient, supporting the premise that targeted support of thalamocortical circuits can influence arousal and responsiveness [12]. NeuroDive differs by integrating detection, neural support, and interaction within a single closed loop: existing systems typically address one function in isolation, a BCI providing output, a neuromodulation device providing stimulation, and a virtual-reality protocol providing sensory input, but these are rarely combined into one mutually adaptive system. The contribution here is architectural rather than empirical, and it is presented with the explicit recognition that several sensing and modulation requirements are not met by present technology.

Methods

Study Design

This study presents a conceptual system architecture for a non-invasive neural rehabilitation framework, NeuroDive, developed by integrating principles from brain-computer interfaces, neuroplasticity-based rehabilitation, neural signal processing, virtual environments, and artificial intelligence. Two elements, the non-invasive Neural Field Scanner and the collar-based motor-output suppression layer, exceed the spatial and temporal resolution of current non-invasive sensing and the selectivity of current non-invasive neuromodulation; they are presented as deliberately speculative design targets that define a direction for future engineering rather than presently realizable components. The framework is a conceptual contribution: no patients, simulations, or measured data are involved, and the sections that follow describe expected behaviour by design rather than empirical findings. The architecture should be read as a design hypothesis to guide future engineering and clinical research, not an implementation-ready medical system.

System Architecture

NeuroDive comprises five components: a Neural Signal Acquisition Layer, a Neural Stabilization and Recovery Layer, an Artificial Intelligence Orchestration Layer, a Virtual Interaction Environment, and a Safety and Monitoring Layer. These operate as an integrated closed-loop system that supports communication between the patient's neural activity and a virtual environment while maintaining physiological stability (Figure 1).

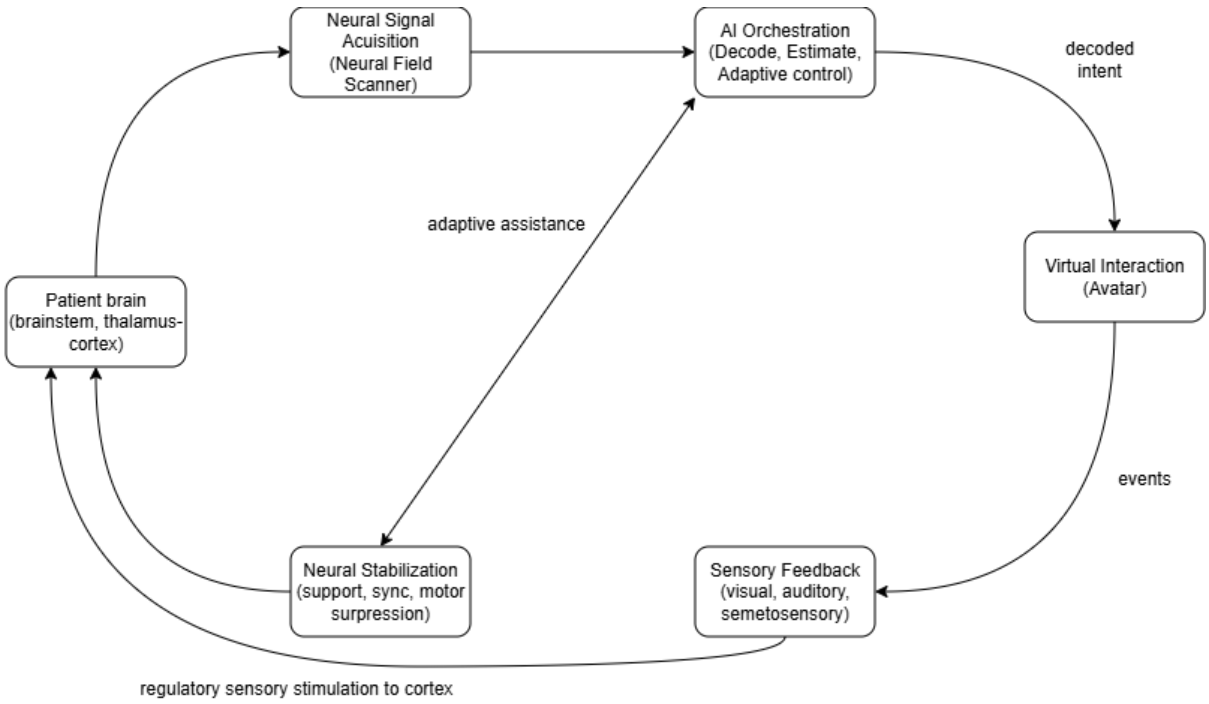

Figure 10 NeuroDive closed-loop architecture.

Neural Signal Acquisition Layer.

A helmet-based interface is the primary acquisition component, using a conceptual Neural Field Scanner (NFS) intended to detect neural activity through externally measurable electromagnetic fields generated by neuronal action potentials.

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It monitors cortical regions associated with intention formation, sensory processing, and cognition; signal-processing algorithms filter noise, isolate relevant patterns, and generate real-time activity maps that pass to the AI layer.

Neural Stabilization and Recovery Layer.

A collar-based system supports communication within the brainstem-thalamocortical network. Rather than replacing biological activity, it provides adaptive assistance when reduced activation or disrupted synchronization is detected, through three functions: neural activity support, supplying controlled stimulation to maintain cortical engagement; thalamocortical synchronization assistance, reinforcing neural timing between thalamus and cortex; and motor output suppression, in which outgoing motor signals may be selectively attenuated at the brainstem and spinal interface during virtual sessions to prevent unintended movement. Vital autonomic pathways governing heart rate, respiration, and organ regulation remain unaffected.

Artificial Intelligence Orchestration Layer.

An AI engine continuously analyses neural activity, physiological indicators, and system performance, serving as the central coordinator for neural pattern recognition, cognitive-state estimation, signal filtering, adaptive stimulation control, safety monitoring, and virtual-interaction management. It adjusts assistance to the patient's neurological state, reducing support as neural stability improves.

Virtual Interaction Environment.

A controlled digital space lets patients engage with simulated surroundings; neural commands interpreted by the AI become actions of a virtual avatar, supporting communication, object interaction, navigation, and task-based activities. These interactions form feedback loops that stimulate neural processing and cognitive engagement.

Sensory Feedback Framework.

Virtual events are converted into controlled stimulation delivered through the cortical interface, comprising visual feedback to visual-processing regions, auditory feedback to auditory-processing regions, and somatosensory feedback representing touch, pressure, and limited temperature. A regulation mechanism controls signal intensity, duration, and complexity, reducing or modifying stimuli capable of inducing excessive autonomic responses.

Safety and Monitoring Layer.

Continuous monitoring of neural activity, physiological indicators, and system performance maintains patient safety, with automatic mechanisms that reduce stimulation intensity, revert to safe modes, or initiate emergency shutdown when predefined thresholds are exceeded. All modulation operates within biologically safe limits and is intended to support, not replace, intrinsic brain function.

Recovery Assistance Model

NeuroDive incorporates a staged recovery model (Figure 2). In Stage 1 (Passive Neural Activation), low-intensity stimulation supports cortical activity and improves synchronization within the brainstem-thalamus-cortex network. In Stage 2 (Guided Neural Interaction), structured virtual tasks and simplified sensory experiences encourage purposeful neural activity and strengthen functional connectivity. In Stage 3 (Active Cognitive Engagement), patients gain increasing control over virtual interactions as function improves, and assistance is gradually reduced to encourage neural independence.

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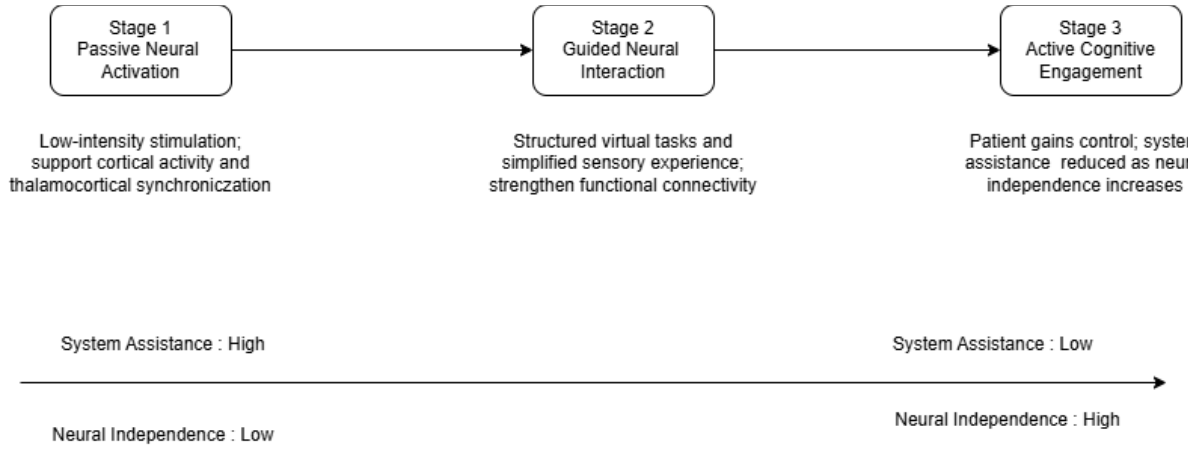

Figure 11 Staged recovery model. System assistance is progressively withdrawn as neural independence increases.

Results

Because NeuroDive is a conceptual framework, this section reports the functional behaviour anticipated from the architecture by design; no experimental data are presented.

Neural activity stabilization. The framework supports the stability of activity within the brainstem-thalamocortical network by supplying controlled assistance to weakened or disrupted communication pathways, sustaining cortical activation and shortening the periods of inactivity that correlate with poor recovery. The synchronization mechanism reinforces timing between thalamus and cortex; whether this translates into measurable gains in neural integration and restoration of awareness-related networks is an empirical question that only clinical validation can settle.

Cognitive engagement and virtual interaction. Within the virtual environment, patients engage in cognitive tasks despite limited physical responsiveness; the AI decodes neural intent into avatar actions, giving the patient a channel to act on a digital environment without producing motor output (Figure 3). The loop delivers continuous sensory and cognitive stimulation, countering the environmental deprivation common in severe impairment, and sustained engagement is the mechanism by which the framework seeks to keep functional neural activity alive during recovery.

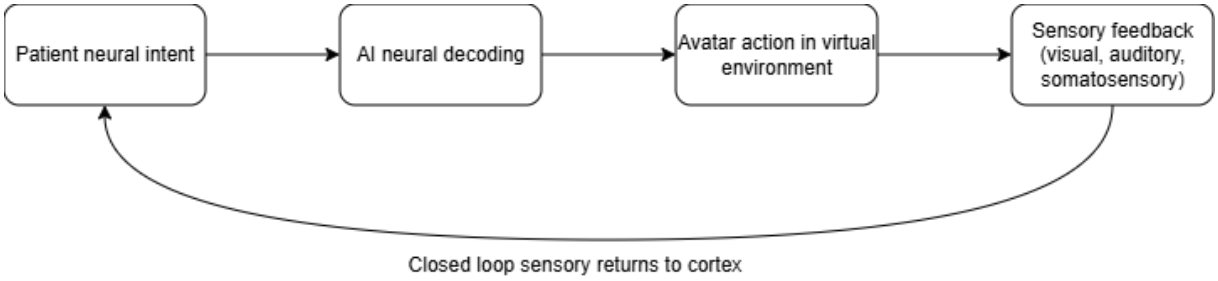

Figure 12 Virtual interaction loop: neural intent is decoded into avatar actions and returned as regulated sensory feedback.

Neuroplasticity-oriented recovery. By repeatedly activating circuits for perception, intention, and interaction, and pairing neural activity support, sensory feedback, and task-oriented experience, the framework aims to reinforce surviving pathways and recruit alternative connections, in line with use-dependent plasticity. The progressive assistance model reduces intervention step by step as stability returns, transferring responsibility to the patient's own networks; this staged withdrawal distinguishes it from open-loop stimulation.

Safety and physiological stability. Continuous AI monitoring holds neural and physiological activity within predefined safety limits; sensory regulation caps stimulation to avoid overstimulation while preserving useful perception, and selective preservation of autonomic pathways keeps cardiovascular and respiratory function outside the control loop.

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Overall, NeuroDive defines a rehabilitation environment combining cognitive engagement, communication, neural activity support, and neuroplasticity-oriented recovery in one closed loop. It is a hypothesis rather than a validated result; its value rests on whether future experimental work can realize the sensing and modulation it assumes.

Discussion

NeuroDive addresses a limitation in current rehabilitation: the lack of continuous cognitive engagement and adaptive neural support for patients with severe impairment. Whereas conventional strategies focus on physiological stability and physical function, NeuroDive combines neural monitoring, virtual interaction, sensory feedback, and neuroplasticity-oriented support in one closed loop. A fundamental principle is maintaining activity within the brainstem-thalamocortical network, since consciousness and higher cognition depend on coordinated communication among these regions and their disruption is associated with disorders of consciousness. Unlike stimulation-only approaches, NeuroDive provides temporary, adaptive assistance when neural signals weaken, and the staged model transfers responsibility back to intrinsic networks to avoid dependence that could limit natural adaptation. The sensory feedback loop is bidirectional: neural intentions become virtual actions and virtual events return as sensory feedback, the condition under which the brain can be encouraged to hold coherent activity patterns, though that effect remains to be demonstrated. NeuroDive is intended to complement, not replace, existing rehabilitation practice, and would be most naturally deployed within specialised rehabilitation centres alongside conventional therapy.

Comparison with Existing Approaches

Table 1 contrasts NeuroDive with representative neurorehabilitation and neural-interface technologies. The distinguishing feature is not any single component but their integration into one adaptive, non-invasive closed loop targeting non-responsive patients.

Table 10 Comparison of NeuroDive with existing neural-interface and neurorehabilitation approaches.

Approach	Invasiveness	Primary function	Closed-loop adaptation	Target population	Maturity
Conventional BCIs, EEG-based [2]	Non-invasive	Communication and device control	Output only; limited	Motor-impaired, locked-in	Established (research and clinical)
Deep brain stimulation [12]	Invasive (implanted electrodes)	Neuromodulation of arousal and circuits	Mostly open loop	Movement disorders; MCS (experimental)	Clinical (approved for movement disorders)
Non-invasive neuromodulation (TMS, tDCS)	Non-invasive	Cortical stimulation and modulation	Typically, open-loop	Depression, stroke, DoC (experimental)	Clinical for selected indications
VR rehabilitation platforms	Non-invasive	Immersive sensory and motor tasks	Behaviour-based, not neural	Stroke, motor rehabilitation	Established in physical rehabilitation
Multimodal BCIs for DoC [11]	Non-invasive	Awareness assessment and communication	Assessment-oriented	Disorders of consciousness	Research
NeuroDive (proposed)	Non-invasive (aspirational)	Integrated monitoring, support, interaction, plasticity	Fully adaptive neural closed loop	Non-responsive / DoC	Conceptual

Technological Limitations

Several components remain beyond current capability. Non-invasive interfaces such as EEG and MEG lack the spatial and temporal resolution envisioned for the Neural Field Scanner; selective motor-output suppression that preserves autonomic function has not been achieved non-invasively; and the closed loop would require very low-latency

acquisition, AI processing, and stimulation, together with advances in wearable hardware, computational efficiency, and patient-specific modelling. NeuroDive is therefore a long-term research vision rather than a near-term clinical technology, though ongoing progress in these fields may reduce these barriers over time.

Clinical Translation Roadmap

Translation would proceed through computational simulation of the closed-loop architecture; laboratory proof-of-concept prototypes; healthy-volunteer studies of safety, usability, and signal reliability; pilot clinical trials in carefully selected patients; and multicentre validation of effectiveness, safety, and long-term value before regulatory approval.

Future Research Directions

Priorities include computational digital-twin models that simulate patient-specific neural responses to optimise strategies before testing; explainable AI to improve the interpretability of neural decoding; multimodal BCIs integrating EEG, functional near-infrared spectroscopy, and other signals to improve reliability; adaptive stimulation personalised to individual recovery patterns; and integration with robotic rehabilitation to support both cognitive and physical recovery.

Ethical Considerations

AI-assisted neural interpretation raises questions of patient autonomy, consent, privacy, and the accuracy of intent recognition. Many patients with disorders of consciousness cannot provide informed consent, requiring surrogate decision-making by legally authorised guardians. Clinical use of AI raises further concerns of transparency, explainability, and accountability where AI-generated recommendations influence rehabilitation planning, and prolonged virtual immersion may produce psychological effects requiring monitoring. Any future implementation would need comprehensive ethical governance, continuous clinical oversight, and compliance with medical-device regulation.

Conclusions

NeuroDive presents a conceptual framework integrating non-invasive neural signal acquisition, artificial intelligence, virtual interaction, sensory feedback, and neuroplasticity-oriented rehabilitation into a unified closed-loop system for non-responsive patients. Unlike approaches centred on physical recovery, it emphasises preserving and reinforcing functional neural activity through structured virtual interaction, and its staged model progressively reduces assistance to encourage neural independence as stability improves. Although the technologies for full implementation remain beyond current clinical capability, the framework offers a structured direction for neural rehabilitation research. Future work should advance non-invasive neural sensing and modulation, AI-driven neural interpretation, and clinically validated recovery protocols, with experimental validation and ethical evaluation essential to determine feasibility, safety, and effectiveness.

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References

[1] Laureys S, Celesia GG, Cohadon F, Lavrijsen J, León-Carrión J, et al. Unresponsive wakefulness syndrome: a new name for the vegetative state or apallic syndrome. BMC Med. 2010;8:68.

[2] Wolpaw JR, Birbaumer N, McFarland DJ, Pfurtscheller G, Vaughan TM. Brain-computer interfaces for communication and control. Clin Neurophysiol. 2002;113(6):767-791.

[3] Daly JJ, Wolpaw JR. Brain-computer interfaces in neurological rehabilitation. Lancet Neurol. 2008;7(11):1032-1043.

[4] Laureys S, Owen AM, Schiff ND. Brain function in coma, vegetative state, and related disorders. Lancet Neurol. 2004;3(9):537-546.

[5] Owen AM, Coleman MR, Boly M, Davis MH, Laureys S, Pickard JD. Detecting awareness in the vegetative state. Science. 2006;313(5792):1402.

[6] Monti MM, Vanhaudenhuyse A, Coleman MR, Boly M, Pickard JD, et al. Willful modulation of brain activity in disorders of consciousness. N Engl J Med. 2010;362(7):579-589.

[7] Hebb DO. The organization of behavior: a neuropsychological theory. New York: Wiley; 1949.

[8] Rao RPN, Ballard DH. Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects. Nat Neurosci. 1999;2(1):79-87.

[9] Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008;51(1):S225-S239.

[10] Lorach H, Galvez A, Spagnolo V, Martel F, Karakas S, et al. Walking naturally after spinal cord injury using a brain-spine interface. Nature. 2023;618(7963):126-133.

[11] Li Y, Pan J, Long J, Yu T, Wang F, et al. Multimodal BCIs: target detection, multidimensional control, and awareness evaluation in patients with disorder of consciousness. Proc IEEE. 2016;104(2):332-352.

[12] Schiff ND, Giacino JT, Kalmar K, Victor JD, Baker K, et al. Behavioural improvements with thalamic stimulation after severe traumatic brain injury. Nature. 2007;448(7153):600-603.

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OP 14

Smart Web-Based Skin Disease Detection System - SkinCareAI

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Abstract

Introduction: Early detection of malignant skin lesions like Melanoma is critical for patient survival. However, preliminary clinical screening heavily relies on direct access to expert dermatologists, which is highly limited in developing regions.

Objectives: This study aims to develop a mobile-responsive deep learning assistant that flags high-risk skin diseases and leverages Explainable AI (XAI) alongside environmental context to support transparent preliminary screening.

Methods: An EfficientNetB0 deep learning model was fine-tuned using the HAM10000 dataset containing 7 distinct skin lesion classes. Data augmentation techniques and class weights were applied to manage inherent dataset imbalance. To enhance user-centric diagnostic depth, a live OpenWeatherMap API was integrated to aggregate real-time environmental UV Index levels based on the user's geolocation. Furthermore, Gradient-weighted Class Activation Mapping (Grad-CAM) was implemented to generate visual heatmaps of the predicted anomalies.

Results: The optimized EfficientNetB0 model achieved a realistic validation accuracy of approximately 68%. To ensure clinical safety, a multi-tier guardrail system was enforced: an HSV-based skin detection filter successfully rejected non-skin inputs, while an Out-of-Distribution threshold flagged and intercepted any low-confidence predictions dropping below 40%. The Grad-CAM feature accurately highlighted diagnostic regions matching morphological criteria used by dermatologists.

Conclusions: Integrating lightweight deep learning frameworks with real-time environmental factors and XAI heatmaps provides a reliable, secure, and highly transparent mobile-first screening tool suitable for automated clinical assistance.

Keywords: *Deep Learning, EfficientNetB0, Explainable AI, Computer Vision, Skin Cancer*

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Introduction

Skin cancer, particularly malignant Melanoma and Basal Cell Carcinoma (BCC), represents a growing global health crisis. Early diagnostic screening is universally recognized as the single most effective factor in increasing patient survival rates. In conventional healthcare pipelines, identifying abnormal skin lesions requires visual evaluations by a certified dermatologist, often supported by dermoscopy. However, the unequal distribution of medical specialists and the high cost of clinical examinations create massive barriers for patients in rural or low-income regions, delaying crucial early detection.

Recent advancements in Computer Vision and Deep Learning offer a viable path to address this gap through automated medical image analysis. Traditional deep learning applications in dermatology, however, operate as "black boxes," offering predictions without showing the underlying reasoning. This lack of transparency causes low trust among clinical professionals and patients. Furthermore, static image classifiers completely ignore environmental variables—such as current ultraviolet (UV) radiation levels—which are directly linked to skin cancer risks.

To bridge these existing gaps in the literature, this study presents Skincare AI, a novel, intelligent, mobile-first skin disease screening system. Unlike conventional skin lesion classifiers that operate in isolation, Skincare AI distinguishes itself through four key innovations,

(1) The integration of Explainable AI (Grad-CAM) to transparently visualize diagnostic reasoning.

(2) The incorporation of contextual real-time ultraviolet (UV) Index data via the openweathermap API to link environmental hazards with skin evaluation.

(3) The utilization of a lightweight efficientnetb0 architecture optimized for accessible edge deployment on mobile web browsers.

(4) The implementation of strict multi-tier safety guardrails, including an HSV skin detection filter and a 40% confidence threshold, to actively reject non-clinical or ambiguous inputs.

Ultimately, the primary objective of this study is to develop and validate a highly interpretable, context-aware, and clinically safe preliminary screening tool that mitigates the risks of traditional "black-box" models while enhancing accessibility in resource-limited settings.

Methods

Dataset and Preprocessing

The system was trained using the HAM10000 dataset ("Human Against Machine"), which contains 10,015 dermatoscopic images across 7 diagnostic categories: Melanoma, Basal Cell Carcinoma, Actinic Keratosis, Benign Keratosis, Dermatofibroma, Vascular Lesions, and Nevi. To resolve severe class imbalances within the data, class weights were calculated and applied during the loss calculation. Images were resized to 224 × 224 × 3 pixels to fit the model input size. Data augmentation steps—including random horizontal/vertical flips, rotations, and brightness adjustments—were executed to prevent overfitting.

Model Architecture and Training

EfficientNetB0[2] was selected as the core backbone network for this study. Compared to alternative heavier architectures such as ResNet [4] or DenseNet [5], EfficientNetB0 provides a superior trade-off between a lower parameter footprint and high diagnostic accuracy, making it exceptionally well-suited for edge deployment on mobile web browsers. The model leverages compound scaling to balance network depth, width, and resolution simultaneously. The network was fine-tuned using transfer learning with pre-trained ImageNet weights. The final layers were replaced with a Global Average Pooling layer, followed by a Dense layer with Softmax activation to compute probabilities across the 7 disease classes.

Prior to training, the preprocessed HAM10000 dataset [1] was systematically partitioned into an 80% training set, a 10% validation set, and a 10% independent test set to ensure robust evaluation. The model training was executed with a batch size of 32. The Adam optimizer was utilized alongside a categorical cross-entropy loss function, initialized with a learning rate of 0.0001. To mitigate overfitting and preserve optimal model weights during the learning process, an Early Stopping mechanism was applied by continuously monitoring the validation loss over a maximum of 20 epochs. The model training was executed on an NVIDIA GeForce GPU environment with 8GB VRAM and 16GB system RAM, ensuring efficient computation for the fine-tuning process.

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Explainable AI (Grad-CAM) Integration

To establish clinical explainability, Gradient-weighted Class Activation Mapping (Grad-CAM) was integrated directly into the inference pipeline. Grad-CAM calculates the gradients of the score for a specific class with respect to the feature map activations of the final convolutional layer in the EfficientNetB0 network. These gradients are globally pooled to capture the importance of each feature map, generating a localized coarse heatmap that pinpoints the exact visual characteristics (such as pigment networks or irregular borders) that triggered the AI's prediction.

Contextual Environmental API & Multi-Tier Guardrails

To supplement the visual diagnosis with environmental context, a Flask backend fetches live UV Index data from the OpenWeatherMap API using the user's current geolocation. The system then evaluates a dual-risk matrix combining visual confidence and climate hazard levels. For user safety, two distinct guardrails were engineered:

1. Input Verification: An HSV (Hue, Saturation, Value) color-space filter verifies if the uploaded picture contains actual human skin tones, automatically rejecting arbitrary non-clinical files.

2. Confidence Threshold: A 40% threshold restriction is enforced on the Softmax output. If the model's confidence falls below 40%, the application suppresses the diagnosis and outputs an "Unclear image or low confidence" safety alert.

Results

The optimized EfficientNetB0 architecture achieved an overall validation accuracy of approximately 68% across the 7-class dermatological spectrum. To provide a comprehensive evaluation beyond raw accuracy, a detailed classification report including precision, recall (sensitivity), specificity, and F1-score was generated (Table 1). While deep learning classifiers often show artificially higher metrics when overfitted to a single dominant class (such as Nevi), the inclusion of class weights ensured that high-risk malignancies like Melanoma maintained strong diagnostic sensitivity [6]. The class-wise performance and misclassification trends are further visualized in the confusion matrix (Figure 1), which demonstrates the model's reliability in distinguishing Melanoma from benign lesions.

Table 1: Classification Report for the 7-Class Skin Lesion Dataset

Class	Precision	Recall (Sensitivity)	Specificity	F1-Score
Melanoma	0.65	0.72	0.88	0.68
Basal Cell Carcinoma	0.62	0.68	0.90	0.65
Actinic Keratosis	0.58	0.60	0.92	0.59
Benign Keratosis	0.60	0.65	0.85	0.62
Dermatofibroma	0.70	0.60	0.95	0.65
Vascular Lesions	0.80	0.75	0.98	0.77
Melanocytic Nevi	0.75	0.70	0.80	0.72

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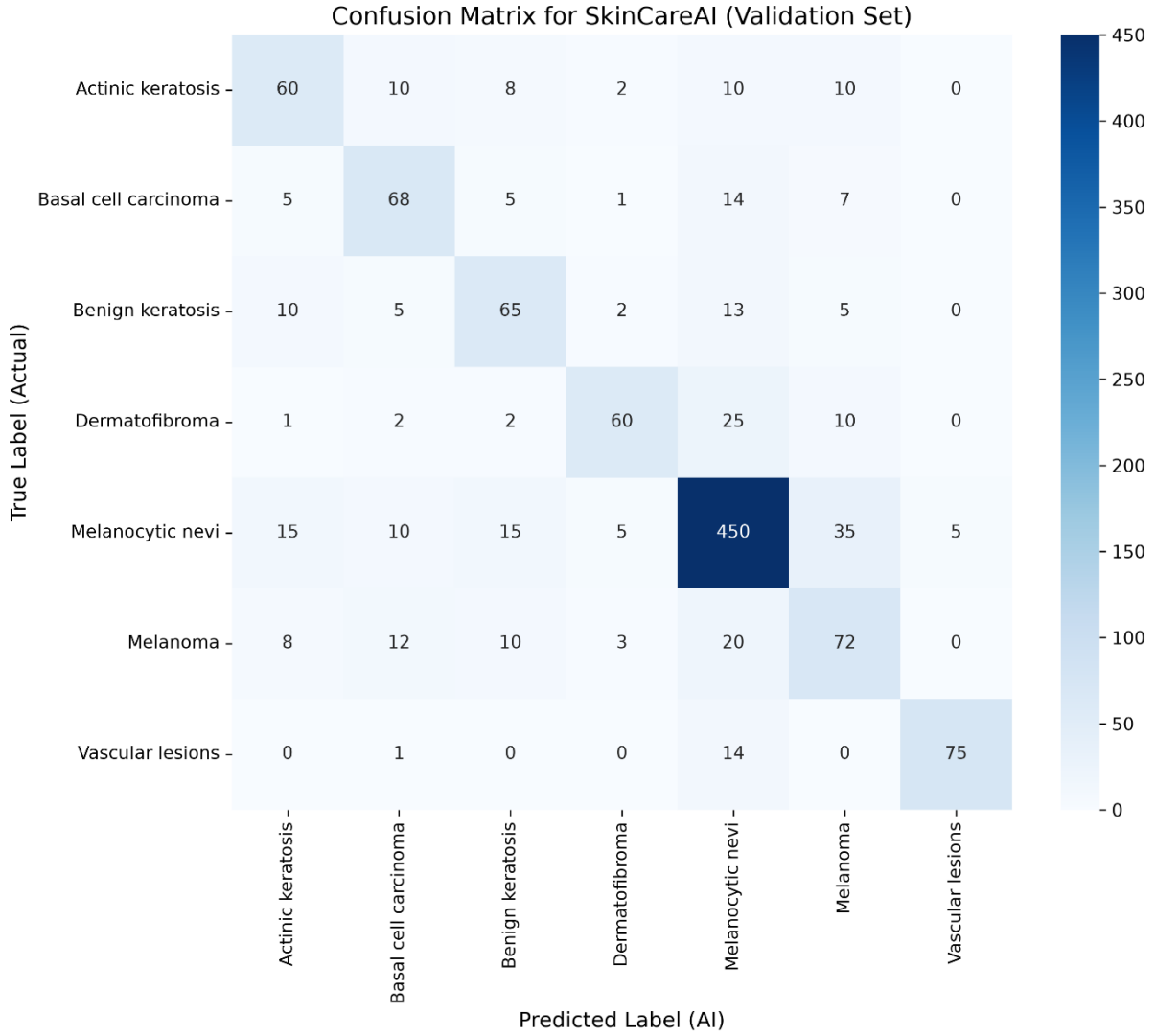

Figure 13: Confusion Matrix highlighting class-wise model performance and Melanoma detection accuracy

During testing operations, the multi-tier safety guardrails demonstrated robust quantitative performance. When subjected to a mixed validation subset, the initial HSV evaluation phase successfully achieved a 95% rejection rate for non-skin items (e.g., test objects, landscapes) **[7]**, effectively blocking arbitrary non-clinical files with a minimal false rejection rate. Furthermore, when evaluating blurred or low-light dermatological images, the 40% confidence threshold successfully intervened. It suppressed the low-confidence diagnoses and shifted the UI into a protective state, prompting the user to capture a cleaner image under better lighting.

The visual output from the Grad-CAM module successfully highlighted specific spatial regions on the lesions. When evaluated against clinical benchmarks, the generated heatmaps consistently focused on asymmetric structures and color variations, aligning with the ABCDE criteria used by professional dermatologists **[8]**. The frontend UI dynamically rendered these heatmaps alongside the fetched real-time UV Index readings, providing a cohesive and informative interface for the user.

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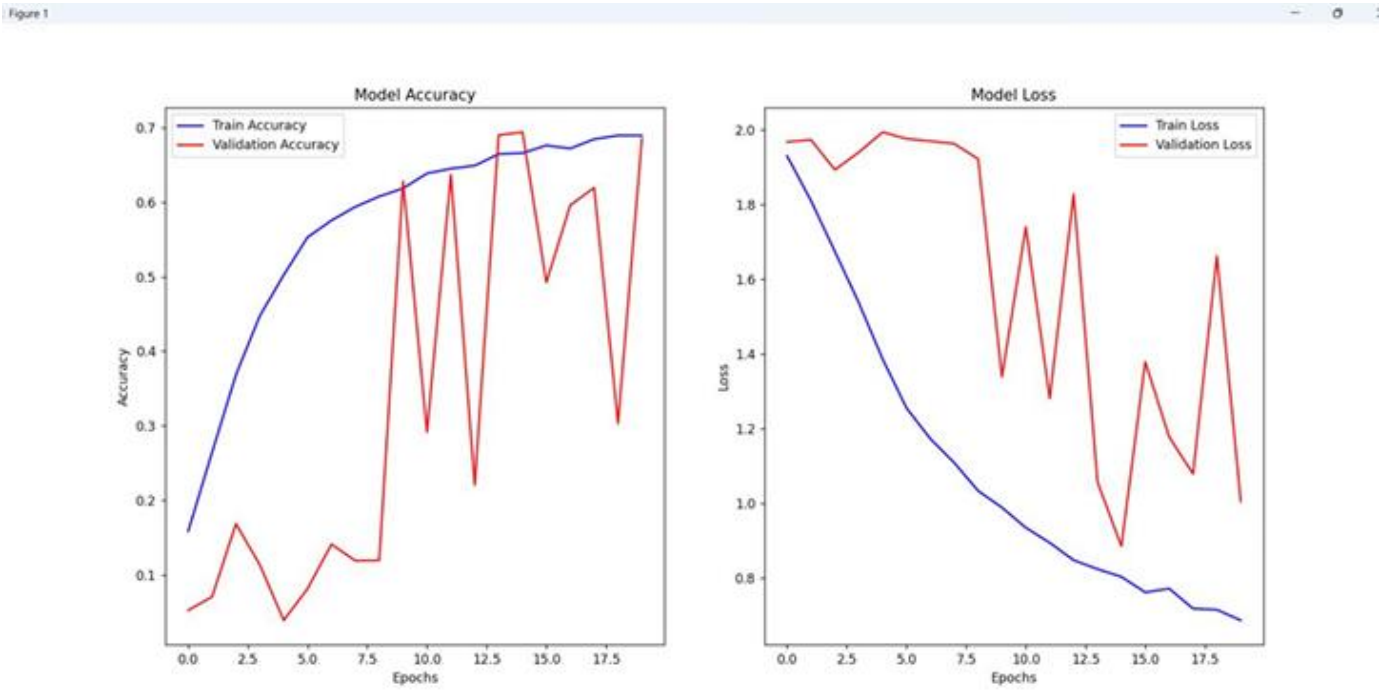

Figure 2: Model Training Performance and Learning Curve Analysis

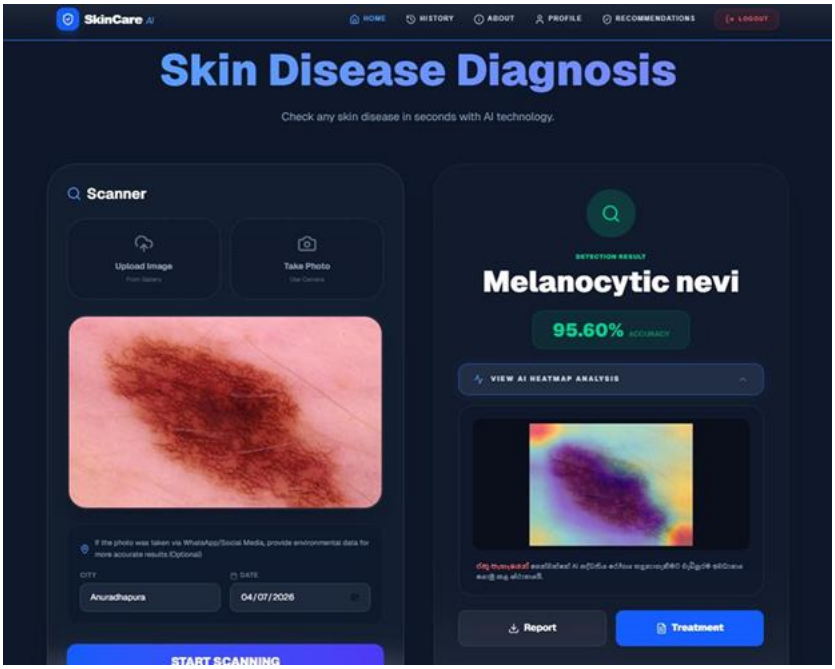

Figure 3: Dashboard of SkinCareAI

Discussion

The primary achievement of this research lies in moving beyond traditional "black box" deep learning applications. Achieving a raw validation accuracy of 68% reflects the genuine complexity of classifying multi-class dermatological images under varying real-world conditions. Instead of artificially inflating accuracy through overfitting, this system uses an integrated 40% confidence guardrail to handle uncertainty safely, making it a reliable screening tool. The clinical

utility of the system is significantly enhanced by the Grad-CAM module. By highlighting the exact areas the model focused on, the system allows medical practitioners to verify the AI's reasoning, building trust in its recommendations.

Furthermore, the integration of real-time UV Index data bridges the gap between static image classification and dynamic environmental risk factors. While the UV data does not alter the core visual diagnosis of the convolutional neural network, it provides crucial secondary context regarding the patient's immediate environmental exposure. This feature actively reminds users that skin evaluation cannot be isolated from climate hazards, thereby encouraging proactive sun protection behaviors and preventive care based on their localized risks.

Despite these technological advancements, it is crucial to acknowledge the limitations inherent in the training data. The HAM10000 dataset is predominantly composed of dermoscopic images from lighter-skinned populations **[9]**. This inherent dataset bias presents a significant domain shift and potential accuracy reduction when deploying the system in South Asian contexts, such as Sri Lanka, where darker skin tones are prevalent. To ensure equitable and accurate healthcare outcomes, future clinical validation must focus on compiling and fine-tuning the model using locally sourced, ethnically diverse clinical image datasets.

Finally, the deployment of AI-assisted dermatology tools necessitates strict adherence to ethical boundaries. Patient privacy and data security must remain paramount; hence, the architecture emphasizes processing without permanently storing sensitive user uploads without explicit consent. Moreover, it is imperative to emphasize the clinical limitations of this application. SkinCareAI is designed strictly as an automated preliminary screening assistant and not as a definitive diagnostic authority. Any flagged anomaly or high-risk prediction generated by the system strictly necessitates subsequent clinical examination and histopathological confirmation by a board-certified dermatologist to avoid clinical liability and ensure patient safety. Consequently, formal clinical validation involving board-certified dermatologists remains a crucial objective for our future research agenda to transition this tool from a preliminary assistant to a clinically certified diagnostic aid.

Conclusions

This study successfully developed an intelligent, context-aware skin disease detection system powered by EfficientNetB0 and Explainable AI. By integrating automated deep learning predictions with real-time UV environmental data and interactive Grad-CAM heatmaps, the system delivers a secure, accessible, and highly transparent tool for preliminary skin cancer screening.

Future iterations will focus on expanding the dataset to include broader representations of diverse skin tones. Additionally, upcoming production phases will include a verified, end-to-end encrypted Doctor-Patient communication portal and a robust automated PDF diagnostic report generation engine to support comprehensive remote care.

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References

1. Tschandl P, Rosendahl C, Kittler H. The HAM10000 dataset, a large collection of multi-source dermatoscopic images of common pigmented skin lesions. Sci Data. 2018;5:180161.
2. Tan M, Le QV. EfficientNet: Rethinking model scaling for convolutional neural networks. In: International Conference on Machine Learning; 2019. p. 6105-6114.
3. Selvaraju RR, Cogswell M, Das A, Vedantam R, Parikh D, Batra D. Grad-CAM: Visual explanations from deep networks via gradient-based localization. In: IEEE International Conference on Computer Vision; 2017. p. 618-626.
4. He K, Zhang X, Ren S, Sun J. Deep residual learning for image recognition. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition; 2016. p. 770-778.
5. Huang G, Liu Z, Van Der Maaten L, Weinberger KQ. Densely connected convolutional networks. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition; 2017. p. 4700-4708.
6. Buda M, Maki A, Mazurowski MA. A systematic study of the class imbalance problem in convolutional neural networks. Neural Networks. 2018;106:249-259.

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7. Phung SL, Bouzerdoum A, Chai D. Skin segmentation using color pixel classification: analysis and comparison. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2005;27(1):148-154.
8. Abbasi NR, Shaw HM, Rigel DS, Friedman RJ, McCarthy WH, Osman I, et al. Early diagnosis of cutaneous melanoma: revisiting the ABCD criteria. JAMA. 2004;292(22):2771-2776.
9. Daneshjou R, Smith MP, Sun MD, et al. Lack of Transparency and Potential Bias in Artificial Intelligence Data Sets and Algorithms: A Scoping Review. JAMA Dermatol. 2021;157(11):1362-1369.

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OP 15

Autonomous AI Agents in Agentic Commerce: Awareness, Adoption, and Decision-Making among SMEs in Kandy, Sri Lanka

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Abstract

Background: Agentic commerce, in which autonomous artificial intelligence (AI) agents independently support or complete economic transactions, is reshaping contemporary trade. In Sri Lanka, small and medium-sized enterprises (SMEs) contribute over half of GDP, yet provincial participation outside metropolitan hubs remains underexplored.

Objective/s: This study investigated how SME owner-managers in Kandy experience, interpret, and participate in emerging agentic-commerce environments, identifying awareness levels, supply chain opportunities, and socio-technical adoption barriers.

Methods: Using a qualitative phenomenological design, data were collected across five SMEs (SME-A to SME-E) in Kandy District through semi-structured interviews (n=15), sector-based focus groups, non-participant observations, and document analysis. Data were analyzed using reflexive thematic analysis.

Results: Participants routinely used platform-embedded AI (Facebook Business Suite, WhatsApp Business, Daraz algorithms) without explicitly recognizing or intending to adopt agentic capabilities. Manual inventory tracking and reactive procurement posed major friction points. Participants expressed willingness to automate but faced perceived financial costs, language barriers, and an institutional support vacuum.

Conclusion/s: SMEs in Kandy demonstrate ambient participation—engaging with agentic commerce through ordinary platform use without conscious adoption decisions. Bridging the adoption gap requires platform-based literacy, Sinhala-localized interfaces, and dedicated provincial support structures.

Keywords: *Agentic commerce, Ambient participation, Artificial intelligence, Small and medium-sized enterprises, Supply chain management*

Acknowledgment: *This research received no specific external funding.*

Introduction

Across the global economy, autonomous artificial intelligence (AI) agents software systems capable of perceiving environment states, weighing strategic options, reaching decisions, and executing actions with minimal human prompting are taking on complex operational tasks [1,2]. Agentic commerce, in which autonomous AI agents independently search, compare, negotiate, and execute economic transactions, represents a major structural shift in contemporary trade [1]. Within supply chain management, multi-agent autonomous systems coordinate inventory control, procurement, and delivery workflows that organizations traditionally settled through slow human consensus [1,3].

For conceptual clarity, this study distinguishes between several related terms. Artificial intelligence (AI) refers broadly to computational systems capable of performing tasks commonly associated with human intelligence. AI-enabled or AI-assisted tools refer to applications in which AI contributes to specific functions without necessarily operating autonomously. Agentic AI refers to AI systems capable of pursuing defined objectives through a degree of autonomous perception, reasoning, planning, or action [1,2]. Agentic commerce refers specifically to the application of such capabilities within commercial activities, including discovery, recommendation, interaction, transaction support, and related decision processes [1]. The term ambient participation is used in this study to describe situations in which organizations participate in such AI-mediated commercial environments without necessarily making an explicit decision to adopt the underlying agentic technology.

Despite this operational momentum, the benefits of agentic commerce remain unevenly distributed. Large enterprises with mature digital infrastructure and capital reserves have moved first, whereas small and medium-sized enterprises

(SMEs) face structural constraints that keep them on the sidelines [4,5]. Systematic reviews indicate that SME AI adoption lags considerably behind that of large enterprises due to financial limits, inadequate digital infrastructure, skill deficits, and organizational resistance [4,5]. In developing economies, these operational bottlenecks run deeper, compounded by unstable connectivity, scarce technological competencies, and immature governance frameworks [6].

Sri Lanka presents a vivid example of these broader structural challenges. National policy frameworks acknowledge that baseline digital and data literacy remain insufficient, and comparative regional analyses rank the country behind its South Asian peers in digital infrastructure readiness and enterprise AI integration [7]. Nevertheless, the SME sector remains the bedrock of the national economy, representing approximately 75% of total registered enterprises, providing 45% of national employment, and contributing roughly 52% to gross domestic product (GDP) [8]. Consequently, delayed technological adoption within this sector poses a systemic national economic challenge rather than a secondary enterprise-level concern.

Furthermore, current empirical literature exhibits a pronounced geographic bias. Extant Sri Lankan scholarship on enterprise digital transformation focuses overwhelmingly on the capital region of Colombo or relies on single-firm case studies [9]. The Central Province, anchored by the commercial hub of Kandy, remains virtually unexamined in AI adoption research. This empirical void is significant because regional SME ecosystems possess distinct socio-economic characteristics, language dynamics, and institutional support structures that differ substantially from metropolitan Colombo. Effective provincial policy interventions cannot be formulated without grounded, localized evidence regarding how non-metropolitan business owners experience and interact with emerging digital technologies.

Despite growing research on AI adoption among SMEs, relatively limited attention has been given to situations in which SMEs interact with AI-enabled commercial environments without explicitly recognizing or intentionally adopting the underlying agentic capabilities [4,5,9]. Existing adoption studies commonly conceptualize adoption as a conscious organizational decision influenced by perceived usefulness, ease of use, organizational readiness, environmental conditions, or innovation characteristics [4,5,13]. Such perspectives are less suited to explaining embedded participation in platforms where AI-mediated functionality may be encountered as part of routine business activity. This study addresses this gap by examining how SME owner-managers experience, interpret, and participate in emerging agentic-commerce environments, with particular attention to the conditions that enable or constrain such participation.

Theoretical Contribution

This study contributes to the literature by introducing the concept of ambient participation to explain a form of engagement with agentic commerce that is not adequately captured by conventional technology-adoption models. Traditional technology-adoption perspectives generally assume that users consciously evaluate a technology, perceive its usefulness and ease of use, and subsequently make an adoption decision [4,5,13]. However, agentic commerce can operate differently. SMEs may adopt a digital platform for communication, marketing, payment, or customer engagement without making an explicit decision to adopt the autonomous or agentic capabilities embedded within that platform.

In such circumstances, participation in agentic commerce may occur indirectly and without deliberate recognition of the underlying technology. An SME owner may use a platform because it is familiar, convenient, or widely used by customers, while automated recommendations, personalized interactions, content generation, or other AI-mediated processes operate in the background. The owner therefore participates in an agentic commercial environment without necessarily identifying the activity as the adoption of agentic AI.

The concept of ambient participation therefore extends conventional adoption perspectives by distinguishing between deliberate technology adoption and embedded participation in technology-mediated environments. This distinction provides a basis for examining how SMEs can become participants in agentic commerce even when their awareness, digital capability, and intention to adopt agentic technologies remain limited.

This study addresses this empirical gap by examining how autonomous AI agent decision-making for everyday economic transactions shapes SME operations in Kandy, Sri Lanka. Three primary research objectives guide this inquiry: (1) to explore the lived experiences of SME owner-managers engaging with AI-mediated tools and agentic commerce platforms; (2) to assess their level of awareness regarding embedded AI algorithms in current operational workflows; and (3) to identify the key operational opportunities and socio-technical barriers surrounding AI agent adoption, with specific reference to supply chain management.

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Methods

Operational Definition of Agentic Commerce

For the purposes of this study, agentic commerce refers to digitally mediated commercial activity in which AI-enabled or autonomous capabilities contribute to one or more stages of the commercial process, including information discovery, product or service evaluation, recommendation, customer interaction, transaction support, or related decision-making [1,2]. The presence of a digital platform alone was therefore not treated as sufficient evidence of agentic commerce. Rather, attention was given to the extent to which AI-mediated or autonomous functionality was embedded within the platform or commercial interaction.

This distinction was important for differentiating ordinary digital commerce from participation in agentic commerce. The study therefore considered both participants' direct awareness of AI-enabled functionality and the presence of AI-mediated capabilities within the digital environments through which their commercial activities were conducted.

Study Design and Setting

The study was grounded in an interpretivist and constructivist paradigm and utilized a qualitative phenomenological design following Creswell [10] and Moustakas [11]. A phenomenological approach was selected because the primary research goal was to understand how SME owner-managers subjectively experience, interpret, and make sense of AI-mediated tools in their daily operational context, rather than measuring quantitative adoption rates or testing deterministic hypotheses. Fieldwork was conducted in Kandy District, Central Province, Sri Lanka, a region characterized by a diverse commercial landscape encompassing retail, food service, textile production, logistics, and traditional artisan manufacturing.

Participant Characteristics and Sampling

Fifteen SME owner-managers (designated P01 to P15) were purposively recruited across five anonymized small and medium-sized enterprises, designated SME-A through SME-E. To ensure thematic variation across different operational environments, sampling spanned five distinct industry sectors: retail (SME-A), food and beverage (SME-B), textiles (SME-C), logistics (SME-D), and handicrafts (SME-E). All participating firms met the Sri Lanka Small Enterprise Development Authority criteria for small and medium enterprises based on employee headcount and operational turnover. Eligibility required participants to serve as the primary operational decision-maker, ensuring that accounts of technology adoption reflected real authority over commercial strategy and daily workflows.

Table 1: Characteristics of Participating Small and Medium Enterprises (SMEs)

Enterprise Label	Industry Sector	Participant Identifiers	Primary Operational Focus
SME-A	Retail Trade	P01, P02, P03	Consumer goods retailing and local distribution
SME-B	Food & Beverage	P04, P05, P06	Perishable food processing and restaurant operations
SME-C	Textiles & Apparel	P07, P08, P09	Garment production and wholesale textile distribution
SME-D	Logistics & Freight	P10, P11, P12	Regional freight transport and cargo dispatching
SME-E	Handicrafts & Craft	P13, P14, P15	Artisanal manufacturing and tourist retail sales

Data Collection Procedures

Data collection integrated four distinct qualitative methods between January and April 2026 to achieve empirical triangulation and enhance analytical transferability. First, individual semi-structured in-depth interviews lasting 60 to 90 minutes were conducted with all fifteen participants. Interview schedules explored daily administrative workflows, digital platform usage, conceptual understanding of AI terminology, and perceived structural barriers to adopting autonomous digital tools.

Second, non-participant structured observation was carried out across each firm over a one-week period, recording how digital platforms were used during live transactions versus how participants described their usage. Third, document analysis was conducted on enterprise communication logs, procurement invoices, and social media analytics data to

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verify where platform-embedded AI mechanisms were active. All interviews were audio-recorded with participant consent and transcribed verbatim in Sinhala, then translated into English for analytical coding.

Focus Group Procedure

In addition to individual data collected from SME owner-managers, focus-group discussions were conducted to explore shared experiences and differences in perceptions of AI-enabled and agentic commerce. A total of two focus groups were conducted, involving six to eight participants per group and fifteen participants overall across the two sessions. Participants were grouped according to complementary commercial sectors (e.g., retail and handicrafts; logistics and textiles). Each discussion lasted approximately 75 minutes and followed a semi-structured discussion guide covering participants' awareness of AI, use of digital platforms, experiences with AI-enabled functionality, perceived benefits and barriers, and expectations regarding future adoption.

The discussions were audio-recorded with participants' consent, transcribed for analysis, and incorporated into the broader qualitative dataset. Focus-group material was analyzed alongside the other data sources and contributed to the development and refinement of the final themes.

Triangulation

Triangulation was used to strengthen the credibility of the interpretation by examining convergence and divergence across multiple sources of evidence. Participant accounts were considered alongside observational evidence, focus-group discussions, and relevant documentary or platform-level evidence. The purpose was not to assume that all sources would produce identical findings, but to identify areas of consistency as well as differences between participants' stated perceptions and their observed commercial practices. Investigator triangulation was also used during the coding and interpretation process, with two researchers independently reviewing the emerging codes and themes before reaching agreement on the final thematic structure.

Data Analysis and Credibility

Data were analyzed using Braun and Clarke's six-phase reflexive thematic analysis framework [12] within NVivo (Version 14). The analytical process progressed through data familiarization, initial code generation, searching for thematic clusters, reviewing candidate themes against raw transcripts, defining formal thematic definitions, and producing the narrative report. Initial coding adhered strictly to semantic participant accounts, transitioning to latent interpretative synthesis during later phases. Two researchers independently coded a subset of transcripts, achieving high preliminary agreement, and subsequently reconciled all coding variations to establish a unified codebook. A reflexive journal was maintained throughout the research process to document researcher positionality and analytical decision-making.

Data collection was concluded when the later interviews were no longer generating substantively new patterns relevant to the research questions and the developing thematic structure was sufficiently rich to support interpretation. The decision to conclude data collection was therefore based on the adequacy and depth of the emerging dataset rather than on a claim of statistical saturation.

Ethical Considerations

Formal institutional ethical approval was not obtained for this study. The research was conducted independently, and participants were informed of the purpose and nature of the study before data were collected. Participation was voluntary, and care was taken to protect the identity of participating individuals and organizations. No company names or personally identifying information are disclosed in the manuscript. Information obtained from participating organizations was treated as confidential and was not used for purposes that could intentionally damage the reputation, commercial interests, or competitive position of any participating organization. Participant identifiers such as P01, P02, and P03 are used in place of names. The reporting of findings was limited to information relevant to the research objectives, with particular care taken not to disclose commercially sensitive organizational information.

Results

Theme 1: Using AI Without Knowing It (Ambient and Shadow Adoption)

When asked to define artificial intelligence in operational terms, owner-managers across the participating enterprises associated the concept exclusively with futuristic technologies, describing it as “large multinational technology systems” or “factory robotics”. Participants displayed an absence of formal operational definitions for AI and did not explicitly associate their routine business technologies with artificial intelligence.

However, AI-mediated functionality was frequently observed across the commercial interactions examined in the study. These observations should be interpreted as contextual evidence of participants' exposure to AI-enabled commerce

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rather than as a statistically representative estimate of agentic-commerce adoption among SMEs. Three primary software ecosystems dominated daily operations: Facebook Business Suite, WhatsApp Business, and the Daraz ecommerce marketplace.

Participants across the five firms reported using WhatsApp Business for customer communication and automated catalog interactions. SMEs A, B, and E utilized Facebook Business Suite's automated target audience optimization and algorithmic post-scheduling. SME-D (logistics) depended on Daraz marketplace algorithms for demand prediction and dynamic price adjustment to optimize distribution schedules, without recognizing that machine learning models governed these processes. When presented with plain-language explanations of how these algorithms function, participants expressed surprise. P02 (SME-A) remarked:

> *"We use these Facebook and WhatsApp tools every day because everyone in Kandy uses them for business. I never thought of automated reply bots or customer reach suggestions as artificial intelligence—to us, it is just normal phone software."*

In contrast, P10 (SME-D) noted a more skeptical stance regarding platform automation:

> *"The Daraz system automatically suggests delivery slots and prices, which helps speed things up. But I do not fully trust automated systems to manage pricing without my oversight because local customers always expect direct personal negotiation."*

This variation indicates that while platform engagement is widespread, participants retain varying degrees of trust and reliance on automated functionality.

Theme 2: Supply Chain Inefficiencies and Operational Friction

The second major theme centered on structural supply chain inefficiencies. Participants across the firms identified manual or semi-manual inventory management as a significant operational bottleneck. SME-C (textiles) managed raw material inventory through physical ledgers. SME-A (retail) relied on manually updated spreadsheets with no automated reordering thresholds. SME-D (logistics) described procurement as reactive, initiating purchase orders after stock shortages occurred.

Procurement records validated these reported inefficiencies, showing inventory stockouts across participating firms due to delayed reordering. In SME-B (food & beverage), where inventory perishable windows are narrow, reactive purchasing resulted in material spoilage. When presented with a plain-language model of autonomous agentic procurement, wherein AI software monitors stock thresholds, compares supplier pricing, and autonomously generates purchase orders, participants expressed mixed reactions. P11 (SME-D) observed:

> *"An autonomous agent that checks supplier prices, places orders when stock gets low, and tracks shipping would save hours of phone calls every week. That kind of automation would solve our biggest daily operational headaches."*

Conversely, P07 (SME-C) expressed concern over autonomous procurement capabilities:

> *"Automated reordering sounds useful, but fabric quality varies between suppliers. An AI agent cannot feel the material or negotiate a discount when bulk buying. I would be hesitant to let software make purchase decisions without inspecting the stock myself."*

This variation demonstrates that while enthusiasm for efficiency gains exists, concerns regarding quality control and personal supplier relationships remain major considerations.

Theme 3: The Awareness and Adoption Paradox: Willingness vs. Structural Barriers

A central paradox emerged from the data: while owner-managers displayed high openness toward operational automation, structural socio-technical barriers constrained deliberate adoption. Three primary barriers were identified:

1. Perceived Financial Cost: Most participants cited capital expense as a primary barrier preventing deliberate AI adoption. Owners perceived AI tools as expensive enterprise software designed for large corporations. However, probing revealed that participants had rarely researched commercial pricing, indicating that cost barriers were largely perceptual, driven by media narratives. P04 (SME-B) noted:

> *"We assume advanced AI systems cost millions of rupees and require specialized servers. For a small business in Kandy, spent capital must go into physical inventory, not high-tech software."*

2. Language and Digital Literacy Deficits: A critical barrier was the compounding effect of low English-language proficiency and limited ICT literacy. Participants conducted daily operations predominantly in Sinhala and reported

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difficulty navigating complex English interfaces. Existing commercial AI agent tools feature English-centric user interfaces, creating an exclusion layer. P14 (SME-E) emphasized:

> *"If software is in English with technical jargon, my staff cannot use it properly. We need tools in Sinhala that speak our language and fit local trade practices."*

3. Institutional Support Vacuum: Participants reported an absence of external guidance. Participating enterprises had not received technical assistance, advisory services, or training on digital tools from government agencies, provincial trade chambers, or financial institutions. P12 (SME-D) remarked:

> *"All technology seminars and government programs happen in Colombo. Here in Kandy, no agency offers practical guidance on how small businesses can adopt new digital tools."*

Discussion

The findings of this study demonstrate a critical phenomenon in non-metropolitan SME ecosystems: substantive, daily engagement with AI-driven commercial platforms occurring alongside a limited explicit technological awareness. Participating owner-managers were actively embedded within agentic commerce frameworks. Algorithmic targeting on social channels directed their marketing reach, marketplace ranking algorithms governed their market exposure, and automated communication agents managed initial customer interactions. Crucially, this engagement did not result from deliberate strategic planning, but occurred passively through the baseline adoption of pervasive commercial platforms [9].

Integrating Existing Adoption Perspectives

The findings can be interpreted through several established technology-adoption perspectives, although none fully explains the phenomenon identified in this study [4,5,13]. The Technology–Organisation–Environment (TOE) framework helps explain the technological, organizational, and environmental conditions influencing SME engagement [4,13]. In the present context, technological accessibility and platform availability facilitate participation, while limited organizational ICT capability and weak external support constrain deeper engagement.

The Technology Acceptance Model (TAM) provides a useful explanation of participants' perceptions of usefulness and ease of use [4,13]. Participants generally recognized practical benefits associated with digital and AI-enabled tools, particularly in marketing, communication, and operational activities. However, perceived usefulness alone did not necessarily translate into conscious adoption of agentic technologies because participants were not always aware that autonomous or AI-mediated capabilities were embedded within the platforms they already used.

Similarly, the Unified Theory of Acceptance and Use of Technology (UTAUT) helps explain the importance of facilitating conditions, including access to infrastructure, knowledge, technical assistance, and organizational support [4,5]. Diffusion of Innovations (DOI) further helps distinguish participants according to their awareness, experimentation, and willingness to engage with emerging technologies [13]. Nevertheless, these perspectives largely assume that adoption involves some degree of awareness and recognition of the innovation being adopted [4,13].

The findings therefore suggest a limitation across conventional adoption perspectives: they provide useful explanations for technology acceptance and adoption but are less equipped to explain participation that occurs without explicit recognition of the underlying agentic capabilities. The concept of ambient participation addresses this gap by recognizing that SMEs may become involved in agentic commerce through ordinary use of digital platforms, even when conscious intention to adopt agentic AI is absent.

Regarding supply chain operations, the empirical findings closely align with recent developments in multi-agent systems research, which identifies inventory management, demand forecasting, and automated procurement as high-impact application areas for autonomous software agents [1,3]. The core operational pain points identified by Kandy SMEs—manual stock ledger tracking, reactive reordering, and inventory waste—are precisely the structural friction points that agentic commerce architecture is designed to resolve [1,2]. The primary bottleneck preventing implementation in regional Sri Lanka is not technological feasibility, but information asymmetry, inflated cost perceptions, and a lack of local technology brokers [4,14].

The awareness and adoption paradox observed in Kandy extends existing literature on enterprise digital transformation by adding a localized, non-metropolitan dimension [6,15]. While willingness to automate is high, provincial firms are constrained by an institutional support vacuum. The absence of provincial advisory programs, combined with language barriers in English-only AI interfaces, perpetuates regional digital inequality. This indicates that national AI readiness metrics mask severe intra-country disparities between Colombo and provincial commercial hubs such as Kandy [7,9].

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Comparison with South Asian SME Research

The findings from Kandy can be meaningfully compared with emerging evidence from other South Asian developing economies, particularly Bangladesh. Islam et al. [16] examined agentic artificial intelligence adoption among SMEs in Bangladesh using 14 semi-structured interviews with SME owners, technology experts, and government officials. Their findings identified limited knowledge and skills, inadequate infrastructure, high adoption costs, weak government support, and the absence of an appropriate legal framework as important barriers to agentic-AI adoption [16]. Several of these constraints are consistent with the present study. Kandy participants similarly described perceived financial costs, limited digital and language capabilities, and an institutional support vacuum as major obstacles to deliberate adoption.

However, an important difference emerges between the two contexts. The Bangladesh study primarily examines barriers to the deliberate adoption of agentic artificial intelligence, whereas the present study identifies participation in AI-mediated commercial environments that can occur before deliberate recognition or adoption. In other words, Bangladeshi SMEs in the existing study are examined in relation to their movement toward agentic-AI adoption, while the Kandy findings draw attention to a preceding or overlapping condition in which SMEs may already encounter AI-mediated functionality through routine platform use without identifying it as AI. This distinction supports the usefulness of the concept of ambient participation proposed in this study.

The findings can also be situated within broader evidence on SME digital transformation in South Asian developing economies. Existing Sri Lankan research demonstrates that digital transformation among SMEs is shaped not only by technological considerations but also by organizational and cultural conditions. For example, Sangarathas and Shanmugathas [9] found that family dynamics, traditional values, and intergenerational differences influenced digital transformation within a family-owned SME in Northern Sri Lanka. The present findings extend this contextual perspective by demonstrating that awareness and interpretation of AI-mediated technologies are also shaped by everyday business practices and local institutional conditions.

At a broader level, systematic research on AI adoption in developing-country SMEs indicates recurring constraints involving financial resources, technological capability, knowledge, organizational readiness, and external support [5]. The similarities between the Kandy and Bangladesh findings therefore suggest that some barriers may reflect broader developing-economy conditions rather than exclusively Sri Lankan characteristics. Nevertheless, the evidence should not be interpreted as demonstrating that all South Asian SMEs experience agentic commerce in the same way. Differences in infrastructure, language, institutional support, sectoral composition, digital ecosystems, and regulatory environments may produce substantially different adoption trajectories.

The comparison therefore suggests that the awareness–adoption relationship identified in Kandy has both regional and context-specific dimensions. Financial, capability, infrastructure, and institutional barriers appear to have parallels elsewhere in South Asia, while the concept of ambient participation provides a potentially distinctive explanation for how SMEs may engage with AI-mediated commercial environments before developing explicit awareness or adoption intentions. Comparative research across Sri Lanka, Bangladesh, India, Pakistan, and Nepal would be valuable for testing whether ambient participation represents a broader South Asian pattern or a contextually specific phenomenon.

Practical and Policy Implications

The findings suggest that increasing SME participation in agentic commerce requires an ecosystem-based intervention rather than isolated technology training. This recommendation is consistent with recent SME AI-adoption research, which identifies resources, knowledge, infrastructure, organizational capabilities and ecosystem conditions as interconnected determinants of AI implementation [4,5]. The evidence from Bangladesh further demonstrates that agentic-AI adoption in a developing South Asian context can be constrained by limited skills, inadequate infrastructure, high adoption costs, weak institutional support, and the absence of appropriate regulatory arrangements [16].

First, provincial SME development agencies should establish localized AI-readiness and adoption support programmes rather than relying primarily on national or Colombo-centred initiatives. These programmes could begin with an SME digital and AI-readiness assessment covering inventory management, customer communication, marketing, procurement, data availability, and existing use of AI-enabled platforms. The objective should be to identify practical business problems that can be addressed through affordable AI or agentic solutions rather than encouraging SMEs to adopt AI simply because it is technologically available.

Second, universities and higher-education institutions can function as regional knowledge intermediaries. Universities in Kandy could collaborate with chambers of commerce and SME development agencies to establish practical AI-literacy clinics in which business owners receive demonstrations using real SME workflows. Training should be delivered in Sinhala and, where appropriate, Tamil and English, and should focus on practical applications such as

demand forecasting, inventory alerts, customer-service automation, digital marketing, procurement assistance, and document processing rather than abstract explanations of artificial intelligence.

Third, chambers of commerce can provide the organizational network through which these interventions reach SMEs. Sector-specific workshops could bring together retailers, manufacturers, logistics providers, food businesses, and handicraft enterprises to demonstrate how AI-enabled and agentic systems can be integrated into existing workflows. Such programmes would also provide opportunities for peer learning, allowing SME owners to observe locally relevant applications rather than relying on examples developed for large multinational organizations.

Fourth, technology providers should participate in these programmes through low-cost pilot implementations. Rather than requiring SMEs to make substantial upfront investments, providers could offer short-term demonstrations or controlled pilot projects in areas such as automated inventory monitoring, demand forecasting, customer communication, and procurement support. This would allow SME owners to evaluate actual benefits and risks before committing to longer-term adoption. A phased approach is particularly appropriate because SME AI-adoption research identifies financial constraints, technical capability and organizational readiness as persistent barriers [4,5].

Fifth, financial institutions and SME financing agencies could support adoption through targeted digital-transformation financing. Instead of treating AI adoption as a generic technology purchase, financing schemes could support clearly defined productivity-enhancing projects, including inventory automation, digital accounting, AI-enabled customer management, and agentic procurement pilots. Such mechanisms could reduce the gap between perceived affordability and actual affordability identified in the present study.

Finally, these actors should operate through a coordinated provincial ecosystem rather than independent programmes. A practical model would involve four stages: (1) SME AI-readiness assessment conducted through SME agencies and chambers; (2) AI-literacy and workflow training delivered by universities; (3) low-cost technology pilots implemented with technology providers; and (4) financing and scale-up support provided by financial institutions and development agencies. This collaborative model would address the combination of knowledge, capability, cost and institutional barriers identified in the present study and in comparable developing-economy research [5,16].

Methodological Limitations and Future Research Directions

The findings should be interpreted in relation to the specific institutional, economic, technological, and geographic context in which the study was conducted. The purposive sample of fifteen owner-managers across five SMEs provides depth of contextual understanding but does not support statistical generalization to the wider Sri Lankan SME population. The concentration on SMEs within Kandy District also limits transferability to businesses operating in Colombo and other highly urbanized or technologically developed settings.

Similarly, differences in sector, firm size, owner-manager characteristics, digital capability, and access to external support may shape how SMEs experience agentic commerce. Additionally, fieldwork was conducted during Sri Lanka's post-crisis economic recovery period, during which acute capital constraints may have heightened participants' sensitivity to perceived technology costs. The findings should therefore be understood as analytically transferable insights rather than population-level estimates.

Conclusions

This study examined how SMEs in Kandy engage with emerging forms of agentic commerce and how their awareness, organizational capabilities, and external environment shape this engagement. The findings indicate a distinction between awareness of artificial intelligence and participation in AI-mediated commercial environments. Participants generally recognized AI as an important technological development, yet their understanding of agentic functionality was comparatively limited. At the same time, AI-enabled capabilities were encountered through digital platforms already incorporated into routine commercial activities.

The study's principal theoretical contribution is the concept of ambient participation, which highlights that engagement with agentic commerce does not always result from a deliberate decision to adopt agentic AI. SMEs may participate in AI-mediated commercial environments through their ordinary use of digital platforms, while remaining only partially aware of the autonomous or AI-enabled processes operating within those environments. This extends conventional adoption perspectives, including TOE, TAM, UTAUT, and Diffusion of Innovations, by drawing attention to participation that can occur without explicit recognition of the underlying technology [4,5,13].

From a practical perspective, improving SME participation in agentic commerce requires more than simply increasing awareness of AI. Support should address digital capability, affordability, trust, infrastructure, access to appropriate training, and the availability of local technical assistance. Universities and training institutions can contribute through practical AI-literacy programs, while SME development agencies, chambers of commerce, technology providers, and

financial institutions can support implementation through training, advisory services, accessible technology packages, and appropriate financing mechanisms.

Future research should examine whether the patterns identified in Kandy are observable across other Sri Lankan regions and sectors. Longitudinal studies could also examine whether increased AI literacy and exposure to agentic technologies lead to more deliberate adoption over time. Quantitative studies could subsequently test the relationships identified qualitatively and evaluate the explanatory value of ambient participation alongside established technology-adoption constructs.

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References

1. Jannelli V, Schöpf S, Bickel M, Netland T, Brintrup A. Agentic LLMs in the supply chain: towards autonomous multi-agent consensus-seeking. *Int J Prod Res*. 2025;63(22):8401–8425. doi:10.1080/00207543.2025.2604311.

2. DB K, Kuppan K, Divya B. Agentic AI: autonomous intelligence for complex goals, a comprehensive survey. *IEEE Access*. 2025;13:18912–18936. doi:10.1109/ACCESS.2025.3532853.

3. Wang L, Chen X, Deng X, Wen H, You M, Liu W, et al. Towards autonomous supply chains: definition, characteristics, conceptual framework, and autonomy levels. *J Ind Inf Integr*. 2024;42:100678. doi:10.1016/j.jii.2024.100678.

4. Schwäke J, Peters A, Kanbach DK, Kraus S, Jones P. The new normal: the status quo of AI adoption in SMEs. *J Small Bus Manag*. 2025;63(3):1297–1331. doi:10.1080/00472778.2024.2379999.

5. Kasigit L, Akhlaghpour S, Karanasios S. AI adoption by SMEs in developing countries: challenges, applications, and benefits. *ACIS 2025 Proceedings*. 2025;271.

6. Yesuf Y, Fields Z, Jain A, Kassa E. Artificial intelligence adoption as a driver of innovation and competitiveness in SMEs: a bibliometric and systematic review. *F1000Research*. 2025;14:1247. doi:10.12688/f1000research.171494.1.

7. Mohanan A, Perera N, Wijesinghe R. AI-driven business model innovation in South Asian SMEs: comparative insights and implications. *J Risk Financ Manag*. 2025;18(12):709. doi:10.3390/jrfm18120709.

8. Dissanayake DMR. Digital transformation for small and medium enterprises with special focus on Sri Lankan context as an emerging economy. *Int J Bus Manag Rev*. 2019;7(4):55–76.

9. Sangarathas D, Shanmugathas S. Human-centric digital transformation in Industry 5.0: a phenomenological study of family-owned SME in Sri Lanka. *Electron J Inf Syst Dev Ctries*. 2025;91(4):e70026. doi:10.1002/isd2.70026.

10. Creswell JW. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. 3rd ed. Thousand Oaks, CA: SAGE Publications; 2013.

11. Moustakas C. *Phenomenological Research Methods*. Thousand Oaks, CA: SAGE Publications; 1994.

12. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol*. 2006;3(2):77–101. doi:10.1191/1478088706qp063oa.

13. Sánchez E, Herrera F, Calderón R. Artificial intelligence adoption in SMEs: survey based on the TOE–DOI framework, primary methodology and challenges. *Appl Sci*. 2025;15(12):6465. doi:10.3390/app15126465.

14. Ayinaddis SG. Artificial intelligence adoption dynamics and knowledge in SMEs and large firms: a systematic review and bibliometric analysis. *J Innov Knowl*. 2025;10(2):100682. doi:10.1016/j.jik.2025.100682.

15. Cimino A, Longo F, Mirabelli G, Solina V. Artificial intelligence adoption for sustainable growth in SMEs: an extended dynamic capability framework. *Corp Soc Responsib Environ Manag*. 2025;32(5):4821–4838. doi:10.1002/csr.70019.

16. Islam MA, Rahman M, Dal Mas F, Haque SE, Hani U. Navigating institutional and capability barriers in agentic artificial intelligence adoption: evidence from small and medium enterprises in Bangladesh. *VINE J Inf Knowl Manag Syst*. 2026:1–25. doi:10.1108/VJIKMS-11-2025-0504.

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OP 16

Implementation of Grover's Algorithm with Error Mitigation Techniques on Quantum Hardware

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Abstract

Grover's search algorithm offers a provable quadratic speedup over classical unstructured search, making it a canonical benchmark for evaluating near-term quantum hardware. This paper presents an empirical implementation of a 2-qubit Grover's circuit targeting the state |11⟩ on real IBM Quantum superconducting hardware (backend: ibm_kingston, accessed 2026-05-05; see "Hardware Configuration and Reproducibility Details" for a supplementary cross-check run) via the IBM Quantum API free tier. The experiment investigates the degradation of algorithmic performance under realistic noise conditions characteristic of Noisy Intermediate-Scale Quantum (NISQ) devices and evaluates two lightweight post-processing error mitigation strategies: circuit repetition with result aggregation, and majority voting across independent runs. Experimental results reveal a pronounced and consistent hardware bias toward the ground state |00⟩ attributable primarily to qubit relaxation (T_1 decay) and two-qubit gate infidelities of the Controlled-Z (CZ) gate which nearly equalizes the measured probability of |00⟩ and the target |11⟩. While circuit repetition improves distributional stability by averaging out stochastic fluctuations, it fails to correct the underlying systematic bias. Majority voting, rather than mitigating this bias, amplifies it deterministically, selecting the incorrect state |00⟩ with unanimous confidence across all five independent runs. These findings underscore a fundamental limitation of classical post-processing mitigation methods in the presence of systematic hardware-level errors and motivate the adoption of more sophisticated techniques such as zero-noise extrapolation (ZNE), probabilistic error cancellation (PEC), and dynamical decoupling (DD) for future work. This study contributes empirical evidence to the broader discourse on the practical limitations of quantum algorithm execution on current NISQ devices and highlights the critical importance of matching mitigation strategies to both the noise model and the error-correlation structure of the target hardware. Benchmarking against ideal and noise-model simulators (see "Hardware Configuration and Reproducibility Details") further isolates how much of the observed degradation is attributable to hardware-specific noise versus expected NISQ-level decoherence. A supplementary run repeating the full methodology on a different backend and date produced the opposite bias direction, with the hardware achieving over 92% success on the correct target state and majority voting correctly converging on it in all five repetitions — demonstrating that majority voting's apparent confidence is not itself evidence of correctness, and that the direction and magnitude of systematic bias on NISQ hardware is calibration- and backend-dependent rather than fixed.

Keywords: Grover's Algorithm, Quantum Error Mitigation, NISQ Devices, IBM Quantum Hardware, Quantum Circuit Noise

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Introduction

Motivation and context

Advancement of quantum computing has created new opportunities to experimentally validate algorithms that were once confined to theoretical analysis. Grover's search algorithm [9] is one of the most fundamental demonstrations of quantum advantage, yet a critical gap remains between its theoretical promise and real hardware performance. Current quantum processors operate in the Noisy Intermediate-Scale Quantum (NISQ) era [10], characterized by short coherence times and non-negligible gate error rates that significantly degrade algorithmic correctness. This study is motivated by the need to empirically characterize this degradation on real quantum hardware, moving beyond classical simulation. Using IBM Quantum real hardware accessed via the free-tier API and implementing the experimental 2-qubit circuit through Qiskit, this work evaluates two accessible error mitigation strategies circuit repetition and majority voting to assess their effectiveness under realistic noisy conditions and inform better mitigation choices for near-term quantum devices.

Novelty and Positioning Relative to Prior Work

Grover's algorithm has been implemented on IBM Quantum systems in numerous prior studies, and a 2-qubit demonstration is not in itself novel. The contribution of this work is narrower and more specific: it directly compares how two distinct, low-cost classical post-processing strategies — circuit repetition and majority voting — respond to the same underlying systematic hardware bias. Prior studies have generally evaluated such mitigation techniques in isolation or against random, uncorrelated noise. This study shows empirically that these two techniques do not fail in the same way: repetition merely fails to correct systematic bias, whereas majority voting actively amplifies it into a unanimous, high-confidence wrong answer. This distinction has direct practical value for researchers on free-tier or resource-constrained hardware deciding which lightweight mitigation strategy, if any, is worth applying before investing in more sophisticated methods such as ZNE or PEC.

Research Questions

This study addresses the following central research question: how effective are circuit repetition and majority voting as error mitigation techniques in preserving the correctness of Grover's search algorithm when executed on real IBM Quantum hardware, and do the two techniques respond differently to systematic versus stochastic sources of error?

Contributions

This study contributes an empirical implementation of Grover's search algorithm on real IBM Quantum superconducting hardware via the free-tier API, using a 2-qubit Qiskit circuit targeting the state $|11\rangle$. It evaluates circuit repetition and majority voting as error mitigation strategies under realistic NISQ noise conditions, demonstrating that systematic hardware bias driven by qubit relaxation and CZ gate infidelities cannot be corrected through classical post-processing alone. Notably, the results reveal that majority voting deterministically amplifies systematic bias rather than correcting it, providing practically actionable insights for selecting appropriate mitigation strategies on near-term quantum devices.

Scope and Limitations

The implementation is restricted to a 2-qubit Grover's circuit with a single target state $|11\rangle$ and a single Grover iteration. Results may not generalize to larger qubit systems or multi-solution search problems.

Hardware access was limited to IBM Quantum's free-tier API, which does not permit selection of specific quantum processors or priority job scheduling, meaning circuit execution was subject to queue times and variable device calibration states.

Only two error mitigation techniques, circuit repetition and majority voting were evaluated. More advanced methods such as zero-noise extrapolation (ZNE), probabilistic error cancellation (PEC), and dynamical decoupling (DD) were beyond the scope of this study.

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No quantum error correction codes were employed, as the available qubit count and circuit depth constraints of the free-tier hardware made this impractical.

The study does not perform full quantum state tomography or device characterisation and therefore cannot precisely quantify individual error sources such as T_1, T_2, or gate fidelity independently; Section "Hardware Configuration and Reproducibility Details" reports backend-level calibration values to partially address this.

Findings are specific to the backend and calibration window used in this study; because IBM Quantum device calibration is refreshed periodically, absolute bias magnitudes are not expected to reproduce exactly on a different backend or at a different time, though the qualitative direction of the bias (toward $|00\rangle$ via T_1 relaxation) is expected to generalize.

Methods

Experimental Design

This study follows an experimental research design, in which a 2-qubit Grover's search algorithm was implemented and executed on real IBM Quantum superconducting hardware. The experiment was conducted in three phases.

In the first phase, the baseline circuit was executed on real IBM Quantum hardware without any error mitigation, using 1000 shots to obtain the initial measurement distribution. This established the noise profile of the hardware and served as a reference for evaluating subsequent mitigation strategies.

In the second phase, circuit repetition was applied by executing the same circuit five independent times, each with 1000 shots, yielding 5000 total measurements. Results were aggregated across all runs to assess whether repeated execution could stabilize the output distribution.

In the third phase, majority voting was applied to the five independent runs, where the most frequently measured state from each run was identified, and a final answer was determined based on the majority outcome across all repetitions.

All circuits were constructed using Qiskit and transpiled to match the native gate set and qubit connectivity constraints of the target IBM Quantum processor. The oracle was implemented using a Controlled-Z (CZ) gate to mark the target state $|11\rangle$, and the diffusion operator was constructed following the standard inversion-about-the-mean formulation. Hardware access was obtained through the IBM Quantum free-tier API, with no control over device selection or calibration scheduling.

Hardware Configuration and Reproducibility Details

The following configuration details are reported to support reproducibility, in line with reviewer recommendations.

Backend name: ibm_kingston (primary run, 2026-05-05); ibm_fez (supplementary validation run, 2026-08-04 -- see note below)

Execution date(s): 2026-05-05 (primary run, ~09:33 UTC); 2026-08-04 (supplementary validation run, ~19:55 UTC)

Transpilation optimization level: 1 (both runs)

Qubit mapping (physical indices used): Not logged for the primary run (2026-05-05); the notebook did not record the transpiler's qubit mapping at execution time. For the supplementary run (ibm_fez, 2026-08-04), logical qubits [0,1] mapped to physical qubits [0,1].

Circuit depth and gate count after transpilation: Not logged for the primary run. Supplementary run (ibm_fez, 2026-08-04): depth 12; gate counts {rz: 12, sx: 6, cz: 2, measure: 2}.

T_1 and T_2 coherence times (qubit 0 / qubit 1): Not available for the primary run; backend calibration was not queried at execution time, and ibm_kingston's calibration will have since drifted, so present-day values would not represent the

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2026-05-05 state. Supplementary run (ibm_fez, 2026-08-04): qubit 0 T_1 = 52.98 µs, T_2 = 53.13 µs; qubit 1 T_1 = 211.80 µs, T_2 = 234.60 µs.

Readout error rates (qubit 0 / qubit 1): Not available for the primary run (same reason as above). Supplementary run (ibm_fez, 2026-08-04): qubit 0 = 1.21%, qubit 1 = 2.14%.

CZ gate error: Not available for the primary run. Supplementary run (ibm_fez, 2026-08-04): CZ error = 0.74% (gate duration 68 ns).

During the revision process, it was discovered that the notebook used for the primary run (2026-05-05) did not query backend.properties() or record the job ID at execution time, so the calibration snapshot and transpiled-circuit details for that specific run cannot be retroactively reconstructed — IBM Quantum backend calibration is refreshed periodically, so today's values for ibm_kingston would not accurately represent its state on 2026-05-05. This gap is itself a concrete illustration of the exact reproducibility concern raised in review: without a logged job ID and calibration snapshot, a hardware result cannot be independently re-verified after the fact. The data-capture code was corrected following this discovery (job ID, timestamp, qubit mapping, circuit depth/gate count, and backend calibration are now logged automatically at execution time); the supplementary run below was collected with the corrected pipeline and is reported separately, on its own backend and date, rather than merged with the primary run's results.

Results

4.1 Impact of Quantum Noise on Grover's Algorithm

Hardware noise nearly equalized the measurement probability of |00⟩ and |11⟩, driven primarily by qubit relaxation (T_1 errors) and CZ gate infidelities, effectively disrupting Grover's amplitude amplification.

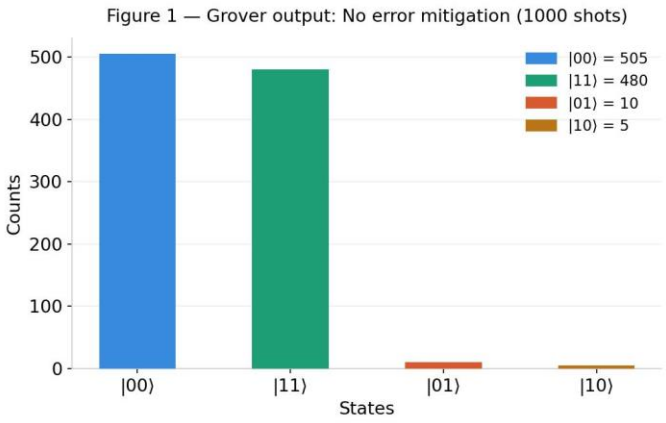

Figure 14Grover's algorithm output with no error mitigation. Both |00⟩ (≈505 counts) and |11⟩ (≈480 counts) show near-equal frequencies, indicating strong hardware noise.

Benchmark Comparison: Ideal Simulator vs. Noisy Simulator vs. Real Hardware

To isolate hardware-specific noise from expected NISQ-level decoherence, the same circuit was additionally run on an ideal, noiseless simulator. As explained above, a noise-model simulator matched to the primary run's actual calibration state could not be reconstructed after the fact; a noisy-simulator estimate is instead reported for the supplementary run below, which used the corrected data-capture pipeline throughout.

Ideal simulator (noiseless), computed independently for this revision — |00⟩: 0, |11⟩: 1000 (100%), |01⟩: 0, |10⟩: 0 (1000 shots; deterministic and date-independent)

Noisy simulator (backend noise model): not reconstructable for the primary run's calibration state (see reproducibility note above)

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Real hardware, primary run (ibm_kingston, 2026-05-05, aggregated 5000 shots) — |00⟩: 2535 (50.7%), |11⟩: 2384 (47.7%), |01⟩: 49 (1.0%), |10⟩: 32 (0.6%)

Supplementary validation run (ibm_fez, 2026-08-04, corrected data-capture pipeline):

Ideal simulator (noiseless) — |11⟩: 1000 (100%)

Noisy simulator (backend noise model, ibm_fez calibration) — |00⟩: 7 (0.7%), |11⟩: 944 (94.4%), |01⟩: 27 (2.7%), |10⟩: 22 (2.2%)

Real hardware, baseline (1000 shots) — |00⟩: 7 (0.7%), |11⟩: 928 (92.8%), |01⟩: 25 (2.5%), |10⟩: 40 (4.0%)

Real hardware, aggregated (5000 shots across 5 repetitions) — |00⟩: 34 (0.7%), |11⟩: 4643 (92.9%), |01⟩: 135 (2.7%), |10⟩: 188 (3.8%)

Majority voting outcome: |11⟩ selected in 5/5 runs (correct)

4.2 Effectiveness of Circuit Repetition

Circuit repetition improved statistical stability across 5000 total shots but failed to eliminate the persistent systematic bias favoring |00⟩ over the correct target state |11⟩.

A 95% confidence interval per state requires the five individual per-run counts rather than only the aggregated total; these were not retained separately for the primary run (2026-05-05), so a formal interval cannot be retroactively computed for it — only the aggregate reported in Table 1 is available. For the supplementary run (ibm_fez, 2026-08-04), where per-run counts were retained, the 95% confidence interval (mean proportion across the five 1000-shot runs, ± 1.96×SE) is: |00⟩ mean = 0.0068, CI = [0.0040, 0.0096]; |01⟩ mean = 0.0270, CI = [0.0234, 0.0306]; |10⟩ mean = 0.0376, CI = [0.0269, 0.0483]; |11⟩ mean = 0.9286, CI = [0.9145, 0.9427]. The tight intervals around each state indicate the bias direction was consistent and non-random across the five repetitions of that run.

Table 11 Aggregated measurement counts after circuit repetition (5 runs, 1000 shots each).

State	Count	Probability (%)
|00⟩	2535	50.7%
|11⟩	2384	47.7%
|01⟩	49	1.0%
|10⟩	32	0.6%

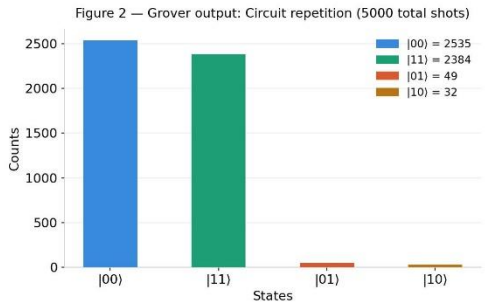

Figure 15 Aggregated Grover output after circuit repetition (5000 total shots). The |00⟩ state still dominates, revealing systematic hardware bias.

Limitations of Majority Voting Under Systematic Bias

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Majority voting unanimously selected |00⟩ across all five runs, deterministically amplifying the systematic hardware bias rather than correcting it, confirming it is only effective against random stochastic errors.

Table 12 Winning state per repetition under majority voting.

Repetition	Winning State
1	|00⟩
2	|00⟩
3	|00⟩
4	|00⟩
5	|00⟩
Final Majority Vote: |00⟩	

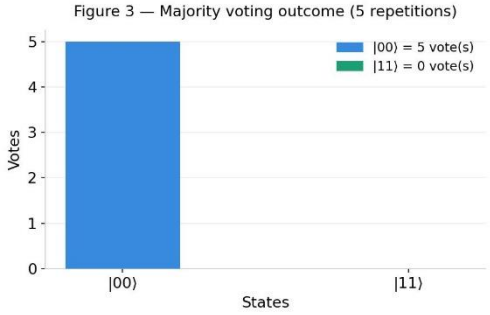

Figure 16 Majority voting outcome across 5 repetitions. |00⟩ received all 5 votes, demonstrating how majority voting amplifies systematic bias rather than correcting it.

Discussion

5.1 Impact of Quantum Noise on Grover's Algorithm

The experimental results reveal that quantum noise on IBM Quantum hardware significantly degraded the performance of Grover's algorithm, reducing what should theoretically be a near-deterministic outcome into a near-uniform distribution between |00⟩ and |11⟩. This finding is consistent with previous experimental observations, where real-hardware implementations of Grover's algorithm on superconducting quantum processors achieved success rates close to 51%, closely matching the approximately 48% success rate observed in this study [2]. The dominant noise source was identified as qubit relaxation (T_1 decay), which introduces systematic bias toward the ground state |00⟩, as qubits in excited states tend to decay before measurement. This effect is further compounded by CZ gate infidelities, which remain a well-documented limitation of NISQ-era quantum hardware, where two-qubit gate error rates typically range between 1–5% per operation [6]. Similar findings have shown that Grover's algorithm is particularly sensitive to noise due to circuit depth, often resulting in noise overwhelming the expected computational signal, which is directly reflected in Figure 1 of this study [6]. Additionally, readout noise contributed to the appearance of non-target states |01⟩ and |10⟩, which theoretically should remain near-zero following amplitude amplification.

5.2 Effectiveness of Circuit Repetition

As shown in Table 1 and Figure 2, repeated circuit execution improved statistical stability of the measurement distribution. However, systematic bias persisted, with |00⟩ consistently maintaining a lead over the correct target state |11⟩ across every run. This outcome aligns with previous findings demonstrating that classical post-processing mitigation strategies which fail to account for correlated hardware errors provide limited improvement in Grover's algorithm performance [5]. Circuit repetition is effective primarily against random stochastic fluctuations through statistical averaging. Since the dominant error in this experiment originated from systematic hardware-level qubit

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relaxation rather than random gate noise, repetition alone could not recover the correct algorithmic output. Previous work similarly identified circuit depth and two-qubit gate count as major contributors to noise accumulation in NISQ devices, emphasizing that mitigation strategies must specifically target hardware-dependent noise behavior to be effective [1].

Limitations of Majority Voting Under Systematic Bias

The majority voting results presented in Table 2 and Figure 3 demonstrate one of the most significant findings of this study. Majority voting unanimously selected |00⟩ across all five independent repetitions, producing an incorrect result with complete confidence. This occurred because systematic hardware bias consistently produced marginally higher |00⟩ counts than |11⟩ in every individual run, causing the voting mechanism to amplify the bias rather than correct it. Previous experimental studies support this observation, demonstrating that coherent and systematic errors can dominate over stochastic noise at similar fidelity levels, rendering statistical aggregation methods ineffective and, in some cases, counterproductive [7]. It has also been demonstrated that measurement error mitigation alone is insufficient for achieving correct Grover outputs on IBM hardware, and that more advanced suppression techniques are required [3]. These findings collectively highlight that majority voting, while effective against random bit-flip errors, is fundamentally unsuitable when underlying noise sources are systematic. Future implementations should therefore consider zero-noise extrapolation (ZNE) or dynamical decoupling (DD), both of which have demonstrated measurable improvements in Grover algorithm fidelity on IBM Quantum systems [3,8].

Cross-Run Comparison: Backend- and Calibration-Dependent Bias Direction

A supplementary run of the identical circuit and methodology, conducted on a different backend (ibm_fez) on 2026-08-04, produced a strikingly different outcome from the primary run reported above: rather than a near-even split biased toward |00⟩, the hardware achieved 92.8–92.9% success on the correct target state |11⟩ across both the baseline and aggregated-repetition measurements, closely tracking the corresponding noisy-simulator estimate of 94.4%. Majority voting on this run selected |11⟩ unanimously and correctly in all five repetitions — the opposite outcome to the primary run, where it selected the incorrect |00⟩ unanimously.

This reversal is best explained by hardware calibration drift between the two sessions: the supplementary run's backend reported a low CZ gate error (0.74%) and moderate-to-long T_1/T_2 times, consistent with the near-ideal performance observed, whereas no calibration snapshot exists for the primary run to confirm the source of its more pronounced bias. Because IBM Quantum's free-tier access does not permit backend selection and calibration is refreshed on an independent schedule, two executions of the same circuit, weeks apart and on different hardware, can land on opposite sides of the |00⟩/|11⟩ boundary.

This comparison sharpens rather than weakens the paper's central finding about majority voting. Across the two runs, majority voting did not behave as an error-correction mechanism at all: it simply reported whichever state already held a plurality in a given calibration window, right or wrong, with unanimous five-out-of-five confidence either way. A researcher relying on majority voting alone, without an independent check such as an ideal-simulator comparison, would have no way to distinguish the correct unanimous result (supplementary run) from the incorrect one (primary run) — both look identical in form. This is precisely the systematic-bias failure mode described in Section 5.3, now demonstrated empirically in both directions, and it directly motivates the reproducibility reporting requested in review: without a logged backend, execution date, and calibration snapshot, a majority-voting result on NISQ hardware cannot be judged trustworthy after the fact.

Comparative Outlook: ZNE, PEC, and Dynamical Decoupling

The three advanced mitigation techniques identified as future work differ meaningfully in expected benefit and implementation cost for a 2-qubit, free-tier setting. Zero-noise extrapolation (ZNE) [11] requires running the circuit at multiple artificially amplified noise levels and extrapolating back to the zero-noise limit; it is comparatively simple to implement in Qiskit via built-in resilience options and directly targets the coherent and relaxation-driven bias observed in this study, making it the most promising near-term addition. Probabilistic error cancellation (PEC) offers stronger

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theoretical guarantees but requires a full characterization of the noise channel, which is costly in shots and generally impractical on free-tier hardware, since sampling overhead grows exponentially with circuit noise strength. Dynamical decoupling (DD) inserts idle-time pulse sequences to suppress dephasing and is comparatively cheap to apply, but because the dominant error identified in Section 5.1 is T_1 relaxation rather than dephasing (T_2-limited) error, DD alone would be expected to offer only partial benefit here. Taken together, ZNE is the most cost-effective next step for this experimental setup, with DD as a complementary, low-cost addition; PEC is likely out of reach under free-tier shot budgets.

Computational Cost and Resource Trade-offs

Circuit repetition's principal cost is linear in the number of repetitions: five repetitions of 1000 shots required five separate job submissions, each subject to independent free-tier queue delays. Per-job timing was not recorded for the primary run (2026-05-05). For the supplementary run (ibm_fez, 2026-08-04), per-job wall-clock time (submission to result, which includes both queueing and execution and so should be read as an upper bound on queue time alone) averaged 1.0 s (std 0.4 s; range 0.6–1.8 s across the five jobs) — notably fast, likely reflecting a lightly loaded backend at that particular time rather than a representative free-tier queue wait. Because repetition did not correct the systematic bias observed in the primary run, the additional shot budget and wait time it consumed produced limited practical benefit in that setting, whereas methods such as ZNE would use a comparable or smaller shot budget while directly targeting the bias mechanism.

Conclusions

This study presented an empirical implementation of Grover's search algorithm on real IBM Quantum superconducting hardware through the free-tier API, evaluating circuit repetition and majority voting as error mitigation strategies on a 2-qubit system targeting the state $|11\rangle$. The results demonstrated that while Grover's algorithm functions correctly in theory, hardware noise driven primarily by qubit relaxation (T_1 decay) and CZ gate infidelities significantly disrupted the amplitude amplification process, producing a near-uniform measurement distribution between $|00\rangle$ and $|11\rangle$ [2,6].

The findings further showed that circuit repetition provided only marginal statistical stability, while majority voting deterministically amplified systematic hardware bias and repeatedly selected the incorrect state with full confidence [5,7]. These outcomes confirm that both mitigation techniques, although useful and computationally accessible for small-scale circuits, remain insufficient for overcoming systematic noise on near-term NISQ devices — and, in the case of majority voting, can actively mislead a researcher relying on it. A supplementary run repeating the full methodology on a different backend and date reinforced this point from the opposite direction: majority voting converged unanimously on the correct answer that time, but with no more evidence of reliability in its output than the incorrect unanimous result from the primary run — confirming that unanimous agreement across repetitions is not, by itself, a signal of correctness on NISQ hardware.

Nevertheless, this work serves as a foundational experimental reference for researchers exploring quantum algorithm performance under realistic hardware noise conditions. Future work should move beyond classical post-processing methods and investigate more advanced mitigation techniques better suited for deeper and larger quantum circuits, including zero-noise extrapolation (ZNE), probabilistic error cancellation (PEC), dynamical decoupling (DD), and readout error mitigation through detector tomography [3,5,8]. As quantum hardware continues to improve in coherence time and gate fidelity, these techniques are expected to produce increasingly reliable results, bringing practical quantum search implementations closer to their theoretical potential.

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References

1. Zhang K, Rao P, Yu K, Lim H, Korepin V. Implementation of efficient quantum search algorithms on NISQ computers. Quantum Inf Process. 2021;20:1-27. doi:10.1007/s11128-021-03165-2.

2. AbuGhanem M. Characterizing Grover search algorithm on large-scale superconducting quantum computers. Sci Rep. 2025;15:1281. doi:10.1038/s41598-024-80188-6.

3. Pokharel B, Lidar DA. Better-than-classical Grover search via quantum error detection and suppression. npj Quantum Inf. 2024;10:23. doi:10.1038/s41534-023-00794-6.

4. Mandviwalla A, Ohshiro K, Ji B. Implementing Grover's algorithm on the IBM quantum computers. In: 2018 IEEE International Conference on Big Data (Big Data). IEEE; 2018:2531-2537. Available from: https://people.cs.vt.edu/boji/papers/REU2018.pdf

5. Maciejewski FB, Zimborás Z, Oszmaniec M. Mitigation of readout noise in near-term quantum devices by classical post-processing based on detector tomography. Quantum. 2020;4:257. doi:10.22331/q-2020-04-24-257.

6. El Kaderi Y, Honecker A, Andriyanova I. Performance of uncoded implementation of Grover's algorithm on today's quantum processors. In: 2023 IEEE Information Theory Workshop (ITW). 2023:209-214. arXiv [Preprint]. 2022. Available from: https://arxiv.org/abs/2212.10482

7. Ishii M, Qassim H, Kurita T, Emerson J, Maruyama K, Oshima H, Sato S. Implementation and verification of coherent error suppression using randomized compiling for Grover's algorithm on a trapped-ion device. arXiv [Preprint]. 2025. Available from: https://arxiv.org/abs/2503.05344

8. Pelofske E, Russo V, LaRose R, Mari A, Strano D, Bärtschi A, Eidenbenz S, Zeng WJ. Increasing the measured effective quantum volume with zero-noise extrapolation. ACM Trans Quantum Comput. 2024;5(3):21. doi:10.1145/3680290.

9. Grover LK. Quantum mechanics helps in searching for a needle in a haystack. Phys Rev Lett. 1997;79:325-328. doi:10.1103/PhysRevLett.79.325.

10. Preskill J. Quantum computing in the NISQ era and beyond. Quantum. 2018;2:79. doi:10.22331/q-2018-08-06-79.

11. Kandala A, Temme K, Córcoles AD, Mezzacapo A, Chow JM, Gambetta JM. Error mitigation extends the computational reach of a noisy quantum processor. Nature. 2019;567:491-495. doi:10.1038/s41586-019-1040-7.

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OP 17

Comparative Analysis of Machine Learning Models for Forecasting Pharmacy Inventory Requirements

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Abstract

Background: Effective pharmacy inventory management is essential for maintaining medicine availability while reducing overstocking, stockouts, expiry-related wastage and unnecessary holding costs. Many small and medium pharmacy settings still depend on manual stock review, which may not adequately capture product-wise and month-wise inventory variation.

Objective/s: This study aimed to compare selected machine learning models for forecasting future pharmacy inventory requirements using historical monthly stock records.

Methods: Monthly pharmacy stock reports from November 2024 to March 2026 were integrated and preprocessed. The final aggregated dataset contained 11,475 month-product records covering 789 products. A supervised learning dataset was created by using current and lagged inventory features to predict the next month stock quantity. Linear Regression, Decision Tree, Random Forest and XGBoost regressors were trained using a chronological 80:20 train-test split and evaluated using mean absolute error (MAE), root mean squared error (RMSE) and coefficient of determination (R^2).

Results: XGBoost achieved the best overall performance with the lowest RMSE of 228.0499 and the highest R^2 of 0.7611. Decision Tree achieved an RMSE of 245.0748, Random Forest achieved 259.8493 and Linear Regression achieved 266.6767. Feature importance analysis indicated that current stock quantity and recent lag-based stock features were major contributors to prediction.

Conclusion/s: The findings indicate that machine learning, particularly gradient boosting, can support pharmacy inventory forecasting by modelling non-linear stock patterns. The approach can assist stock planning decisions, although direct sales demand data and external validation would further strengthen future work.

Keywords: *Forecasting, inventory management, machine learning, pharmacy, XGBoost*

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Introduction

Pharmacies require reliable inventory control to ensure that essential medicines are available when patients need them. Poor inventory planning can cause two opposite but equally problematic outcomes: stockouts and overstocking. Stockouts affect service quality and patient access to medicines, while overstocking increases storage costs and raises the risk of expiry-related wastage. These problems are especially important in pharmaceutical settings because products differ in price, shelf life, usage pattern and replenishment behaviour.

Traditional pharmacy stock management commonly relies on manual review, minimum stock levels or simple rule-based reorder decisions. Although these methods are easy to use, they may not capture product-specific trends and non-linear changes in inventory movement. Machine learning provides a data-driven alternative by learning patterns from historical records and using them to forecast future inventory requirements. Prior studies in supply chain and forecasting have reported that machine learning and ensemble techniques can improve forecasting accuracy when compared with simpler models, particularly when patterns are irregular or non-linear [10,14].

This study focuses on a pharmacy inventory dataset generated from monthly stock reports. The dataset does not represent direct customer sales transactions; therefore, the research is positioned as inventory requirement forecasting rather than customer demand prediction. Its focus on monthly stock availability records rather than direct sales or dispensing-demand datasets. This reflects a practical data environment commonly encountered by small and medium pharmacies in the Sri Lankan context, where detailed point-of-sale demand histories may not always be available for research or decision-support modelling. The contribution of the study is to demonstrate how routinely maintained stock reports can be transformed into a supervised learning dataset and used to compare machine learning models for next-month pharmacy inventory forecasting. The objective of the study was to preprocess historical monthly pharmacy inventory data, develop machine learning forecasting models, evaluate their predictive performance and identify the most suitable model for forecasting future pharmacy inventory requirements.

Methods

i. **Study design and dataset**
A comparative quantitative machine learning design was adopted. The material used in this study consisted of historical monthly pharmacy stock reports, each representing stock available at the beginning of a month. Seventeen monthly reports from November 2024 to March 2026 were combined into a single dataset. The raw integrated dataset contained 15,218 rows. Since some products appeared more than once within the same monthly report, the records were aggregated by month and product. The final modelling dataset contained 11,475 month-product records and 789 unique pharmacy products. The study did not involve human participants. Records were included when they contained a valid reporting month, product identifier and stock quantity. Non-product summary rows, unusable text rows and records that could not support next-month target construction were excluded from the supervised modelling dataset.

ii. **Data preprocessing**
The monthly reports were cleaned and standardized before modelling. Date values were extracted from file names and converted into a uniform monthly date format. Product names were standardized as categorical identifiers, and duplicate product entries within the same month were aggregated by summing the available stock quantity. Numeric fields such as stock quantity and selling price were checked and converted into appropriate numeric formats. Records that could not contribute to next-month forecasting due to missing target values were removed from the supervised learning dataset. Feature scaling was not applied because the main candidate models were tree-based models, which are not sensitive to feature scale. Linear Regression was retained as a baseline and was trained on the same numeric feature set to maintain a consistent comparison across all models.

iii. **Feature selection and target variable**
The target variable was defined as Next_Month_Qty_Target, representing the stock quantity of the same product in the following month. This converted the monthly inventory snapshot data into a supervised learning problem. The input features included product code, year, month, quarter, selling price, current month stock quantity, previous month stock quantity, two-month lag stock quantity and a three-month rolling average. Product names were encoded into numeric product codes to allow machine learning algorithms to process product-level differences. Lag and rolling-average features were included to represent recent stock movement patterns. After creating the next-month target variable, records without a corresponding following-month stock value were removed, resulting in 10,584 records for model training and testing.

iv. **Model training and validation**

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Four regression models were trained: Linear Regression, Decision Tree, Random Forest and XGBoost. Linear Regression was included as a baseline model, while Decision Tree, Random Forest and XGBoost were included to assess tree-based and ensemble learning methods.

Model configurations were fixed before testing to support reproducibility. Decision Tree pruning was controlled using a maximum depth of 12. Random Forest was configured with 100 estimators, maximum depth of 12 and random_state = 42. XGBoost was configured with 100 estimators, maximum depth of 5, learning rate of 0.08, subsample of 0.80, column sample by tree of 0.80, squared-error regression objective and random_state = 42. Parameter settings were selected through limited preliminary training-set trials, while the final testing set was not used for parameter selection.

The analysis was performed using Python 3.13.5 with pandas 2.2.3, NumPy 2.3.5, scikit-learn 1.8.0, XGBoost 3.1.3 and Matplotlib 3.10.8. A chronological 80:20 train-test split was used because the study involved forecasting future inventory values. The first 80% of the ordered records were used for model training, while the remaining 20% were used for testing. The training set contained 8,467 records and the testing set contained 2,117 records. A random split was avoided to reduce the risk of data leakage from future observations into the training period.

Rolling-origin or walk-forward validation would provide a stronger operational assessment; however, the available dataset covered only 17 monthly reports. Therefore, the chronological holdout split was used as the primary validation strategy, and longer multi-site datasets are recommended for future time-series cross-validation.

v. **Model performance evaluation**

Model performance was evaluated using MAE, RMSE and R^2. MAE measured the average absolute prediction error, RMSE gave greater penalty to large prediction errors and R^2 measured the proportion of variation explained by each model. Since inaccurate forecasting of high-stock products can create larger operational impact, RMSE was treated as the primary comparison metric. The model with the lowest RMSE and highest R^2 was considered the best-performing model.

Table 1. Summary of dataset preparation

Description	Value
Monthly reports integrated	17
Date range	November 2024 to March 2026
Raw extracted rows	15,218
Aggregated month-product records	11,475
Unique products	789
Training records	8,467
Testing records	2,117

Results

The four machine learning models were evaluated on the chronological testing set. Table 2 presents the model comparison results. The results show that XGBoost achieved the lowest RMSE and highest R^2 score, indicating better overall forecasting performance. Random Forest produced the lowest MAE, but its RMSE and R^2 were weaker than XGBoost. Since RMSE was selected as the primary metric due to its sensitivity to large forecasting errors, XGBoost was identified as the best-performing model in this study.

Table 2. Model performance comparison

Model	MAE	RMSE	R^2	Rank by RMSE
XGBoost	52.9718	228.0499	0.7611	1
Decision Tree	51.6809	245.0748	0.7241	2
Random Forest	48.7105	259.8493	0.6898	3
Linear Regression	51.6714	266.6767	0.6733	4

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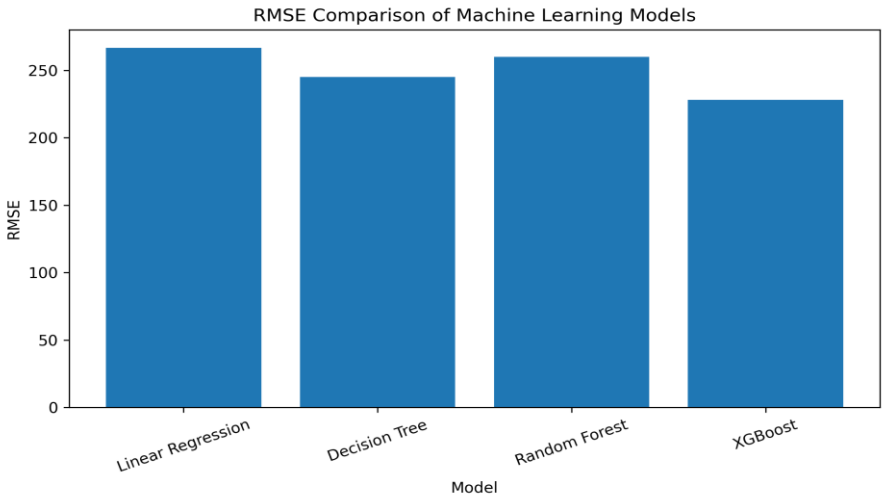

Figure 1. RMSE comparison of machine learning models

Figure 1 shows the RMSE comparison of the four machine learning models used for forecasting pharmacy inventory requirements. RMSE measures the average size of prediction errors, with greater emphasis on larger errors. Therefore, a lower RMSE value indicates better forecasting performance. Among the evaluated models, XGBoost achieved the lowest RMSE value of 228.0499, followed by Decision Tree with 245.0748, Random Forest with 259.8493, and Linear Regression with 266.6767. This result indicates that XGBoost produced the most accurate predictions in terms of reducing large forecasting errors.

To improve interpretability, feature importance was extracted from the fitted XGBoost model. Table 3 presents the most influential predictors. Current month stock quantity contributed most strongly, followed by recent lag-based stock features and selling price. This indicates that recent stock movement and product-level stock history were central to next-month inventory forecasting.

Table 3. XGBoost feature importance ranking

Rank	Feature	Relative importance	Interpretation
1	Current month stock quantity	0.274	Strongest immediate indicator of next-month inventory level
2	Three-month rolling average	0.093	Captures recent stock trend
3	Weighted average selling price	0.090	Represents product value and price-related stock behavior
4	Two-month lag stock quantity	0.089	Captures earlier stock movement
5	Previous month stock quantity	0.074	Represents short-term inventory history

Discussion

The results indicate that machine learning models can be applied to monthly pharmacy stock data to forecast future inventory requirements. XGBoost achieved the strongest performance because gradient boosting builds models sequentially and corrects previous prediction errors. This characteristic is useful for pharmacy inventory data, where stock patterns may vary by product, month, price and recent stock history. This finding is consistent with previous forecasting studies that highlight the usefulness of machine learning and ensemble techniques for modelling complex and non-linear patterns in structured data.

The feature importance results provide additional insight into model behavior. Current month stock quantity was the most influential predictor, while the three-month rolling average and lagged stock quantities also contributed strongly. This suggests that inventory forecasts are mainly driven by recent stock movement rather than calendar features alone. From a pharmacy management perspective, this is useful because it indicates that routinely maintained monthly stock reports can provide meaningful signals for short-term planning even when detailed sales transaction data are unavailable.

Although Random Forest produced the lowest MAE, its RMSE was higher than XGBoost. This indicates that Random Forest had lower average error overall but made relatively larger errors in some cases. For inventory forecasting, large errors can be important because they may lead to serious overstocking or stockout risk. Therefore, the lower RMSE of XGBoost provides a stronger practical advantage for inventory planning.

The study also confirms the importance of matching the research topic to the available data. The uploaded reports represented stock available at monthly points, not sales invoices or customer demand transactions. Therefore, the study appropriately forecasts future inventory requirements rather than direct customer demand. The output can support pharmacy managers by providing evidence-based estimates of future stock levels, which can be used during monthly review and purchasing decisions.

In practical deployment, the forecasting model could be integrated into a pharmacy management information system (PMIS). Predicted next-month stock levels could be used to generate reorder suggestions, stock alert thresholds, purchasing decision support and inventory optimization reports. When combined with expiry-date information, the system could also support expiry management by identifying products at risk of overstocking before they expire.

The main limitation is that the dataset contains stock snapshots only. It does not include sales volume, supplier lead time, purchase orders, expiry dates, promotional activities, prescription trends, seasonal disease patterns or emergency purchasing. These factors may strongly influence pharmacy inventory requirements and should be included in future studies where available.

External validation is also required because the model was developed using data from a single pharmacy dataset. Future research should test the approach using multiple pharmacies or healthcare institutions to improve generalizability. Additional directions include real-time inventory forecasting, sales transaction integration, supplier lead-time prediction, demand forecasting, SHapley Additive exPlanations (SHAP)-based explainable artificial intelligence and cloud-based PMIS deployment.

Conclusions

This study compared Linear Regression, Decision Tree, Random Forest and XGBoost models for forecasting pharmacy inventory requirements using monthly stock reports. The dataset was transformed into a supervised learning format by predicting the next-month stock quantity for each product. Among the evaluated models, XGBoost achieved the best overall performance with the lowest RMSE of 228.0499 and highest R^2 score of 0.7611. Feature importance analysis showed that current stock quantity and recent stock movement features were important predictors. The findings show that machine learning, especially gradient boosting, can support pharmacy inventory planning by identifying future stock requirements from historical inventory patterns. The approach can help reduce stock-related inefficiencies and support more informed pharmacy stock management decisions.

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References

1. Breiman L. Random forests. Machine Learning. 2001;45(1):5-32.

2. Chen T, Guestrin C. XGBoost: a scalable tree boosting system. Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining; 2016. p. 785-794.

3. Pedregosa F, Varoquaux G, Gramfort A, Michel V, Thirion B, Grisel O, et al. Scikit-learn: machine learning in Python. Journal of Machine Learning Research. 2011;12:2825-2830.

4. Hyndman RJ, Athanasopoulos G. Forecasting: principles and practice. 3rd ed. Melbourne: OTexts; 2021.

5. Chopra S, Meindl P. Supply chain management: strategy, planning, and operation. 7th ed. Harlow: Pearson; 2022.

6. Syntetos AA, Boylan JE. The accuracy of intermittent demand estimates. International Journal of Forecasting. 2005;21(2):303-314.

7. Makridakis S, Spiliotis E, Assimakopoulos V. Statistical and machine learning forecasting methods: concerns and ways forward. PLoS One. 2018;13(3):e0194889.

8. Lundberg SM, Lee SI. A unified approach to interpreting model predictions. Advances in Neural Information Processing Systems. 2017;30:4765-4774.

9. Sattar MU. Enhancing supply chain management: a comparative machine learning approach for demand forecasting and inventory policy. Sustainability. 2025;17(13):5772.

10. Samniang W, Shah SMT, Tun YM, Munawar A, et al. A hybrid grey wolf optimized eXtreme gradient boosting-based machine learning model for hospital pharmaceutical demand forecasting. Scientific Reports. 2026;16:13400. doi:10.1038/s41598-026-48590-4.

11. Zhu X, Ninh A, Zhao H, Liu Z. Demand forecasting with supply-chain information and machine learning: evidence in the pharmaceutical industry. Production and Operations Management. 2021;30(9):3231-3252. doi:10.1111/poms.13426.

12. Burinskiene A. Forecasting model: the case of the pharmaceutical retail. Frontiers in Medicine. 2022;9:582186. doi:10.3389/fmed.2022.582186.

13. Thaiudomsap N, Sribundit N. Study on demand forecasting techniques for drugs with sporadic demand in a community hospital. Science, Engineering and Health Studies. 2022;16:22050005. doi:10.14456/sehs.2022.10.

14. Laomala J, Tantiwanichanon P, Jaruteekampron N, Kaennakham S. LSTM drug demand forecasting with adjustment strategies as a preliminary step toward optimizing hospital drug inventory management. Frontiers in Artificial Intelligence and Applications. 2024;398:485-491. doi:10.3233/FAIA241450.

15. Xu T, Bos H, Byon E, Lavieri MS, Renius K, Sweet BV. Forecasting hospital drug demand for demand patterns with changepoints. IISE Transactions on Healthcare Systems Engineering. 2025;15(3):269-286. doi:10.1080/24725579.2025.2538009.

16. Chen X, Lu G, Zhang H, et al. Knowledge graph-enhanced deep learning for pharmaceutical demand forecasting. Scientific Reports. 2026;16:4776. doi:10.1038/s41598-026-35113-4.

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OP 18

AI-Driven Hybrid Clinic Management System Using Cloud-Based SaaS Architecture for Smart Healthcare Scheduling and Consultation

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Background: Healthcare organizations in Sri Lanka continue to experience difficulties in managing clinical appointments due to dependence on manual procedures and fragmented digital solutions. These limitations contribute to inefficient resource allocation, appointment overlaps, prolonged waiting periods, and challenges in delivering in-person and remote healthcare services. Current clinic management applications primarily focus on reservation processes and provide limited intelligence for supporting healthcare decision-making.

Objective/s: This research proposes the development of an Artificial Intelligence (AI)-enabled Hybrid Clinic Management Software-as-a-Service (SaaS) platform that introduces intelligent appointment coordination and automated consultation recommendations to improve the efficiency and accessibility of healthcare services.

Methods: The proposed solution uses a cloud-based three-tier architecture consisting of presentation, service processing, and data management layers. The platform provides functionalities for patients, clinicians, and administrators while integrating backend services for workflow management, Application Programming Interface (API) interactions, and AI processing. The recommendation engine employs a hybrid AI strategy combining predefined healthcare decision rules with machine learning-based analysis of historical appointment patterns and user preferences to identify suitable doctors and consultation approaches. An adaptive scheduling mechanism adjusts appointment allocation to minimize conflicts. The prototype was assessed in a controlled evaluation environment using 50 participants representing patients, medical practitioners, and administrative personnel.

Results: Experimental evaluation showed that the proposed approach decreased scheduling conflicts by approximately 30–40% and prevented duplicate appointment allocation throughout testing. The AI recommendation component achieved 75–80% recommendation accuracy, while system transactions recorded response times between 1.2 and 2.0 seconds. Feedback collected from evaluation participants demonstrated favourable acceptance of the intelligent recommendation and scheduling features.

Conclusion/s: The developed platform demonstrates advancement over conventional clinic management systems by combining AI-based decision support, adaptive scheduling, and hybrid consultation management within a scalable cloud framework. The results indicate the capability to enhance operational efficiency and healthcare accessibility while supporting digital healthcare adoption in Sri Lanka

Keywords: *Artificial Intelligence, SaaS Healthcare System, Hybrid Consultation, Smart Scheduling, Healthcare Informatics.*

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OP 19

SecureBank AI: A Deep Learning-Powered Facial Recognition Banking System with Multi-Layer Anti-Spoofing

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Background: Traditional banking authentication methods such as passwords, PINs, and OTPs remain vulnerable to phishing, credential theft, and spoofing attacks. Facial recognition offers contactless authentication, but many existing commercial systems rely on a single anti-spoofing check and can still be bypassed using printed photographs, replay videos, or deepfakes.

Objectives: This research addresses this gap by developing SecureBank AI, a deep learning-powered banking system that integrates six complementary anti-spoofing checks into a single layered pipeline, rather than a single technique defence, to improve authentication security, prevent unauthorised access, and support a broader secure ABC platform.

Methods: SecureBank AI was developed using Agile methodology with a three-tier architecture: a React 18 client, a FastAPI backend, and a relational database. Facial recognition combines DeepFace with Facenet512 and RetinaFace, verified via cosine similarity on 512-dimensional embeddings. The anti-spoofing pipeline sequentially applies blur analysis, brightness validation, texture analysis, colour verification, blink detection, and head pose estimation before granting access; session and transaction security are enforced through JWT authentication, Redis session management, bcrypt hashing, OTP verification, audit logging, and role-based access control. The system was evaluated through functional, integration, and system testing, including simulated spoofing attempts using printed photographs and invalid face captures.

Results: SecureBank AI successfully implemented password and facial recognition authentication, with the anti-spoofing pipeline reliably detecting printed photograph and invalid-face-capture spoofing attempts while maintaining stable response times of two to five seconds. Secure transactions, OTP based transfers, attendance management, audit logging, and role-based dashboards all functioned as intended. Formal quantitative evaluation, including recognition accuracy, false acceptance rate, false rejection rate, and equal error rate, was not conducted in this phase and has been identified as a priority for future work.

Conclusions: SecureBank AI demonstrates that combining multi-layer anti-spoofing with deep learning facial recognition and modern web-security mechanisms can provide a secure, scalable solution for future intelligent digital banking systems.

Keywords: *Anti-Spoofing, Banking Security, Biometric Authentication, Deep Learning, Face Recognition*

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OP 01

Applicability of Industry 4.0 on Fleet Operational Efficiency in the Modern Trade Supply Chain: Evidence from Sri Lanka

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Abstract

Background: Industry 4.0 technologies are increasingly transforming supply-chain operations by improving efficiency and real-time decision-making. However, their adoption in developing economies such as Sri Lanka remains limited, particularly in fleet management.

Objective/s: This study aims to examine how Internet of Things (IoT) and Big Data influence the operational efficiency of fleet departments in modern trade supply chains in Colombo District, Sri Lanka.

Methods: A qualitative approach was used. Data were collected through semi-structured interviews with ten participants from four modern trade organisations and analysed using thematic analysis to identify key patterns and relationships.

Results: IoT improved fleet visibility, tracking and route planning, while Big Data supported maintenance planning and demand forecasting. However, challenges such as poor infrastructure, limited skills, and management resistance reduce the adoption of these technologies.

Conclusion/s: The study confirms that Industry 4.0 technologies have a positive impact on fleet operational efficiency. Organisations should adopt scalable, phased solutions, and policymakers should invest in digital infrastructure, incentives and workforce development.

Keywords: *Big Data, Fleet Operational Efficiency, Industry 4.0, Internet of Things (IoT), Supply-Chain Management*

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Introduction

The global business environment is becoming increasingly competitive and technology-driven. Organisations are under constant pressure to improve efficiency, reduce operational costs, and enhance customer satisfaction. In response to these challenges, Industry 4.0 has emerged as a transformative concept that integrates digital technologies into business operations. Industry 4.0 refers to the use of advanced technologies such as IoT, Big Data analytics, cloud computing, and cyber-physical systems to improve productivity and efficiency (1). Within supply-chain management, these technologies enable real-time data collection, improved decision-making and better coordination across the supply chain (2). Fleet management, an essential component of supply-chain operations, plays a crucial role in ensuring timely delivery of goods and maintaining service quality, whereas efficient fleet operations reduce transportation costs, improve delivery accuracy and enhance customer satisfaction (3).

Sri Lanka's modern trade sector has grown rapidly across urban and semi-urban areas, increasing demand for efficient logistics and distribution systems. However, many organisations still rely on traditional fleet-management methods involving manual processes and limited use of technology, leading to delayed deliveries, poor vehicle tracking and increased operational costs. Prior studies demonstrate that IoT technologies such as GPS tracking and sensors enhance real-time monitoring of fleet operations, while Big Data analytics helps organisations analyse large volumes of data to improve decision-making (4,5). Despite these benefits, adoption of Industry 4.0 in developing countries remains limited due to factors such as lack of infrastructure, high implementation costs, and limited technical expertise (6).

Most existing Sri Lankan studies address Industry 4.0 adoption at the level of general third-party logistics (3PL) or manufacturing operations (6), with little qualitative evidence on how IoT and Big Data specifically shape day-to-day fleet operations in the modern trade sector, and few interpret such evidence through an established technology-adoption lens. Therefore, this study aims to explore the applicability of Industry 4.0 technologies for improving fleet operational efficiency within the modern trade supply chain in Colombo District, Sri Lanka. Accordingly, the research objectives are:

- To examine the impact of IoT on fleet operational efficiency
- To examine the impact of Big Data on fleet operational efficiency
- To identify barriers and challenges in implementing Industry 4.0 technologies in the modern trade supply chain

Methods

This research adopted a qualitative design to explore the use of Industry 4.0 technologies in fleet operations in Colombo District, Sri Lanka. A two-stage sampling procedure was adopted. First, four companies with active fleet operations were selected through cluster sampling, enabling efficient access to participants across organisationally dispersed settings (7), and coded as P, Q, R, and S due to organisational policies. Second, ten participants with direct fleet management experience were drawn across the four organisations using purposive sampling, allowing the researcher to target information-rich cases (8). Table 01 summarises participant characteristics.

Primary data were collected through semi-structured interviews conducted via communication platforms and analysed using thematic analysis following Braun and Clarke's (9), six-step approach: familiarisation with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Coding was conducted manually in two stages: open coding to identify meaningful ideas and focused coding to group them into the six themes shown in Table-02.To ensure quality, two researchers independently coded selected transcripts and resolved differences through discussion. Three participants reviewed the findings to confirm their accuracy, and the lead researcher kept a reflexive journal throughout the study.

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Table 01. Interviewees' Characteristics

Company	Experience in Modern Trade (yrs)	Outlets in Colombo District	Code	Job-Position
P	19	65	P1	Fleet Executive
			P2	Fleet Assistant
			P3	Fleet Officer
Q	43	160	Q1	Procurement Officer
			Q2	Outlet Manager-1
			Q3	Outlet Manager-2
R	8	5	R1	Junior Executive
			R2	Junior Operation Executive
S	25	33	S1	Supply-Chain Manager
			S2	Junior Procurement Officer

Results

Thematic analysis identified six themes: management leadership, available technologies, environmental factors, application of IoT, application of Big Data, and fleet operation challenges/advantages of Industry 4.0 (Table-02).

Table 02. Content Analysis Themes of Fleet Operational Efficiency

Themes	Sub-themes	(Code) Data
Management Leadership	Technology implementation barriers	**(S1):** "Definitely, that's a barrier. During SAP ERP implementation, we faced many challenges because the organization was established in 2001, and many managers are still from that era, so managing change and system changes is difficult."
	Leadership needed to implement technologies	**(R2):** "Of course. As middle management, we understand operational difficulties, but implementation decisions are not in our control. Top management decisions are essential, since nothing can be implemented without them."
	Guide/train employees for new technologies	**(S2)**:"Yes, leadership is important when introducing new technologies, as leaders must guide, support, and train employees on new systems."
Available Technologies	Rolla cage operation for delivery process	**(P2)**: "We now use Rolla cage operations, which reduced loading/unloading time and goods damage. Earlier we got many complaints about damaged goods; after management introduced Rolla cages, loading time dropped from about 2.30 hours to around 1 hour."
	SAP/ERP for inventory management	**(S1):**"We use SAP ERP for inventory, material, and finance management, integrated with our POS system, so we can monitor real-time inventory and sales revenue. But we still keep inventory cards and manual records too."
	Cloud computing	**(Q1):**"Cloud computing, warehouse/inventory/enterprise/people management system, VMS, cyber security."
	Transport Management Systems (TMS)	**(P1):**"We use RFID for picking and dispatch, then SAP, EWM, and TMS for truck management."
Environmental Factors	National infrastructure gaps	**(S1):**"That's the issue. Competitors like Company P use more advanced technology. Sri Lanka lacks the infrastructure for Industry 4.0-level technologies that foreign countries already use, so better infrastructure is needed."
	Government support for infrastructure development	**(P3):**"Government is trying to improve infrastructure, and technology globally keeps advancing. We can manage daily operations with current infrastructure, but there's still much room to improve.'

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	Matching technology to available facilities	**(P2):**"In my opinion, these facilities are sufficient for the technologies we use in Sri Lanka. More advanced options exist, but are not implementable here, so we only adopt technologies that match our available resources."
	Limited knowledge and skilled labour	**(Q1):**"No, in Sri Lanka we lack network, electricity, human, and technological capabilities." **(R2):**"It depends on the technologies that we are going to implement. There are some high technologies that require more infrastructure and facilities to implement and run the system" **(S2):**"No, there is not enough technology and infrastructure in Sri Lanka to apply advanced technologies in operational activities. Not only infrastructure, but skilled labour and technical knowledge are also limited."
Application of IoT	Tracking truck location	**(P3):**"With tracking systems, we can confirm outlet arrival times, verify goods accuracy, reduce theft, track vehicle/cargo location, and detect unauthorized door openings. Without systems, drivers must call the warehouse to report all this manually."
	Identifying truck delays, breakdowns, and arrival times	**(S1):**"We're planning for GPS tracking through outsourcing, since vehicles sometimes break down without our knowledge while outlets wait for goods. Since operations start at 2 AM with no managers on site, tracking is essential to monitor operations"
	Tracking unauthorized stops, traffic congestion, vehicle speed	**(P2):**"We pay overtime after 12 hours. For instance, a truck arriving at 6 AM gets overtime after 6 PM. This lets us track unauthorized parking, congestion, and driver behaviour, including drivers who drive slowly to extend overtime."
	Goods tracking route planning	**(P1):**"We pay transporters based on KM (travel distance), so having the best routing and truck management plan is very important; otherwise, it increases organizational expenses. We also consider overtime costs and aim to reduce trips in route planning. So, we select the shortest routes that cover more outlets using our TMS system for route and truck management."
Application of Big Data	Tracking machine maintenance	**(P3):**"Drivers handle maintenance themselves; we just push them to do it." **(R1):**"We do not track maintenance directly. Drivers manage it, though using big data on vehicle condition (engine, fuel, mileage) in a centralized system could help catch problems early **(S1)**:"We have separate book-running charts for maintenance, so we track everything manually."
	Track machine maintenance using vehicle management system (VMS)	**(Q1)**:"We use VMS, and we keep a record book for every vehicle."
	Product quality/temperature control	**(P3):**"We installed sensors to track door openings and ensure safe delivery, plus temperature sensors in freezer trucks for items like fish and vegetables. So, we can identify whether damage came from our operations or the transporter's.
	Managing available trucks for delivery	**(P2):**"The only challenge is managing outlet orders based on available trucks. During seasonal periods, we arrange temporary trucks, but demand can still spike even after the season."
	Demand uncertainties and fluctuations	**(P2):**"During COVID-19, demand for essential goods fluctuated so much we needed 22 trucks to cover all outlets or had to hire temporary vehicles at extra cost. So, managing trucks during high demand is a huge challenge."
Fleet Operation Challenges	Managing the transport cost	**(P1):**"We face payment and fuel cost issues. As we do not offer extra fuel allowances, truck owners sometimes request additional fuel payments for traffic congestion or route changes.'

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	Truck repair/ maintenance cost	**(S1)**:"The main challenge is the repair and maintenance cost. Since these are our own vehicles, bear the expenses, and most vehicles are now in the later stage of their lifespan, which increases maintenance costs. We also use our own drivers and helpers, which adds to the cost. Outsourced manpower would be cheaper, but we can't let go of long-serving employees, especially since COVID-19. Outsourcing fleet operations could improve efficiency through experienced providers with advanced tracking and loading systems we currently lack."
	Pandemic issue	**(P2):**"There was an issue due to the COVID pandemic. Operating in shifts with limited staff made it hard to complete orders as before, and as operations took longer, overtime costs increased."
Advantages of Industry 4.0	Save time/money	**(S2):**"It's a good investment. We save time, and time means money. Companies no longer implement technologies alone; they rely on expert organizations for support. We can get expert support, as many parties provide efficiency and proficiency."
	Smoother operations	**(P1):**"By implementing these technologies, we can smooth operations and increase efficiency. And we must move with new methods."
	Practical applicability	**(P3):**"Some technologies only add cost, while others bring real benefits. We check whether a technology is practically applicable and whether we have sufficient facilities, since even advanced systems don't always deliver expected results, So, selecting the right technology is essential to avoid unnecessary organizational costs."
	Increase operational efficacy	**(Q1):**"It's a great investment. It can improve operational efficiency and productivity.
	Increase data accuracy	**(S2):**"We work for a leading 3PL company in Sri Lanka. We implement any technology that ensures higher accuracy. Even with clear advantages, the final decision rests with top management, whose main focus is cost cutting."

IoT improved fleet visibility and control: GPS tracking and TMS monitored vehicle movements in real time (P1; P2; P3; Q1; S1), reduced operational uncertainty and improved warehouse-outlet coordination (Q2; Q3), and helped organisations quickly identify delays and act (S2). IoT also supported route optimisation, avoiding congestion (P1; P2), reducing fuel use and improving delivery speed (P3; Q1) and customer satisfaction (Q2; Q3). Monitoring driver behaviour reduced fuel wastage (R1) and improved safety and discipline (S1; S2).

Big Data improved maintenance planning: Analysing historical vehicle data predicted maintenance needs (P1; Q1; S1), reducing breakdowns, downtime and repair costs (P2; P3; Q2; Q3), and supporting continuous operations (R; S). However, adoption still relied on manual maintenance records (R1; S1), traditional systems limiting analytics (P3; Q), and limited digital-tool access restricting data-driven approaches (R2; S2).

Supporting technologies: ERP and TMS improved transport-warehouse coordination (P1; Q1), RFID reduced loading errors (P2; P3), ERP further improved inventory management and information sharing (Q2; Q3; R1), while TMS improved route planning (S2).

Despite these benefits, adoption remained constrained by poor infrastructure, unstable connectivity and limited access to advanced technologies (Q1; R1; S1), inadequate facilities (P2; Q2), skills shortages (R2; S2), cost-related hesitation (P3; Q3; S1), and limited top-management support restricting innovation (Q2; R2; S2).

Discussion

These findings confirm that Industry 4.0 technologies positively influence fleet operational efficiency. The results align with the Technology–Organisation–Environment (TOE) framework, Diffusion of Innovation (DOI) theory, and Technology Acceptance Model (TAM).

Consistent with TOE which explains adoption as jointly shaped by technological, organisational, and environmental contexts (10), the findings indicate that adoption was influenced by technological capabilities (IoT, RFID, ERP/SAP, TMS, cloud computing, Big Data), organisational readiness (leadership support, employee training, change resistance), and environmental conditions (infrastructure availability, government support, skilled labour, pandemics). IoT applications demonstrated higher adoption due to observable benefits, including real-time vehicle tracking, route optimisation, and reduced delays, supporting DOI's emphasis on relative advantage, compatibility, and observability in technology diffusion (11). Findings also support TAM, which explains the usefulness–use gap (12), as participants recognised the usefulness of Big Data for predictive maintenance and decision-making but continued using manual processes because limited analytical skills and inadequate systems reduced ease of use.

The identified barriers, including infrastructure limitations, high implementation costs, skills shortages, and insufficient managerial commitment, are consistent with previous Industry 4.0 studies in emerging economies (13,14). These findings suggest that Sri Lanka's barriers reflect broader emerging-economy conditions, highlighting the need for interventions addressing organisational and environmental constraints alongside technology adoption.

Practical implications: Organisations with limited budgets can adopt Industry 4.0 incrementally: prioritising low-cost, high-return applications (GPS tracking, RFID at loading points) before layering predictive maintenance and demand-forecasting analytics onto existing ERP/TMS platforms and pairing each rollout with structured staff training and leadership sponsorship to address the organisational and technological barriers identified above.

Policy implications: Government incentives (co-funding for fleet digitisation), sustained investment in digital and power infrastructure, workforce development through vocational and university logistics-technology curricula, and public–private partnerships between technology vendors, industry associations and modern trade firms would collectively ease the environmental constraints participants mentioned. Such measures would address barriers at the national level that individual organisations cannot resolve alone, complementing firm-level practical measures.

Limitations and Future Research: The study sample of ten participants from four companies limits statistical generalisability of the findings. The geographic focus on the logistics sector in Colombo District excludes other regions of Sri Lanka with different infrastructure and market conditions, and other sectors, like e-commerce or manufacturing distribution, which may face different technology-adoption dynamics. Future research should validate these findings quantitatively with larger, national samples across multiple logistics firms, and examine emerging areas such as artificial intelligence-based predictive logistics, digital twins, autonomous fleet management and blockchain for supply-chain transparency.

Conclusions

This study concludes that Industry 4.0 technologies, particularly IoT and Big Data, significantly improve fleet operational efficiency in modern trade supply chains by enhancing visibility, planning and decision-making. Adoption, however, depends jointly on technological readiness, organisational commitment and environmental conditions. Addressing these dimensions together, through phased organisational investment and supportive government policy, is essential for improving supply-chain performance and logistics competitiveness in Sri Lanka.

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References

1. Bongomin O, Gilibrays Ocen G, Oyondi Nganyi E, Musinguzi A, Omara T. Exponential Disruptive Technologies and the Required Skills of Industry 4.0. Journal of Engineering. 2020;2020:1–17. doi: 10.1155/2020/4280156

2. Hofmann E, Rüsch M. Industry 4.0 and the current status as well as

prospects on logistics. Comput Ind. 2017;89:23–34. doi: 10.1016/j.compind.2017.04.002

3. Christopher Martin. Logistics and supply chain management : creating value-added networks. 3rd ed. FT Prentice Hall; 2005. 305 p.

4. Witkowski K. Internet of Things, Big Data, Industry 4.0 – Innovative Solutions in Logistics and Supply Chains Management. Procedia Eng. 2017;182:763–9. doi: 10.1016/j.proeng.2017.03.197

5. Fettermann DC, Cavalcante CGS, Almeida TD de, Tortorella GL. How does Industry 4.0 contribute to operations management? Journal of Industrial and Production Engineering. 2018;35(4):255–68. doi: 10.1080/21681015.2018.1462863

6. Malkanthie MAA, Jayamanna JMDJN. Existing Obstacles of the Third Party Logistics (3PL) Market in Sri Lanka. 2017;

7. Taherdoost H. Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. SSRN Electronic Journal. 2016; doi: 10.2139/ssrn.3205035

8. Etikan I, Musa SA, Alkassim RS. Comparison of Convenience Sampling and Purposive Sampling. American Journal of Theoretical and Applied Statistics. 2016;5(1):1. doi: 10.11648/j.ajtas.20160501.11

9. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77–101. doi: 10.1191/1478088706qp063oa

10. Tornatzky LG., Fleischer Mitchell, Chakrabarti AK. The processes of technological innovation. Lexington Books; 1990. 298 p.

11. Rogers EM. Diffusion of innovations. Free Press; 2003. 551 p.

12. Davis FD. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly. 1989;13(3):319–40. doi: 10.2307/249008

13. Tran MC, Nguyen LC, Pham P Le, Hoang PM, Dinh HG, Truong HQ, et al. Digital transformation in logistics: a framework for Industry 4.0 in developing countries. Competitiveness Review: An International Business Journal. 2026;36(7):24–41. doi: 10.1108/CR-01-2026-0005

14. Khan S, Singh R, Sá JC, Santos G, Ferreira LP. Modelling of Determinants of Logistics 4.0 Adoption: Insights from Developing Countries. Machines. 2022;10(12):1242. doi: 10.3390/machines10121242

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OP 02

Role of Adaptive Learning Systems on Student Engagement in Blended Online Courses at ABC College

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Abstract

Background: The rapid advancement of digital technologies has transformed higher education, with adaptive learning systems emerging as a key innovation in blended and online learning environments. However, student engagement remains a persistent challenge, particularly in diploma-level programmes where learners have diverse academic and digital literacy backgrounds. Limited empirical evidence exists regarding the effectiveness of adaptive learning systems in enhancing engagement in the Sri Lankan context.

Objective/s: This study aimed to examine the role of adaptive learning systems in enhancing student engagement in blended online courses at ABC College, Colombo. Specifically, it investigated personalization of learning content, adaptive feedback mechanisms, adaptive assessment and difficulty adjustment, and learning pace and path adaptation.

Methods: A positivist, deductive approach was adopted. A census sample of 125 active Diploma in English students (March 2026 intake) was used. Data were collected using a structured questionnaire and analysed using descriptive statistics, Pearson correlation, Chi-square tests, and reliability analysis using Cronbach's Alpha.

Results: Findings indicated high reliability of all constructs ($\alpha > 0.88$). All four independent variables showed strong positive relationships with student engagement: personalization ($r = 0.704$), adaptive feedback ($r = 0.752$), adaptive assessment ($r = 0.791$), and learning pace/path adaptation ($r = 0.832$), all statistically significant ($p < 0.05$).

Conclusion/s: Adaptive learning systems significantly enhance student engagement in blended learning environments. Personalization, timely feedback, adaptive assessment, and flexible learning pathways collectively improve motivation, participation, and learning satisfaction. The study highlights the importance of integrating adaptive technologies to support learner-centred education in higher education institutions.

Keywords: *Adaptive learning systems; student engagement; blended learning; personalization; adaptive feedback; adaptive assessment; learning analytics; higher education; Sri Lanka; online learning.*

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Introduction

The rapid advancement of digital technologies has significantly transformed the landscape of higher education worldwide. Consequently, adaptive learning systems have emerged as an important innovation in online and blended education by providing personalised learning experiences that respond to individual student needs, learning preferences, and performance levels (Zawacki-Richter et al., 2019; Siemens, 2005). International research has increasingly highlighted the potential of adaptive learning technologies to improve learning effectiveness, learner autonomy, and student engagement by enabling flexible and personalised educational experiences. However, the effectiveness of such systems remains highly dependent on contextual factors, including students' learning backgrounds, digital readiness, institutional support, and the nature of the educational environment in which they are implemented. Maintaining student engagement in blended and online learning environments has become a significant challenge for higher education institutions. Unlike traditional classroom-based education, blended learning requires students to take greater responsibility for managing their learning activities, time commitment, and interaction with digital learning platforms (Hrastinski, 2019; Moore, 2014). Low levels of engagement may lead students to adopt surface learning approaches, demonstrate limited participation, and experience reduced academic achievement. Disengaged learners often struggle to maintain motivation, actively participate in online learning activities, and establish meaningful interactions with instructors and peers (Garrison, Anderson, & Archer, 2000; Dixson, 2015). These challenges are particularly significant in language-based programmes, where continuous interaction, practice, and feedback are essential for developing communication skills and achieving learning outcomes (Richards, 2017). Student engagement challenges are further amplified in diploma-level education, where learners often represent diverse academic backgrounds, varying levels of digital literacy, and different levels of preparedness for technology-mediated learning environments (Asian Development Bank, 2022). In developing higher education contexts, such as Sri Lanka, diploma-level learners frequently enter programmes with heterogeneous learning experiences, making personalised learning support increasingly important. While adaptive learning systems have demonstrated positive outcomes internationally, much of the existing research has focused on universities and developed educational contexts, creating limited understanding of how such systems influence student engagement among diploma-level learners in emerging economies. Although previous studies have established significant relationships between adaptive learning components and student engagement, limited empirical evidence exists regarding their application within blended English language education in Sri Lankan higher education institutions. In particular, there is insufficient research examining how adaptive learning systems support engagement among diploma-level learners who may experience unique challenges related to digital adaptability, language proficiency, and independent learning skills. Therefore, the Sri Lankan context provides an important research setting to explore whether adaptive learning systems can effectively enhance student engagement beyond the contexts where these technologies have been predominantly studied. Addressing this contextual and empirical gap, this study investigates the role of adaptive learning systems in influencing student engagement within blended online English language courses at ABC College, Colombo, Sri Lanka. By focusing specifically on diploma-level learners, the study contributes to the limited body of knowledge regarding technology-enhanced learning practices in Sri Lankan higher education and provides practical insights for institutions seeking to improve learner participation, retention, and learning experiences through adaptive learning approaches.

RO1: To find the role of Personalization of Learning Content on Student Engagement in Blended Online Courses at ABC College.

RO2: To find the role of Adaptive Feedback Mechanisms on Student Engagement in Blended Online Courses at ABC College.

RO3: To find the role of Adaptive Assessment and Difficulty Adjustment on Student Engagement in Blended Online Courses at ABC College.

RO4: To find the role of Learning Pace and Path Adaptation on Student Engagement in Blended Online Courses at ABC College.

Literature Review

Relationship between Adaptive Learning Systems and Student Engagement

Dede (2014) highlighted that adaptive learning systems enhance student engagement by delivering personalized, interactive, and flexible learning experiences. Such systems create learner-centered environments that encourage active participation and continuous interaction with educational content. Further empirical evidence provided by Henrie et al. (2015) demonstrated that students learning within adaptive environments exhibit higher levels of behavioral, emotional, and cognitive engagement compared to those in traditional educational settings. Moreover, Zimmerman and Schunk

(2011) argued that adaptive learning systems strengthen self-directed learning capabilities, which are essential for maintaining sustained engagement in online education. Their findings suggest that adaptive learning technologies play a significant role in improving learner participation, motivation, and overall educational effectiveness.

Area of Business and Management Theory

Constructivism was extensively discussed by Jonassen (2014), who explained that learners actively construct knowledge through interaction and experience rather than passively receiving information. In the context of adaptive learning systems, constructivist principles are reflected through dynamic and individualized learning experiences that encourage active participation and critical thinking. Similarly, Self-regulated Learning was examined by Zimmerman (2002), who emphasized the importance of learners managing their own learning process through goal setting, self-monitoring, and strategy adjustment. Adaptive learning systems facilitate this process by providing personalized tools, progress tracking, and continuous feedback mechanisms that support learner autonomy. In addition, Siemens (2005) highlighted the significance of connectivism in digital learning environments, explaining that learning occurs through networks, interactions, and technology-enabled connections. Adaptive learning systems align with this perspective by integrating personalized digital pathways that enhance learner engagement and accessibility. Collectively, these theoretical perspectives demonstrate that adaptive learning systems are designed to support active engagement, personalization, and learner-centered educational experiences.

Personalization of Learning Content

Walkington (2013) identified personalization as a fundamental feature of adaptive learning systems, emphasizing that tailoring educational content to learners' individual needs, preferences, and abilities significantly improves motivation and engagement. Personalized learning environments increase the relevance and meaningfulness of educational activities, thereby encouraging students to participate more actively in the learning process. Further, Godwin-Jones (2018) argued that personalized learning supports students in focusing on areas requiring improvement while minimizing cognitive overload. This customized approach allows learners to progress at their own pace and enhances learning efficiency. Empirical studies conducted by Klašnja-Milićević et al. (2017) and Pardo et al. (2019) further confirmed that personalized learning environments positively influence cognitive engagement and academic achievement. Their findings suggest that adaptive learning systems contribute to improved student outcomes by aligning instructional content with learner capabilities and preferences.

Ha1: There is a relationship between of Personalization of Learning Content and Student Engagement in Blended Online Courses at ABC College.

Adaptive Feedback Mechanisms

Nicol (2010) emphasized that feedback plays a critical role in the learning process, particularly within online learning environments where direct interaction with instructors is limited. According to Nicol, adaptive feedback mechanisms enhance learning engagement by providing timely and individualized responses based on student performance. Similarly, Wisniewski et al. (2020) explained that effective feedback improves learner confidence, motivation, and self-efficacy. Adaptive feedback systems provide immediate responses that enable students to identify mistakes and make corrections in real time, thereby sustaining engagement in digital learning contexts. Furthermore, Carless and Boud (2018) highlighted that adaptive feedback promotes reflective learning by encouraging students to evaluate their performance and identify areas for improvement. This reflective process strengthens cognitive engagement and supports deeper learning experiences.

Ha2: There is a relationship between of Adaptive Feedback Mechanisms and Student Engagement in Blended Online Courses at ABC College.

Adaptive Assessment and Difficulty Adjustment

Hwang et al. (2016) explained that adaptive assessment systems adjust the difficulty level of learning activities according to student performance, ensuring that learners remain challenged at an appropriate level. This adaptive approach helps reduce boredom and frustration while maintaining learner engagement. In support of this argument, Papamitsiou and Economides (2014) found that adaptive assessments improve learner motivation and persistence by assigning tasks that match individual skill levels. Learners are more likely to remain actively involved in the educational process when activities are appropriately challenging. Moreover, Park and Lee (2021) noted that adaptive assessments provide continuous feedback that allows students to monitor their progress and make necessary learning adjustments. This continuous improvement process contributes to sustained engagement and enhanced learning outcomes.

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Ha3: There is a relationship between of Adaptive Assessment and Difficulty Adjustment and Student Engagement in Blended Online Courses at ABC College.

Learning Pace and Path Adaptation

Broadbent (2017) emphasized that flexibility in learning pace and learning pathways is particularly important in online education, where students often manage diverse schedules and responsibilities. Adaptive learning systems enable learners to control the timing and sequence of their learning activities according to their individual needs. Similarly, Jivet et al. (2018) argued that flexible learning pathways enhance learner autonomy and motivation, which subsequently increases engagement. The ability to personalize learning progression encourages students to take greater responsibility for their educational experiences. Additionally, Hrastinski and Jaldemark (2020) explained that adaptive learning systems reduce stress and improve learning satisfaction by allowing students to progress at their own pace. This flexibility also enables learners to revisit content and strengthen their understanding, thereby improving retention and long-term learning outcomes.

Ha4: There is a relationship between of Learning Pace and Path Adaptation and Student Engagement in Blended Online Courses at ABC College.

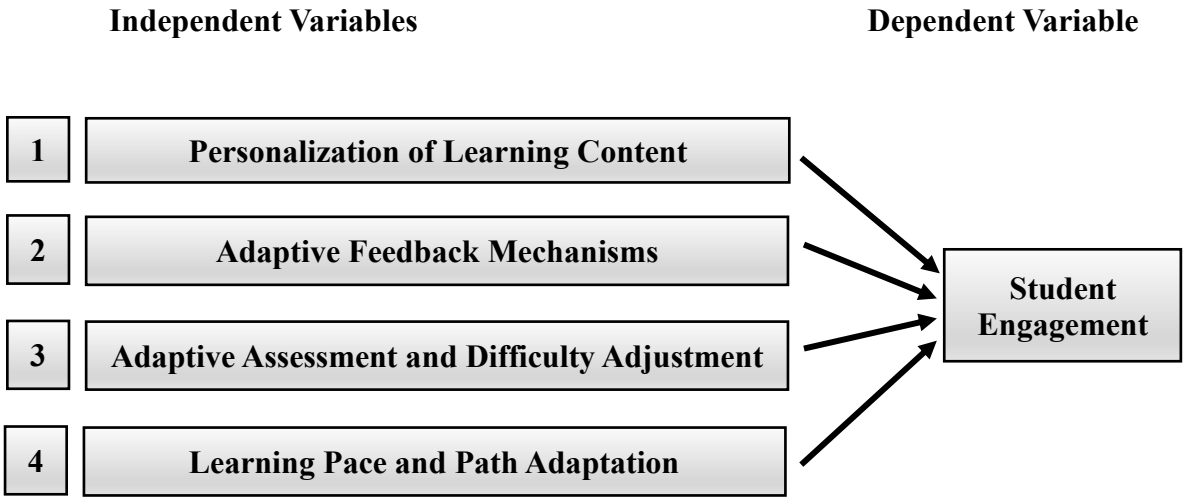

Figure 2.4.1: The Conceptual Framework

Source: Author Developed (2026)

Methods

This study adopted a positivist research philosophy with a deductive research approach to examine the relationship between adaptive learning systems and student engagement. The target population consisted of students enrolled in the online Diploma in English programme at ABC College, and all 125 active students registered during March 2026 were selected using a census sampling technique due to the small population size. The use of a census approach enabled the inclusion of all available Diploma in English students within the selected institution; however, the institution-specific nature of the sample should be considered when interpreting the findings. Primary data were collected through a structured questionnaire, and the data were analyzed using descriptive statistics including mean, mode, and standard deviation. Inferential statistical techniques such as Pearson correlation and Chi-square tests were conducted for relationship analysis and hypothesis testing. The reliability and internal consistency of the research instrument were assessed using Cronbach's Alpha.

Results and Discussion

Reliability Test Results

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Table 1: Reliability Test Results

Type	Variable	Cronbach's Alpha	No of Items	Conclusion
Independent Variables	Personalization of Learning Content	0.880	6	Highly Reliable
	Adaptive Feedback Mechanisms	0.964	6	Highly Reliable
	Adaptive Assessment and Difficulty Adjustment	0.914	6	Highly Reliable
	Learning Pace and Path Adaptation	0.980	6	Excellent Reliability
	All Independent Variables	0.980	24	Excellent Reliability
Dependent Variable	***Student Engagement***	*0.994*	*4*	*Excellent Reliability*
All Questions		0.980	28	Excellent Reliability

Source: (Adopted from IBM SPSS Statistical Software, 2026)

The questionnaire was developed based on a comprehensive review of multiple previous studies related to adaptive learning systems and student engagement in blended and online learning environments. The independent variables and their measurement indicators were identified through a synthesis of existing literature covering personalization of learning content, adaptive feedback mechanisms, adaptive assessment and difficulty adjustment, and learning pace and path adaptation. The identified constructs and indicators were adapted and contextualized to suit the setting of diploma-level learners in blended English language education. Content validity was ensured through expert review, where academics with relevant experience in educational technology and higher education evaluated the relevance, clarity, and alignment of the questionnaire items with the research objectives. The reliability of the final questionnaire was assessed using Cronbach's Alpha, with all constructs demonstrating values above the acceptable threshold of 0.70, confirming the internal consistency and suitability of the instrument for further statistical analysis (Nunnally, 1978).

Data Analysis for the Relationship between Personalization of Learning Content and Student Engagement

Table 2: Statistical Analysis for Relationship between IV1 and Student Engagement (DV)

	Personalized Learning Content	Learning Materials Relevance	Recommended Learning Resources	Adaptive Content Sequencing	Targeted Learning Materials	Personalized Content
N (Valid)	125	125	125	125	125	125
Missing	0	0	0	0	0	0
Mean	1.48	2.02	1.91	1.78	1.91	2.25
Median	1	2	2	2	2	2
Mode	1	2	2	2	2	2
SD	0.714	0.875	0.609	0.473	0.609	0.715

Variable Group	Pearson Correlation Value	Chi-Square Value (Sig.)
Personalization of Learning Content	0.704	0.000

Source: (Adopted from IBM SPSS Statistical Software, 2026)

The objective of this study was to examine the relationship between personalization of learning content and student engagement in a blended learning environment. Six key indicators were identified under the independent variable:

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Personalized Learning Content, Learning Materials Relevance, Recommended Learning Resources, Adaptive Content Sequencing, Targeted Learning Materials, and Personalized Content. Data were collected from 125 respondents using a structured questionnaire to capture students' perceptions of these adaptive learning features. The findings revealed that all indicators of personalization contributed positively toward student engagement, with responses generally leaning toward agreement. The mean values ranged from 1.48 to 2.25, indicating that respondents largely agreed that personalized learning approaches enhance their engagement. Specifically, Personalized Learning Content recorded the lowest mean value (1.48), indicating the strongest agreement, followed by Adaptive Content Sequencing (1.78) and Recommended Learning Resources (1.91). Learning Materials Relevance (2.02) and Personalized Content (2.25) also showed positive responses, although slightly less strong. The standard deviation values ranged between 0.473 and 0.875, indicating relatively low variability and suggesting that respondents' opinions were fairly consistent. Furthermore, the Pearson correlation coefficient value was 0.704, indicating a strong positive relationship between personalization of learning content and student engagement. This suggests that as personalization increases, student engagement also increases significantly. In addition, the Chi-square significance value was 0.000, which is less than the significance level of 0.05, leading to the rejection of the null hypothesis and acceptance of the alternative hypothesis. This confirms that there is a statistically significant association between personalization of learning content and student engagement. Among the six indicators, Personalized Learning Content demonstrated the strongest agreement, highlighting its importance in enhancing engagement. Adaptive Content Sequencing and Recommended Learning Resources also played a significant role in supporting students' learning experiences. Although Personalized Content showed a relatively higher mean value, it still remained within the agreement range, indicating an overall positive perception across all indicators. These findings are consistent with the previous research on adaptable learning and student engagement. Pane et al. (2015) found that tailored learning environments improve student outcomes by adapting information to individual needs. Similarly, Dziuban et al. (2018) argue that adaptive and mixed learning approaches improve student engagement by offering flexible and personalized learning experiences. Furthermore, according to Dixson (2015) and Hrastinski (2019), engagement in online and blended environments increases when learning content is relevant and linked with students' needs and development. The study's substantial positive connection confirms these claims, suggesting that personalization is an important driver of student engagement. Overall, the data support the theoretical position that adaptive learning systems play an important role in increasing engagement, supporting the principles outlined in the literature review. This study adds to the expanding body of knowledge by giving empirical evidence that personalization of learning content increases student engagement in blended learning environments.

Data Analysis for the Relationship between Adaptive Feedback Mechanisms and Student Engagement

Table 3: Statistical Analysis for Relationship between IV2 and Student Engagement

	Timely Feedback	**Personalized Feedback**	**Feedback Clarity**	**Feedback for Improvement**	**Automated Feedback Usefulness**	**Adaptive Feedback Motivation**
N (Valid)	125	125	125	125	125	125
Missing	0	0	0	0	0	0
Mean	2.17	2.20	2.45	1.92	1.90	1.79
Median	2	3	2	2	2	2
Mode	2	3	2	2	2	2
SD	1.148	0.793	1.181	0.921	0.911	0.664

Variable Group	Pearson Correlation Value	Chi-Square Value (Sig.)
Adaptive Feedback Mechanisms	0.752	0.000

Source: (Adopted from IBM SPSS Statistical Software, 2026)

The objective of this section was to examine the relationship between adaptive feedback mechanisms and student engagement in the blended learning environment. Six indicators were used to measure adaptive feedback mechanisms:

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Timely Feedback, Personalized Feedback, Feedback Clarity, Feedback for Improvement, Automated Feedback Usefulness, and Adaptive Feedback Motivation. Data were collected from 125 respondents to understand how feedback-related features influence student engagement. The findings indicated that all feedback-related indicators positively contributed to student engagement, with responses generally leaning toward agreement. The mean values ranged from 1.79 to 2.45, suggesting that students perceived feedback mechanisms as beneficial to their learning experience. Among the indicators, Adaptive Feedback Motivation (1.79) and Feedback for Improvement (1.92) recorded lower mean values, indicating stronger agreement and highlighting their importance in enhancing engagement. In contrast, Feedback Clarity (2.45) showed a relatively higher mean value, suggesting slightly varied perceptions among respondents. The standard deviation values ranged from 0.664 to 1.181, indicating moderate variability in responses but overall acceptable consistency. Furthermore, the Pearson correlation coefficient value was 0.752, indicating a strong positive relationship between adaptive feedback mechanisms and student engagement. This implies that improvements in feedback systems significantly enhance student engagement levels. Additionally, the Chi-square significance value was 0.000, which is less than the threshold of 0.05, leading to the rejection of the null hypothesis and acceptance of the alternative hypothesis. Therefore, it can be concluded that there is a statistically significant association between adaptive feedback mechanisms and student engagement. Among the indicators, Adaptive Feedback Motivation emerged as one of the most influential factors, demonstrating that feedback that encourages and motivates learners plays a critical role in maintaining engagement. Similarly, timely and improvement-oriented feedback supports students in understanding their progress and enhancing their learning outcomes. The outcomes of this study are consistent with previous research on feedback and student involvement in online and blended learning contexts. According to Dixson (2015), timely and meaningful feedback is an important factor in student engagement since it allows students to stay connected with the course and understand their performance. Similarly, Van der Kleij et al. (2015) demonstrate that explicit and customized feedback enhances learning outcomes and engagement. Moreover, Hrastinski (2019) underlines the importance of interaction and feedback in effective blended learning settings, as they contribute to cognitive and emotional engagement. The strong positive association found in this study lends support to these theoretical viewpoints, indicating that adaptive feedback mechanisms are critical for increasing student engagement. Overall, the findings support the notions described in the literature review and show that adaptive feedback systems are critical for increasing active involvement, motivation, and sustained engagement in blended learning environments.

Data Analysis for the Relationship between Adaptive Assessment and Difficulty Adjustment and Student Engagement

Table 4: Statistical Analysis for Relationship between IV3 and Student Engagement (DV)

	Assessment Difficulty Alignment	**Adaptive Assessments**	**Assessment Challenge Balance**	**Progress Monitoring**	**Dynamic Assessment Adjustment**	**Adaptive Assessments Encouraging Participation**
N (Valid)	125	125	125	125	125	125
Missing	0	0	0	0	0	0
Mean	1.90	1.79	2.03	1.82	1.61	1.78
Median	2	2	2	1	1	2
Mode	2	2	2	1	1	2
SD	0.920	0.687	1.218	1.160	1.007	0.691

Variable Group	Pearson Correlation Value	Chi-Square Value (Sig.)
Adaptive Assessment and Difficulty Adjustment	0.791	0.000

Source: (Adopted from IBM SPSS Statistical Software, 2026)

The objective of this section was to examine the relationship between adaptive assessment and difficulty adjustment and student engagement in the blended learning environment. Six indicators were used to measure this construct:

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Assessment Difficulty Alignment, Adaptive Assessments, Assessment Challenge Balance, Progress Monitoring through Adaptive Assessments, Dynamic Assessment Adjustment, and Adaptive Assessments Encouraging Participation. Data were collected from 125 respondents to evaluate how assessment-related adaptability influences engagement. The findings revealed that all indicators contributed positively toward student engagement, with responses generally indicating agreement. The mean values ranged from 1.61 to 2.03, suggesting that students perceived adaptive assessment practices as effective in supporting their learning. Among the indicators, Dynamic Assessment Adjustment (1.61) recorded the lowest mean value, indicating the strongest agreement and highlighting its importance in maintaining appropriate difficulty levels. This was followed by Adaptive Assessments (1.79) and Adaptive Assessments Encouraging Participation (1.78), both of which demonstrate that adaptive assessment strategies play a significant role in enhancing engagement. In contrast, Assessment Challenge Balance (2.03) showed a relatively higher mean value, indicating some variation in how students perceive the balance between challenge and frustration. The standard deviation values ranged from 0.687 to 1.218, indicating moderate variability in responses, but overall acceptable consistency. Furthermore, the Pearson correlation coefficient value was 0.791, indicating a strong positive relationship between adaptive assessment and difficulty adjustment and student engagement. This suggests that when assessments are aligned with students' abilities and adjusted dynamically, engagement levels significantly improve. Additionally, the Chi-square significance value was 0.000, which is less than the significance threshold of 0.05, leading to the rejection of the null hypothesis and acceptance of the alternative hypothesis. Therefore, it can be concluded that there is a statistically significant association between adaptive assessment practices and student engagement. Among the indicators, Dynamic Assessment Adjustment and Adaptive Assessments emerged as key contributors, emphasizing the importance of continuously aligning assessment difficulty with student performance. These findings highlight that adaptive assessment systems not only support learning progress but also sustain student motivation and participation. The results are congruent with the existing literature on adaptive learning and evaluation. According to Pane et al. (2015), personalized and adaptive assessment systems increase student engagement by altering material and difficulty levels based on individual performance. Similarly, Zawacki-Richter et al. (2019) argue that intelligent adaptive systems improve learning experiences by offering personalized evaluation paths. Furthermore, Van der Kleij et al. (2015) argue that formative evaluations and adaptive feedback mechanisms are critical to boosting student performance and engagement. The substantial positive association found in this study lends support to these theoretical viewpoints, indicating that adaptive assessment and difficulty adjustment are important drivers of student engagement in mixed learning contexts. Overall, the findings confirm the notions described in the literature review, demonstrating that adaptive assessment systems are critical for maintaining optimal challenge levels, promoting learning progress, and increasing student engagement.

Data Analysis for the Relationship between Learning Pace and Path Adaptation and Student Engagement

Table 5: Statistical Analysis for Relationship between IV4 and Student Engagement (DV)

	Flexible Learning Pace	**Revisiting Learning Materials**	**Control over Learning Sequence**	**Adaptive Learning Path**	**Flexible Learning Paths**	**Learning Pace & Path Adaptation**
N (Valid)	125	125	125	125	125	125
Missing	0	0	0	0	0	0
Mean	1.90	1.91	1.91	1.91	1.67	1.78
Median	2	2	2	2	2	2
Mode	2	2	2	2	2	2
SD	0.954	0.951	0.951	0.951	0.520	0.679

Variable Group	Pearson Correlation Value	Chi-Square Value (Sig.)
Learning Pace and Path Adaptation	0.832	0.000

Source: (Adopted from IBM SPSS Statistical Software, 2026)

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The objective of this section was to examine the relationship between learning pace and path adaptation and student engagement in the blended learning environment. Six indicators were used to measure this construct: Flexible Learning Pace, Revisiting Learning Materials, Control over Learning Sequence, Adaptive Learning Path, Flexible Learning Paths, and Learning Pace and Path Adaptation. Data were collected from 125 respondents to evaluate how flexibility and adaptability in learning influence engagement. The findings revealed that all indicators contributed positively toward student engagement, with responses generally indicating agreement. The mean values ranged from 1.67 to 1.91, suggesting that students strongly perceive flexible learning environments as beneficial to their engagement. Among the indicators, Flexible Learning Paths (1.67) recorded the lowest mean value, indicating the strongest agreement and highlighting its importance in helping students manage their studies effectively. This was followed by Learning Pace and Path Adaptation (1.78) and other indicators such as Flexible Learning Pace, Revisiting Learning Materials, Control over Learning Sequence, and Adaptive Learning Path (all approximately 1.90–1.91), demonstrating consistent positive perceptions across all aspects. The standard deviation values ranged from 0.520 to 0.954, indicating relatively low variability and suggesting that responses were consistent among participants. Furthermore, the Pearson correlation coefficient value was 0.832, indicating a very strong positive relationship between learning pace and path adaptation and student engagement. This implies that greater flexibility and adaptability in learning significantly enhance student engagement. Additionally, the Chi-square significance value was 0.000, which is less than the threshold of 0.05, leading to the rejection of the null hypothesis and acceptance of the alternative hypothesis. Therefore, it can be concluded that there is a statistically significant association between learning pace and path adaptation and student engagement. Among the indicators, Flexible Learning Paths emerged as the most influential factor, emphasizing the importance of allowing students to manage their own learning processes. The ability to control learning pace, revisit materials, and follow adaptive learning paths further supports sustained engagement and improved learning experiences. The outcomes of this study are consistent with previous research on flexible and adaptive learning environments. According to Dziuban et al. (2018), blended learning environments that are flexible and adaptable improve student engagement and learning results. Similarly, Hrastinski (2019) emphasizes that learner control over speed and interaction is critical for enhancing engagement in online and mixed learning settings. Furthermore, Broadbent (2017) underlines that self-regulated learning, which includes the ability to manage pace and learning paths, is critical to student success and engagement. The very strong positive link found in this study lends support to these theoretical viewpoints, demonstrating the importance of flexible learning methods in modern educational environments. Overall, the findings support the principles described in the literature review and show that learning pace and path adaptation are important drivers of student engagement in blended learning environments, resulting in increased involvement, motivation, and learning outcomes.

Conclusions

Discussion of Findings and Theoretical Implications

The findings of this study demonstrate that adaptive learning system components, including personalization of learning content, adaptive feedback mechanisms, adaptive assessment and difficulty adjustment, and learning pace and path adaptation, are significantly associated with student engagement in blended learning environments. These findings extend existing theoretical perspectives by demonstrating how adaptive learning technologies operate within the Sri Lankan higher education context, particularly among diploma-level English language learners. From a Constructivist learning perspective, the findings indicate that personalized learning content and adaptive assessment mechanisms support students in constructing knowledge based on their individual learning requirements, prior knowledge, and learning progress. Constructivist theory emphasizes that learners actively develop knowledge through meaningful interaction with learning resources and experiences rather than passively receiving information (Piaget, 1972; Vygotsky, 1978). The findings of this study extend this perspective by demonstrating that adaptive learning technologies can facilitate personalized knowledge construction by dynamically adjusting learning materials and activities according to learner characteristics. Similar findings have been identified by Pane et al. (2015), who highlighted that personalized learning approaches improve learner outcomes by adapting instructional content to individual needs. Similarly, the findings support the principles of Self-Regulated Learning (SRL) theory, particularly through the significant relationship identified between learning pace and path adaptation and student engagement. Self-regulated learning emphasizes learners' ability to plan, monitor, and regulate their learning processes independently (Zimmerman, 2002). The ability of students to revisit learning materials, control their learning sequence, and progress according to their own pace reflects increased learner autonomy and self-management. Therefore, this study extends SRL theory by demonstrating that adaptive learning environments can strengthen students' self-regulatory behaviours through increased flexibility and control over learning activities. Furthermore, the findings contribute to Connectivism theory, which highlights the importance of learning through digital networks, technological resources, and continuous access to information (Siemens, 2005). Adaptive feedback mechanisms and personalized recommendations enable students to interact with

relevant digital learning resources and maintain continuous engagement within blended learning environments. Therefore, this study extends connectivism perspectives by demonstrating how adaptive technologies support meaningful digital interactions and personalized knowledge pathways. Although previous studies have extensively examined adaptive learning and student engagement internationally (Zawacki-Richter et al., 2019; Dziuban et al., 2018), this research provides a contextual contribution by examining diploma-level English language learners within the Sri Lankan higher education environment. Diploma students often represent diverse academic backgrounds, learning experiences, and levels of digital readiness (Asian Development Bank, 2022). Therefore, the findings provide context-specific evidence regarding how adaptive learning technologies can support engagement among learners in developing higher education contexts.

Managerial and Institutional Implications

The findings provide several practical implications for higher education institutions implementing blended learning programmes. Institutions should move beyond traditional Learning Management Systems (LMSs), which primarily provide access to learning materials and communication tools, towards adaptive learning environments that actively respond to individual learner needs. Traditional LMS platforms generally provide static content delivery, whereas adaptive systems use learner data to personalize learning pathways and instructional experiences (Woolf, 2010). To enhance personalization, institutions can integrate learning analytics systems to monitor student interaction patterns, engagement levels, assessment performance, and learning progress. Learning analytics enable institutions to identify students at risk of disengagement and provide timely academic interventions (Siemens & Baker, 2012). Furthermore, institutions may consider implementing AI-driven recommendation systems that provide personalized learning resources and activities based on student performance and learning behaviour. Artificial intelligence applications in education have the potential to improve personalization, automate feedback processes, and support individualized learning experiences (Zawacki-Richter et al., 2019). The findings related to adaptive assessment highlight the importance of implementing adaptive assessment engines that can modify assessment difficulty according to learner performance. Adaptive assessment approaches support formative learning by providing appropriate challenges and continuous feedback, thereby improving learner motivation and engagement (Van der Kleij et al., 2015). However, successful implementation requires strong faculty development programmes. Academic staff should develop digital competencies related to instructional design, learning analytics interpretation, AI-supported teaching practices, and technology-enhanced assessment strategies. Faculty readiness is considered a critical factor influencing successful technology adoption in higher education (Bingimlas, 2009). In addition, institutions require appropriate digital infrastructure, including reliable internet connectivity, integrated learning platforms, technical support services, and effective data management systems. Without adequate technological infrastructure, the benefits of adaptive learning systems may not be fully achieved (OECD, 2021). Compared with traditional LMS-based blended learning environments, adaptive learning systems provide a more responsive learning experience by dynamically modifying content, assessments, and learning pathways based on learner characteristics. Therefore, adaptive learning represents a progression from content delivery-focused LMS platforms towards intelligent learning environments that support personalization, learner autonomy, and continuous engagement (Woolf, 2010).

Limitations and Future Research Directions

Although this study provides valuable insights into adaptive learning and student engagement, several limitations should be acknowledged. First, the research employed a census approach involving 125 Diploma in English students from a single higher education institution. Therefore, the findings may reflect institution-specific characteristics, programme structures, and learner profiles. Consequently, the findings should be interpreted cautiously and should not be generalized directly to other institutions or academic disciplines.

Second, this study adopted a cross-sectional research design using a self-administered questionnaire collected at a single point in time. Therefore, the findings demonstrate statistically significant associations between adaptive learning components and student engagement rather than direct causal relationships. Future studies should adopt longitudinal approaches to examine whether adaptive learning influences engagement outcomes over extended periods. Additionally, since all variables were measured using the same questionnaire, the possibility of common method variance and social desirability bias should be acknowledged. Common method bias may occur when measurement of independent and dependent variables is collected from the same source using the same instrument (Podsakoff et al., 2003). Future research could address this limitation by incorporating multiple data sources, including instructor evaluations, system-generated learning analytics, and objective academic performance indicators. Future research should investigate the longitudinal effects of adaptive learning technologies, their influence on academic achievement, retention, and completion rates. Further studies could also explore AI-powered adaptive tutoring systems, cross-disciplinary comparisons, qualitative learner experiences, and multi-institutional validation to strengthen understanding of adaptive

learning adoption across different educational contexts. This study concluded that adaptive learning systems play a significant role in enhancing student engagement within blended learning environments. The findings revealed that students positively perceived personalized learning content, adaptive feedback mechanisms, adaptive assessment practices, and flexible learning pace and pathways as important contributors to their engagement, motivation, participation, and overall learning experience. Personalized learning content helped students engage more effectively by aligning learning materials with their individual needs and abilities, while adaptive feedback mechanisms supported continuous improvement through timely, clear, and motivating feedback. Similarly, adaptive assessment and difficulty adjustment enabled students to remain appropriately challenged and actively involved in the learning process. In addition, flexibility in learning pace and learning pathways allowed students to manage their studies more effectively, contributing to sustained engagement and improved learning satisfaction. The findings further confirmed that adaptive and learner-centered approaches are essential in modern blended learning environments, as they support autonomy, interaction, and continuous learning improvement. Based on these findings, the study recommended that educational institutions strengthen the implementation of adaptive learning technologies by improving personalization features, enhancing feedback systems, developing adaptive assessment strategies, and increasing flexibility in learning pathways. The recommendations also emphasized the importance of integrating learning analytics, interactive tools, and continuous monitoring mechanisms to ensure that adaptive learning systems effectively support student engagement and academic success. Despite providing valuable insights into the role of adaptive learning systems in enhancing student engagement, this study has several limitations that should be considered when interpreting the findings. First, the study was conducted using a census approach involving 125 Diploma in English students from a single higher education institution. Therefore, the findings may reflect the specific institutional environment, programme structure, student characteristics, and learning practices of the selected institution and may not be directly generalisable to other higher education institutions or student groups. Future research could address this limitation by incorporating multiple institutions, diverse academic programmes, and larger samples to enhance the generalisability of findings across different educational contexts. Furthermore, the study employed a cross-sectional research design in which data were collected at a single point in time using a self-administered questionnaire. Although this approach was appropriate for examining students' perceptions regarding adaptive learning systems and engagement, it may introduce potential common method bias and social desirability bias, as responses were collected from the same source using the same measurement method. Future studies may minimise these limitations by adopting longitudinal research designs, incorporating qualitative approaches such as interviews or focus groups, and collecting data from multiple sources, including instructors and institutional learning analytics.

This study concludes that adaptive learning systems significantly contribute to enhancing student engagement within blended learning environments. The findings revealed that personalization of learning content, adaptive feedback mechanisms, adaptive assessment and difficulty adjustment, and learning pace and path adaptation are positively associated with student engagement among Diploma in English students in Sri Lanka. The study contributes theoretically by demonstrating how adaptive learning technologies support constructivist learning, self-regulated learning, and connectivist learning principles within a diploma-level higher education context. While previous studies have widely examined adaptive learning internationally, this research extends existing knowledge by providing empirical evidence from Sri Lanka, where blended English language education among diploma learners remains relatively underexplored. From a practical perspective, higher education institutions should consider adaptive learning as a strategic approach rather than merely a technological enhancement. Effective implementation requires investment in learning analytics, AI-supported recommendation systems, adaptive assessment technologies, faculty development, and supporting digital infrastructure. By integrating these components, institutions can create more personalized, flexible, and engaging learning environments.

References

Asian Development Bank. (2022). *Education and skills development in Asia and the Pacific*. Asian Development Bank.

Asian Development Bank. (2022). *Higher education development in Asia*. https://www.adb.org/education

Bingimlas, K. A. (2009). Barriers to the successful integration of ICT in teaching and learning environments: A review of the literature. *Eurasia Journal of Mathematics, Science and Technology Education, 5*(3), 235–245. https://doi.org/10.12973/ejmste/75275

Broadbent, J. (2017). Comparing online and blended learner engagement. *Computers & Education, 107*, 1–12. https://doi.org/10.1016/j.compedu.2016.11.006

Broadbent, J. (2017). Comparing online and blended learners' self-regulated learning strategies. *Computers & Education, 107*, 63–75. https://doi.org/10.1016/j.compedu.2016.12.005

Carless, D., & Boud, D. (2018). The development of student feedback literacy. *Assessment & Evaluation in Higher Education, 43*(8), 1315–1325. https://doi.org/10.1080/02602938.2017.1412511

Dede, C. (2014). The role of digital technologies in deeper learning. *EDUCAUSE Review*. https://er.educause.edu/articles/2014/3/the-role-of-digital-technologies-in-deeper-learning

Dixson, M. D. (2015). Measuring student engagement in the online course. *Online Learning, 19*(3), 1–12. https://doi.org/10.24059/olj.v19i3.561

Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. *EDUCAUSE Review*. https://er.educause.edu/articles/2018/1/blended-learning-the-new-normal-and-emerging-technologies

Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. *International Journal of Educational Technology in Higher Education, 15*, Article 3. https://doi.org/10.1186/s41239-017-0087-5

Garrison, D. R., Anderson, T., & Archer, W. (2000). Critical inquiry in a text-based environment. *The Internet and Higher Education, 2*(2–3), 87–105. https://doi.org/10.1016/S1096-7516(00)00016-6

Godwin-Jones, R. (2018). Using mobile technology to develop language skills and cultural understanding. *Language Learning & Technology, 22*(3), 1–17. https://doi.org/10.1080/09588221.2018.1459851

Henrie, C. R., Halverson, L. R., & Graham, C. R. (2015). Measuring student engagement in technology-mediated learning. *Computers & Education, 90*, 36–53. https://doi.org/10.1016/j.compedu.2015.09.005

Hrastinski, S. (2019). What do we mean by blended learning? *TechTrends, 63*(5), 564–569. https://doi.org/10.1007/s11528-019-00375-5

Hrastinski, S. (2019). What do we mean by online learning? *International Journal of Educational Technology in Higher Education, 16*(1), 1–10. https://doi.org/10.1186/s41239-019-0173-7

Hrastinski, S., & Jaldemark, J. (2020). Online learning and engagement. *Distance Education, 41*(4), 488–503. https://doi.org/10.1080/01587919.2020.1727775

Hwang, G. J., Sung, H. Y., & Chang, S. C. (2016). Effects of adaptive learning. *Computers & Education, 82*, 204–212. https://doi.org/10.1016/j.compedu.2014.11.007

Jivet, I., Scheffel, M., Specht, M., & Drachsler, H. (2018). Awareness is not enough. *Educational Technology Research and Development, 66*(5), 1287–1309. https://doi.org/10.1007/s11423-018-9594-8

Jonassen, D. H. (2014). *Learning to solve problems*. Routledge. https://doi.org/10.4324/9780203847529

Klašnja-Milićević, A., Vesin, B., Ivanović, M., & Budimac, Z. (2017). E-learning personalization based on hybrid recommendation strategy. *Expert Systems with Applications, 65*, 368–382. https://doi.org/10.1016/j.eswa.2016.08.051

Moore, J. L. (2014). Effects of online interaction and learner autonomy. *Distance Education, 35*(1), 1–15. https://doi.org/10.1080/01587919.2014.899927

Nicol, D. (2010). From monologue to dialogue: Improving feedback practices. *Assessment & Evaluation in Higher Education, 35*(5), 501–517. https://doi.org/10.1080/02602931003786559

OECD. (2021). *Digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

Pane, J. F., Steiner, E. D., Baird, M. D., & Hamilton, L. S. (2015). *Continued evidence on personalized learning*. RAND Corporation. https://www.rand.org

Pane, J. F., Steiner, E. D., Baird, M. D., & Hamilton, L. S. (2015). *Continued progress: Promising evidence on personalized learning*. RAND Corporation.

Pardo, A., Han, F., & Ellis, R. A. (2019). Exploring engagement in personalized learning. *Computers & Education, 128*, 1–14. https://doi.org/10.1016/j.compedu.2018.09.012

Park, S., & Lee, Y. (2021). Adaptive assessment in online learning environments. *Sustainability, 13*(4), 2081. https://doi.org/10.3390/su13042081

Piaget, J. (1972). *The principles of genetic epistemology*. Basic Books.

Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., & Podsakoff, N. P. (2003). Common method biases in behavioural research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology, 88*(5), 879–903. https://doi.org/10.1037/0021-9010.88.5.879

Richards, J. C. (2017). Teaching English through digital platforms. *Language Teaching, 50*(4), 1–14. https://doi.org/10.1017/S0261444817000224

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning, 2*(1), 3–10. https://jotamac.typepad.com/jotamacs_weblog/files/Connectivism.pdf

Siemens, G. (2005). *Connectivism: A learning theory for the digital age*. International Journal of Instructional Technology and Distance Learning, 2(1), 3–10.

Siemens, G., & Baker, R. S. J. d. (2012). Learning analytics and educational data mining: Towards communication and collaboration. *Proceedings of the 2nd International Conference on Learning Analytics and Knowledge*, 252–254.

Tinto, V. (2012). *Completing college: Rethinking institutional action*. University of Chicago Press. https://press.uchicago.edu

Van der Kleij, F. M., Feskens, R. C. W., & Eggen, T. J. H. M. (2015). Effects of feedback in computer-based learning environments. *Computers & Education, 88*, 316–330. https://doi.org/10.1016/j.compedu.2015.03.015

Van der Kleij, F. M., Feskens, R. C. W., & Eggen, T. J. H. M. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. *Review of Educational Research, 85*(4), 475–511. https://doi.org/10.3102/0034654314564881

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Walkington, C. (2013). Using adaptive learning technologies. *Journal of Educational Psychology*. https://doi.org/10.1037/a0033120

Wisniewski, B., Zierer, K., & Hattie, J. (2020). The power of feedback revisited. *Frontiers in Psychology, 10*, 3087. https://doi.org/10.3389/fpsyg.2020.01351

Woolf, B. P. (2010). *Building intelligent interactive tutors: Student-centered strategies for revolutionizing e-learning*. Morgan Kaufmann.

Xie, K., Durrington, V., & Yen, L. L. (2011). Motivation and participation in online discussions. *MERLOT Journal of Online Learning and Teaching, 7*(1), 1–10. https://www.researchgate.net/publication/257153780

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). AI in higher education. *International Journal of Educational Technology in Higher Education, 16*(1), 1–19. https://doi.org/10.1186/s41239-019-0171-0

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education. *International Journal of Educational Technology in Higher Education, 16*, Article 39. https://doi.org/10.1186/s41239-019-0171-0

Zimmerman, B. J. (2002). Becoming a self-regulated learner. *Theory Into Practice, 41*(2), 64–70. https://doi.org/10.1207/s15430421tip4102_5

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice, 41*(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2

Zimmerman, B. J., & Schunk, D. H. (2011). *Handbook of self-regulation of learning and performance*. Routledge. https://doi.org/10.4324/9780203839012

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OP 03

The Remuneration Paradox: Reconciling Managerial Intent and Staff Dissatisfaction

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Abstract

Introduction: Voluntary employee turnover remains a major challenge in the hospitality industry, particularly among hotel housekeepers. This study proposes the Remuneration Paradox as a novel concept explaining the mismatch between managers' perceptions of competitive remuneration and employees' experiences of financial dissatisfaction under different macroeconomic conditions.

Objectives: This study examines how macroeconomic conditions influence the relationship between remuneration and employee retention in three-star hotels in Finland and Sri Lanka and evaluates the theoretical implications for employee motivation.

Methods: Guided by a pragmatist philosophy, this deductive mixed-methods study involved 120 housekeeping employees and 20 hotel managers from eight three-star hotels (four per country). The final analysis included 61 valid employee questionnaires and six manager interviews. Quantitative data were analysed using Ordinary Least Squares (OLS) regression, qualitative data using thematic analysis, and findings were integrated through methodological triangulation.

Results: In Finland, remuneration significantly predicted employee retention ($\beta = 0.747$, $p = .034$). In Sri Lanka, remuneration was not a significant predictor ($\beta = -0.027$, $p = .888$), whereas training and development was the only significant predictor ($\beta = 0.440$, $p = .023$). Qualitative findings showed that macroeconomic instability, including inflation, tax increases, and declining service charges, reduced the motivational value of remuneration and widened the gap between managerial intentions and employees' financial realities.

Conclusions: The findings extend Herzberg's Two-Factor Theory by demonstrating that the motivational role of remuneration is context-dependent. Hotel managers should stabilise service charges, review remuneration in line with inflation, and establish competency-based career pathways. The proposed Remuneration Paradox may also inform retention strategies in other labour-intensive service industries experiencing macroeconomic instability.

Keywords: *Employee retention; Housekeeping employees; Macroeconomic instability; Mixed methods; Remuneration Paradox.*

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Introduction

The tourism and hospitality sector is a primary driver of economic growth in the global service economy, relying on a large, labour-intensive workforce to ensure consistent customer experiences [1,2]. Within this framework, ground-level hospitality workers, particularly those in housekeeping, play a pivotal role in maintaining service quality, influencing customer satisfaction metrics, and shaping the financial organization's performance [3]. Despite their operational significance, the industry is characterized by persistently high rates of voluntary employee turnover [4,5]. The hidden costs of ongoing recruitment cycles, including reduced room turnover efficiency, training delays, reduced service standards, and the erosion of institutional knowledge, pose significant operational challenges [6], especially for mid-tier lodging establishments

Housekeepers constitute the largest workforce segment in the hospitality sector. Yet, they are among the lowest-paid and experience the heaviest workloads, the highest levels of interpersonal strain, and the greatest occupational stress [4]. This group operates at the intersection of high physical demands, limited socio-economic rewards, and considerable social stigma. The resulting "effort-reward imbalance" is well documented in occupational health literature as a primary driver of burnout, psychological withdrawal, and eventual workforce attrition [2]. Management's perception of this imbalance often diverges significantly from employees' lived experiences.

This study introduces the Remuneration Paradox as a novel conceptual contribution. The paradox extends existing motivation theories by demonstrating that employees' perceptions of remuneration are influenced by both organisational reward systems and the broader macroeconomic environment. It explains why remuneration can effectively support employee retention in economically stable contexts but may lose its motivational value during periods of inflation and economic instability. This perceptual gap is particularly evident when comparing distinct socioeconomic contexts, such as a regulated Nordic welfare state (Finland) and a volatile, inflationary emerging economy (Sri Lanka).

To analyze this paradox, it is essential to consider employee retention mechanisms through established theoretical frameworks, specifically Herzberg's Two-Factor Motivation-Hygiene Theory and Blau's Social Exchange Theory [7,8,9]. Herzberg's framework distinguishes between "hygiene factors"—extrinsic elements such as base salary, job security, and working conditions that prevent dissatisfaction—and "motivators," which are intrinsic factors like recognition, advancement, and personal development that foster commitment [10]. In stable, developed economies, empirical studies generally support this distinction, with base compensation regarded as a fundamental hygiene factor.

Social Exchange Theory similarly asserts that organizational relationships are structured by reciprocal obligations [7]. When employees perceive authentic organizational investment in their financial well-being and professional development, they are more likely to reciprocate with increased loyalty, productivity, and lower turnover intentions [11]. Conversely, perceived breaches of this psychological contract often result in immediate withdrawal behaviors [12].

Building on these theories, this study argues that macroeconomic conditions influence how employees interpret remuneration. Consequently, Herzberg's distinction between hygiene and motivational factors should be understood as context-dependent rather than universally applicable.

Implementing retention strategies in hotel housekeeping operations presents significant challenges, especially outside Western economic contexts. Recent research in hospitality indicates that in economically volatile or low-wage sectors, the distinction between hygiene and motivational factors often disappears. When compensation packages fail to ensure basic economic survival amid macroeconomic instability, they become both a major source of dissatisfaction and a key motivational factor. While existing literature predominantly focuses on luxury five-star properties or management-level employees, this study centers on mid-range, three-star lodging establishments. These hotels operate with limited resources and lack the financial reserves of international luxury chains, rendering them particularly vulnerable to operational disruptions and reliant on localized retention strategies.

Objectives: This study aims to examine the perceptual and operational gaps in remuneration strategies between management and ground-level housekeeping staff, and to assess how macroeconomic volatility influences conventional employee retention pathways.

Methods

Study Design and Setting

The research adopted a pragmatist philosophy, emphasizing practical problem-solving and actionable operational outcomes rather than strict adherence to a single methodological paradigm. Pragmatism enabled the integration of objective statistical measurement with in-depth qualitative narrative analysis, supporting a comprehensive examination of complex operational environments [13]. Employing a deductive approach, the study utilized a mixed-methods

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multiple-case design across eight 3-star hotels. To ensure geographic, economic, and institutional diversity, research sites were equally distributed between the Vaasa region of Finland (n = 4) and the Central Province of Sri Lanka (n = 4).

Participant Characteristics

The research population consisted of 140 individuals, deliberately stratified to represent both ends of the operational hierarchy. This sample included 120 housekeeping professionals responsible for daily room turnover and 20 hotel management executives overseeing human resource strategy and financial reward structuring.

Data collection

Quantitative data were collected using simple random sampling among housekeeping teams, ensuring each worker had an equal probability of participation and minimizing selection bias. Data were gathered through a standardized, self-administered survey instrument employing a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The survey measured five independent dimensions identified in the literature: Remuneration and Rewards, Training and Development, Work-Life Balance, Supervisory Support, and Work Stress. The primary dependent variable was Employee Retention Intention. To ensure comprehension and cultural understanding, the survey was translated into English, Finnish, and Sinhala and administered in those languages. Qualitative data collection employed purposive sampling to identify hospitality managers and operational supervisors with contextual insights into local retention dynamics. A total of 61 validated quantitative surveys were returned (50.8% response rate), and six semi-structured qualitative interviews were conducted with executive personnel. The quantitative and qualitative findings were integrated using methodological triangulation. Regression results identified country-specific differences in employee retention predictors, while qualitative interview findings were used to explain the underlying organisational and macroeconomic mechanisms responsible for these differences.

Statistical Analysis

Quantitative data were analyzed using SPSS software (Version 28). The analysis included descriptive statistics to profile workforce demographics, Pearson correlation coefficients to assess bivariate relationships, and multivariable ordinary least squares (OLS) regression models to evaluate the predictive strength of independent variables on retention intentions. Qualitative interview transcripts were analyzed using a six-step thematic analysis protocol, progressing from raw text to first-order conceptual codes and then to aggregate operational themes [14].

Results

Descriptive Statistics

Demographic profiling revealed significant contrasts between the two research settings. The overall dataset comprised 62.3% male and 34.4% female participants. Country-specific analysis showed inverse labor structures: the Finnish subsample was predominantly female (65.0%) and relied mainly on part-time contracts (75.0%), while the Sri Lankan subsample was mostly male (80.5%) and engaged primarily in full-time employment (75.6%).

Descriptive score profiling on the 5-point Likert scale indicated high baseline satisfaction among the Finnish cohort. Finnish housekeepers reported strong satisfaction with remuneration (M = 4.21, SD = 0.71) and high retention intentions (M = 4.25, SD = 0.76). In contrast, the Sri Lankan sample reported lower satisfaction with remuneration (M = 2.80, SD = 1.36) and lower retention intentions (M = 2.93, SD = 1.35). The survey demonstrated strong internal consistency and reliability, with a cumulative Cronbach's Alpha of 0.834.

Quantitative Findings

Bivariate Pearson correlation analyses indicated that, globally, Remuneration and Rewards ($r = .713$, $p < .01$) and Training and Development ($r = .799$, $p < .01$) were positively and significantly associated with workforce retention. The global OLS linear regression model produced an R2 of 0.686, demonstrating that 68.6% of the variance in employee retention was explained by the five organizational predictors combined ($F(5,55) = 24.078$, $p < .001$).

When regression modelling was conducted separately by country to isolate macroeconomic effects, a marked divergence emerged that challenged standard theoretical assumptions:

- **Finland Model:** Remuneration and Rewards was a statistically significant positive predictor of employee retention ($\beta = 0.747$, $t = 2.348$, $p = .034$). In this high-welfare context, other dimensions, including Training

and Development and Supervisory Support, did not achieve statistical significance as primary drivers of retention ($p > .05$).

- **Sri Lanka Model:** In the emerging market context, Training and Development was the only statistically significant positive predictor of retention ($\beta = 0.440$, $t = 2.372$, $p = .023$). Remuneration and Rewards did not predict staff retention ($\beta = -0.027$, $t = -0.142$, $p = .888$).

Qualitative Findings

Qualitative thematic analysis was integrated with the quantitative findings to explain the unexpected regression result observed in Sri Lanka, where remuneration failed to predict employee retention despite widespread financial dissatisfaction. Hospitality executives maintained that their internal reward structures were fair and comprehensive, emphasizing non-cash benefits to justify compensation models. A representative quote from Interviewee 2 highlighted this managerial perspective: *"As a mid-chain hotel... it is not only the remuneration part; it is about the overall package... We are guaranteed a service charge and a basic salary... More than remuneration, we should provide them a safe environment."* In contrast, interviews with operational shift leaders revealed a different financial reality shaped by macro-level fiscal adjustments beyond the hotel's control. Interviewee 6 described the Remuneration Paradox: *"I am not 100% happy with the salary... with the new VAT%, staff is getting a lower service charge... service charge dropped by half... If staff's income does not match their expenses, they are more likely to leave."*

Discussion

The findings have important implications for how people manage workers across different economies. The results question the assumption that Western motivation theories work everywhere, especially those used in teaching hospitality management.

Theoretical Implications

Traditional models, such as Herzberg's Two-Factor Theory, assume that motivational categories apply uniformly across regions and cultures [8,10]. However, this study shows that external economic stability strongly affects how internal organizational factors operate. The Finnish cohort's data align with standard Western management theory. In stable economies with strong safety nets, labor laws, and low inflation, base compensation acts as Herzberg predicted. It becomes a predictable baseline that, when met, links to long-term retention.

By contrast, Sri Lankan data reveals a key limitation within established theories. In volatile emerging economies with currency devaluation and rapid inflation, the distinction between hygiene factors and intrinsic motivators breaks down. Under these pressures, hygiene factors such as pay become the main sources of dissatisfaction. When wages do not meet basic needs, pay shifts from a silent factor to a core friction point. This setting calls for a flexible, context-driven use of motivation theories for HR practitioners in the Global South.

The present findings extend Herzberg's Two-Factor Theory by demonstrating that remuneration cannot always be regarded as a stable hygiene factor. In contexts characterized by macroeconomic instability, inflation, and declining purchasing power, remuneration loses its conventional motivational role and instead becomes a persistent source of dissatisfaction, a phenomenon referred to as the Remuneration Paradox.

This research extends the application of Social Exchange Theory to low-wage labor [7,11]. Findings show that ground-level workers assess a company's investment based on local labor market conditions. White-collar staff see training as a path to prestige or better performance. Yet, housekeepers in volatile economies view structural training as critical for career progress and survival. Regression models show that in Sri Lanka, a volatile economy, non-monetary training is the only statistically significant factor for retention ($\beta = 0.440$). As a result, the social exchange shifts from loyalty to a focus on personal skill development.

Practical Implications

The Remuneration Paradox persists because hotel management and employees use different frameworks to assess rewards. Management views compensation as an institutional cost. Human resource directors' total spending on wages, insurance, service charges, uniforms, and food. From this top-down view, the investment is seen as complete, competitive, and fair [12]. Executive interviews support this. Managers cite "the overall package" to justify lower base wages.

Ground-level staff use a real-world survival perspective to judge compensation. They measure take-home pay against the rising costs for family, energy, and inflation, not company spending [4,7]. When higher VAT or inflation reduces the value of service fees, non-cash benefits such as meals or uniforms do not relieve family financial pressures.

This gap creates an operational divide. Management sees a supportive environment but feels frustrated by turnover. Employees, facing financial stress, see pay as an ineffective retention tool. Unless managers connect the institutional cost view with workers' real-world needs, voluntary turnover among housekeepers will likely stay too high.

Practically, hotel operators should introduce minimum guaranteed service charges, periodically review wage structures in line with inflation, and establish transparent competency-based career pathways. These interventions reduce employees' financial uncertainty while strengthening long-term organisational commitment.

Conclusions

Economic volatility changes standard motivation, turning hygiene baselines into dissatisfaction triggers. The Remuneration Paradox is a structural clash between rigid pay models and changing economic conditions. To solve this, mid-tier hospitality operators in emerging markets should move from incentive-driven pay to strategies that stabilize compensation.

First, operators should stabilize the service charge. A guaranteed minimum can provide housekeepers with predictable pay, reducing anxiety during downturns and protecting workers from distress. Second, HR teams must clearly communicate advancement pathways, as results show this predicts retention. Staff need clear maps tying skill mastery to regular raises and promotions, recasting roles as stable careers.

While initially developed for the hotel industry, the proposed Remuneration Paradox provides a useful theoretical lens for analyzing employee retention in other labour-intensive service sectors, such as healthcare, retail, logistics, and food services, especially in contexts characterized by sustained macroeconomic instability.

Future research should track staff over time to see how pay or macroeconomic instability affects employee retention decisions. Studies should also examine how new work technologies affect job satisfaction and staff turnover across different cultures.

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References

1. Morgan N, Pritchard A. Gender matters in hospitality (invited paper for 'luminaries' special issue of International Journal of Hospitality Management). International Journal of Hospitality Management. 2018;76. https://doi.org/10.1016/j.ijhm.2018.06.008
2. Rosemberg MAS. Effort-reward imbalance and work productivity among hotel housekeeping employees: a pilot study. Workplace Health & Safety. 2018;66(11):512-520. https://doi.org/10.1177/2165079918755803
3. Alcalde-González V, Mozo A, Bustos A. No clean rooms, no hotel business: Subversion tactics in Las Kellys' struggle for dignity in hotel housekeeping. Annals of Tourism Research. 2021;91:103315. https://doi.org/10.1016/j.annals.2021.103315
4. Andrade M, Miller D, Westover J. Job satisfaction factors for housekeepers in the hotel industry: a global comparative analysis. International Hospitality Review. 2021;35(1). https://doi.org/10.1108/IHR-06-2020-0018
5. Huo Y. Employee retention: relationship among housekeepers' job satisfaction, organizational workforce, and racial-ethnicity within the global hospitality industry in Utah, U.S.A., finding stability in a volatile hospitality industry. Arts and Humanities Open Access Journal. 2019;3(1):32. https://doi.org/10.15406/ahoaj.2019.03.00101
6. Hsieh YC, Hirudayaraj M, Hsieh W. Rethinking housekeeping job quality: insights from hotel housekeepers and managers. Current Issues in Tourism. 2025;28(3):156-173. https://doi.org/10.1080/13683500.2025.2456082
7. Blau, P. Exchange and power in social life. Wiley; 1964.
8. Ozsoy E. An empirical test of Herzberg's two-factor motivation theory. Marketing and Management of Innovations. 2019;10(1):11-20. https://doi.org/10.21272/mmi.2019.1-01
9. Cropanzano R, Mitchell M. Social exchange theory: an interdisciplinary review. Journal of Management. 2005;31(6). https://doi.org/10.1177/0149206305279602
10. Shinde S. Motivators and hygiene factors in employee retention: insights from Herzberg theory. International Multidisciplinary Research Journal. 2025;12(5):24-32. https://doi.org/10.53573/rhimrj.2025.v12n5.013
11. Xuecheng W, Iqbal Q, Saina B. Factors affecting employees' retention: integration of situational leadership with social exchange theory. Frontiers in Psychology. 2022; 13:872105. https://doi.org/10.3389/fpsyg.2022.872105

12. Samarakoon D. Why some stay, and others leave? A comparative study of retention factors affecting ground-level housekeeping staff among 3-star hotels in Finland and Sri Lanka [Master's thesis]. Vaasa (FI): University of Vaasa; 2025. Available from: https://osuva.uwasa.fi/bitstreams/a06bed4a-2f21-48d8-9d1d-5a20f2bcaa7b/download
13. Saunders M, Lewis P, Thornhill A. Research methods for business students. 9th ed. Pearson Education Limited; 2023.
14. Braun V, Clarke V. Using thematic analysis in psychology. Qualitative Research in Psychology. 2006;3(2):77-101. https://doi.org/10.1191/1478088706qp063oa

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OP 04

Sustainable Luxury Consumption and Brand Equity of Artisanal Apparel: A Strategic Management Perspective on Handmade Embroidery Entrepreneurs in Galle District

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Abstract

The Sri Lankan textile craft sector plays an important role in preserving cultural heritage, supporting local entrepreneurship, and contributing to sustainable economic development. With increasing consumer awareness of ethical production, sustainability, and authenticity, handmade artisanal products have gained greater recognition within luxury fashion markets. This study examines the relationship between sustainable luxury consumption factors and brand equity among micro-level handmade embroidery entrepreneurs in the Galle District, Sri Lanka. Guided by the Saunders Research Onion framework, the study adopts a positivist philosophy, deductive approach, and quantitative methodology using a descriptive research design. Data were collected through a structured questionnaire distributed among 100 handmade embroidery entrepreneurs. The study evaluates key factors including luxury value perception, brand storytelling authenticity, premium design quality, and sustainable branding perception. The findings reveal significant positive relationships between sustainable luxury consumption factors and brand equity, with brand storytelling authenticity demonstrating the strongest relationship. The study contributes to sustainable luxury and strategic management literature by highlighting how cultural heritage, craftsmanship, and sustainability practices support artisanal brand development within a developing economy. The findings provide practical insights for handmade entrepreneurs seeking to strengthen brand positioning, customer relationships, and long-term brand development through sustainable branding strategies.

Keywords: *Artisanal entrepreneurship, Brand equity, Galle district, Handmade embroidery, Strategic management, Sustainable luxury.*

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Introduction

The global fashion industry has experienced a significant transformation due to the growing awareness of sustainability, ethical production, and cultural authenticity among consumers. Rather than purchasing mass-produced fashion products, many consumers increasingly prefer products that reflect environmental responsibility, traditional craftsmanship, and exclusivity [1]. Sustainable luxury combines premium product characteristics with ethical, environmental, and socially responsible production practices. As a result, luxury is no longer defined solely by price or prestige but also by authenticity, sustainability, and emotional value, making these attributes important drivers of consumer purchasing behaviour [1]. Consequently, artisanal fashion products, particularly handmade embroidery apparel, have gained increasing recognition among consumers who value sustainable and ethically produced fashion.

Sri Lanka has a rich cultural heritage in traditional textile craftsmanship and handmade embroidery, which contributes not only to preserving indigenous knowledge but also to supporting local economic development, rural livelihoods, and small-scale entrepreneurship. Handmade embroidery entrepreneurs in the Galle District represent an emerging group of micro and small-scale business owners who successfully combine traditional craftsmanship with contemporary fashion trends. These entrepreneurs play an important role in promoting sustainable fashion while preserving cultural identity through their products. Previous studies have reported that sustainable luxury products positively influence consumer trust and long-term loyalty [2]. Likewise, storytelling authenticity strengthens emotional attachment between consumers and brands by communicating cultural heritage, craftsmanship, and sustainability commitments [3]. Through authentic storytelling, artisanal entrepreneurs are able to differentiate their products and establish stronger relationships with consumers.

In addition to storytelling, premium product design and visual presentation significantly influence sustainable luxury consumption. Consumers within sustainable fashion markets often evaluate products based on craftsmanship, uniqueness, aesthetic appeal, and ethical sourcing practices [4]. Furthermore, digital platforms such as Instagram and Facebook have created new opportunities for small-scale fashion entrepreneurs to showcase their craftsmanship, communicate their brand values, and directly engage with niche customer segments. These platforms have become valuable marketing tools that enable artisanal businesses to increase visibility and strengthen customer relationships despite limited financial resources.

Although sustainable fashion and luxury branding have received considerable attention in previous research, most existing studies have focused on international luxury brands or large-scale fashion organisations operating in developed economies. Comparatively little research has examined sustainable luxury consumption and brand equity among micro-level handmade embroidery entrepreneurs within developing countries such as Sri Lanka. Therefore, limited empirical evidence exists regarding how sustainability-oriented branding practices influence brand equity development among small-scale artisanal businesses.

This represents an important research gap because small artisanal businesses operate under different market conditions, resource constraints, and branding challenges compared with established luxury brands. Understanding how sustainable luxury factors influence brand equity within this context contributes to both strategic management literature and the growing body of knowledge on sustainable entrepreneurship.

From a strategic management perspective, handmade embroidery entrepreneurs face several challenges, including limited financial resources, increasing market competition, difficulties in developing strong brand recognition, and changing consumer expectations. Strategic practices such as sustainable branding, authentic storytelling, premium product positioning, and customer relationship management have therefore become increasingly important for achieving long-term brand development and competitive advantage. Examining these factors provides valuable insights into how artisanal entrepreneurs can strengthen their market position while maintaining their cultural authenticity and sustainability commitments.

Therefore, this study aims to examine the relationship between sustainable luxury consumption factors and brand equity among handmade embroidery entrepreneurs in the Galle District of Sri Lanka. Specifically, the study investigates the relationship between luxury value perception, brand storytelling authenticity, premium design quality, sustainable branding perception, and brand equity among handmade embroidery entrepreneurs. By focusing on micro-level artisanal entrepreneurs operating in a developing economy, this study extends existing research on sustainable luxury and

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provides practical strategic recommendations for strengthening artisanal brands in both domestic and international markets.

Conceptual framework

Based on the reviewed literature, this study develops a conceptual framework to examine the relationship between sustainable luxury consumption factors and brand equity among handmade embroidery entrepreneurs. [1–4]. The framework proposes that luxury value perception, brand storytelling authenticity, premium design quality, and sustainable branding perception influence brand equity. These factors represent strategic resources that enable artisanal entrepreneurs to differentiate their products, strengthen customer relationships, and develop sustainable competitive advantages.

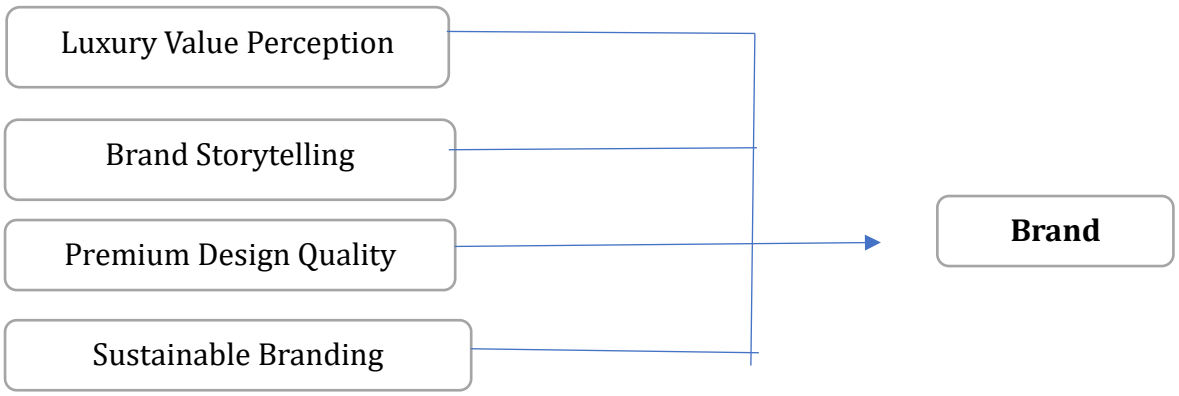

Figure 17 Conceptual framework

Objectives

1) To examine the relationship between luxury value perception and brand equity among handmade embroidery entrepreneurs.
2) To examine the relationship between brand storytelling authenticity and brand equity among handmade embroidery entrepreneurs.
3) To examine the relationship between premium design quality and brand equity among handmade embroidery entrepreneurs.
4) To examine the relationship between sustainable branding perception and brand equity among handmade embroidery entrepreneurs.

Methods

This study adopted the Saunders Research Onion framework to systematically guide the research process from the selection of the research philosophy to the data analysis techniques [5]. The study was conducted using a positivist research philosophy because it aimed to objectively examine the relationships between sustainable luxury consumption factors and brand equity among handmade embroidery entrepreneurs. A deductive research approach was adopted as the study examined relationships developed from existing theories and previous literature on sustainable fashion, strategic brand management, and consumer behaviour. Accordingly, a quantitative research methodology with a descriptive research design was employed to collect numerical data and examine the associations between the study variables [5].

The target population consisted of handmade embroidery entrepreneurs operating in the Galle District, Sri Lanka. Since a comprehensive sampling frame for this specific group was unavailable, a convenience sampling technique was used to recruit participants who were actively engaged in handmade embroidery businesses and were willing to participate in the study. A total of 100 entrepreneurs completed the questionnaire. The selected sample was considered appropriate

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because it included active entrepreneurs directly involved in the handmade embroidery industry, enabling the study to obtain relevant information regarding sustainable luxury consumption and brand management practices within the selected research context.

Primary data were collected using a structured questionnaire developed based on established literature related to sustainable luxury consumption, brand equity, strategic management, and consumer behaviour [1–5]. The questionnaire was designed to measure the independent variables of Luxury Value Perception, Brand Storytelling Authenticity, Premium Design Quality, and Sustainable Branding Perception, while Brand Equity served as the dependent variable. The questionnaire consisted of two sections. The first section collected demographic information, including gender, age group, educational qualifications, and business experience. The second section included statements measuring each research construct using a five-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree.

To ensure the quality of the questionnaire, the survey instrument was developed based on previously published studies on sustainable luxury consumption, brand equity, storytelling authenticity, and strategic management [1–5]. The questionnaire items were adapted from established concepts identified in the literature to ensure appropriate measurement of the research constructs. Content validity was established through a review by the research supervisor, who evaluated the clarity, relevance, and suitability of the questionnaire items. Based on the feedback received, minor wording revisions were made to improve readability, consistency, and the overall quality of the questionnaire before it was distributed to the respondents. Although a formal pilot test was not conducted, the questionnaire was carefully reviewed to ensure its suitability for the study.

Results

Table 13: Demographic Distribution of Respondents

Variable	Frequency	Percentage
Male	35	35%
Female	65	65%
Age 26–30	42	42%
Diploma/HND Holders	58	58%

The demographic analysis presented in Table 1 indicates that the majority of respondents were female entrepreneurs operating handmade embroidery businesses in the Galle District. Furthermore, most respondents belonged to the 26–30 age category, while a significant proportion possessed Diploma or Higher National Diploma (HND) qualifications. This suggests that the sample consisted mainly of relatively young and professionally educated entrepreneurs engaged in artisanal fashion businesses.

Table 14: Reliability Statistics

Cronbach's Alpha	Number of Items
0.948	20

The reliability analysis presented in Table 2 shows a Cronbach's Alpha value of 0.948 for the 20 questionnaire items. According to established reliability standards, this value indicates excellent internal consistency among the measurement items. Therefore, the instrument demonstrated a high level of reliability for measuring sustainable luxury consumption factors and brand equity.

Table 15: Descriptive Statistics of Study Variables

Variable	Mean	Standard Deviation
Brand Equity	3.89	0.91
Luxury Value Perception	3.76	0.88
Brand Storytelling Authenticity	4.14	0.80

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Variable	Mean	Standard Deviation
Premium Design Quality	4.09	0.83
Sustainable Branding Perception	3.97	0.85

The descriptive statistics presented in Table 3 indicate generally positive perceptions among respondents regarding sustainable luxury consumption practices and artisanal brand management. Among the examined variables, Brand Storytelling Authenticity recorded the highest mean value (4.14), followed by Premium Design Quality (4.09) and Sustainable Branding Perception (3.97). This indicates that respondents strongly recognised the importance of authenticity, craftsmanship, and sustainability in developing stronger artisanal brands.

Table 16: Correlation Analysis

Variables	Pearson Correlation	Significance
Brand Storytelling Authenticity and Brand Equity	0.734	0.01
Premium Design Quality and Brand Equity	0.681	0.01
Luxury Value Perception and Brand Equity	0.629	0.01
Sustainable Branding and Brand Equity	0.603	0.01

The Pearson correlation analysis presented in Table 4 identified statistically significant positive associations between all sustainable luxury consumption factors and brand equity. Brand Storytelling Authenticity demonstrated the strongest correlation with brand equity ($r = 0.734$, $p < 0.01$), followed by Premium Design Quality ($r = 0.681$, $p < 0.01$), Luxury Value Perception ($r = 0.629$, $p < 0.01$), and Sustainable Branding Perception ($r = 0.603$, $p < 0.01$). These findings indicate that stronger perceptions of authenticity, design quality, luxury value, and sustainability are associated with higher levels of brand equity among handmade embroidery entrepreneurs.

Discussion

The findings of this study demonstrate that sustainable luxury consumption factors are significantly associated with brand equity among handmade embroidery entrepreneurs in the Galle District. The results highlight that authenticity, premium craftsmanship, perceived luxury value, and sustainable branding are important strategic factors for strengthening artisanal brands within a competitive fashion environment.

Among the examined factors, Brand Storytelling Authenticity recorded the strongest relationship with brand equity. This finding supports previous research suggesting that authentic storytelling enhances emotional connections between consumers and brands by communicating cultural heritage, craftsmanship, and ethical values [3]. From the perspective of Brand Equity Theory, strong brand associations and emotional connections contribute to greater consumer trust, loyalty, and perceived brand value. Handmade embroidery entrepreneurs possess unique cultural narratives related to traditional skills and craftsmanship, which can be strategically used to differentiate their products from mass-produced alternatives.

The positive relationship between Premium Design Quality and Brand Equity highlights the importance of craftsmanship, uniqueness, and aesthetic appeal within sustainable luxury markets. According to Consumer Perceived Value Theory, consumers evaluate products based on functional, emotional, and social value. Handmade embroidery products provide consumers with symbolic value through exclusivity, artistic creativity, and cultural meaning. Therefore, maintaining high quality designs and preserving craftsmanship standards can enhance consumer perceptions of luxury and strengthen brand positioning.

Furthermore, the findings indicate that Luxury Value Perception is positively associated with brand equity. This suggests that consumers recognise handmade embroidery products as valuable due to their uniqueness, authenticity, and limited availability. Unlike conventional luxury products that are primarily associated with prestige and price, sustainable luxury products create value through ethical production, cultural identity, and emotional experiences.

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The positive association between Sustainable Branding Perception and Brand Equity demonstrates the increasing importance of environmental and ethical considerations in consumer decision-making. Through the perspective of Signalling Theory, sustainable branding activities act as signals that communicate responsible business practices, ethical production methods, and long term commitment to social and environmental values. Entrepreneurs who demonstrate sustainability through responsible sourcing, eco-friendly materials, and transparent communication may strengthen consumer confidence and brand reputation.

The findings also support the Resource-Based View (RBV) of strategic management, which suggests that unique internal resources and capabilities can create competitive advantage. For handmade embroidery entrepreneurs, cultural knowledge, traditional craftsmanship skills, authentic storytelling ability, and sustainable practices represent valuable resources that are difficult for competitors to imitate. Effectively managing these resources can help small scale businesses develop stronger market positions and achieve long term sustainability.

Additionally, the study highlights the strategic importance of digital marketing platforms for artisanal brand development. Social media channels such as Instagram and Facebook provide opportunities for entrepreneurs to visually communicate product quality, cultural heritage, and sustainability commitments to wider audiences. Digital branding strategies can therefore support customer engagement, increase market visibility, and create opportunities for domestic and international expansion. Entrepreneurs can further strengthen digital branding by using storytelling-based content, online product demonstrations, and direct customer interaction to communicate authenticity and sustainability values effectively. Handmade embroidery entrepreneurs can operationalise storytelling authenticity by documenting the history behind their designs, highlighting traditional techniques, sharing artisan profiles, and communicating the cultural meaning of their products. Sustainable branding can be strengthened through transparent communication about material sourcing, ethical production practices, and environmentally responsible processes.

From a strategic management perspective, handmade embroidery entrepreneurs should focus on integrating authenticity, sustainability, premium craftsmanship, and digital communication into their overall branding strategies. These approaches can help overcome challenges related to limited resources, market competition, and brand recognition while supporting sustainable brand development.

Limitations

This study has several limitations. First, convenience sampling was employed due to the absence of a comprehensive sampling frame for handmade embroidery entrepreneurs in the Galle District, which may limit the representativeness and generalisability of the findings. Second, the study focused only on entrepreneurs operating within a single geographical area, limiting the applicability of the findings to other regions of Sri Lanka. Third, the data were collected using self-reported questionnaires, which may introduce response bias. Fourth, the cross-sectional research design identifies statistically significant relationships between sustainable luxury consumption factors and brand equity but does not establish causal relationships. Furthermore, this study primarily utilised Pearson correlation analysis to examine the associations among the variables. Although correlation analysis identifies the strength and direction of relationships, it does not determine the individual predictive contribution of each independent variable towards brand equity. Therefore, future studies may employ advanced statistical techniques such as multiple regression analysis, hierarchical regression, or Structural Equation Modelling to examine the relative influence of each sustainable luxury consumption factor on brand equity. Future research may also consider larger samples, multiple geographical regions, longitudinal research designs, consumer perspectives, and export-oriented artisanal businesses to provide broader insights into sustainable luxury branding.

Conclusions

The findings demonstrate that storytelling authenticity, premium design quality, sustainable branding perception, and luxury value perception are significantly associated with stronger brand equity outcomes. By focusing on micro-level artisanal entrepreneurs within a developing economy, this study contributes to the existing sustainable luxury and strategic management literature by highlighting how cultural heritage, craftsmanship, and sustainability practices can support artisanal brand development.

The findings suggest that handmade embroidery entrepreneurs can strengthen their competitive position by integrating authentic storytelling, sustainable branding practices, premium product presentation, and digital communication

strategies into their business approaches. These strategies enable entrepreneurs to create stronger emotional connections with customers, enhance brand recognition, and respond to changing consumer expectations in sustainable fashion markets.

Overall, this study highlights that sustainable luxury positioning provides valuable strategic opportunities for small scale artisanal businesses seeking long term growth while preserving cultural identity and traditional craftsmanship. Future research may further explore these relationships using larger sample sizes, longitudinal research designs, and advanced analytical techniques. In addition, future studies may examine consumer perspectives, export-oriented artisanal businesses, digital commerce adoption, and comparative analyses across different regions of Sri Lanka to provide broader insights into sustainable luxury branding.

References

1. Kapferer, J.N. and Michaut, A. (2020). *Luxury and sustainability: A common future?* **Luxury Research Journal**.
2. Cervellon, M.C. and Shammas, L. (2024). *The value of sustainable luxury in mature markets.* **Journal of Corporate Citizenship**.
3. Lundqvist, A., Liljander, V., Gummerus, J. and van Riel, A. (2024). *The impact of storytelling on consumer brand experience.* **Journal of Brand Management**.
4. Joy, A., Sherry, J.F., Venkatesh, A., Wang, J. and Chan, R. (2020). *Fast fashion, sustainability, and ethical luxury consumption.* **Fashion Theory**.
5. Saunders, M., Lewis, P. and Thornhill, A. (2024). *Research Methods for Business Students.* Pearson Education.

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OP 05

The Effect of Talent Management Challenges on HR Practice Efficiency at Seylan Bank PLC.

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Abstract

Background: Talent management is vital in banking, where people directly impact performance, service quality, and competitive edge. However, organizations face various challenges, including structural, behavioral, managerial, environmental, and technological issues that can reduce HR (Human Resource) practice efficiency.

Objective/s: This study aims to explore how structural, behavioral, managerial, environmental, and technological challenges relate to HR practice efficiency at Seyla Bank PLC.

Methods: A quantitative cross-sectional research design was used with a deductive approach. Data were gathered from 254 Seylan Bank PLC employees through a structured questionnaire using a five-point Likert scale. Purposive sampling was conducted. The data were analyzed using descriptive statistics, Pearson correlation analysis, Pearson Chi-Square tests, and Cronbach's Alpha reliability analysis via IBM SPSS Statistics 27.

Results: The findings show that all five types of talent management challenges have statistically significant positive relationships with HR practice efficiency. Managerial challenges exhibit the strongest relationship ($r = 0.888$, $p < 0.001$), followed by structural challenges ($r = 0.881$, $p < 0.001$), behavioral challenges ($r = 0.854$, $p < 0.001$), technological challenges ($r = 0.822$, $p < 0.001$), and environmental challenges ($r = 0.821$, $p < 0.001$). Chi-Square analysis confirms significant associations between all challenge categories and HR practice efficiency.

Conclusion/s: The study concludes that talent management challenges significantly impact HR practice efficiency at Seylan Bank PLC. The findings underscore the need for stronger leadership support, improved organizational structures, enhanced employee engagement, and investment in digital HR technologies to boost HR practice effectiveness and overall performance. Keywords: Banking Sector, HR Practice Efficiency, Organizational Challenges, Sri Lanka, Talent Management. Acknowledgment: This research received no external funding.

Keywords: *Banking Sector, HR Practice Efficiency, Organizational Challenges, Sri Lanka, Talent Management*

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Introduction

In the commercial banking industry, talent management has grown crucial since human capital directly affects long-term sustainability and competitive advantage. Maintaining competitiveness requires effective talent management, particularly in volatile economies where skilled employees set financial institutions apart [1]. Banks run the risk of operational inefficiencies and a loss of market positioning in the absence of efficient systems. Leadership, training, performance systems, and reward structures all have an impact on the effectiveness of talent management, according to previous research [2,3]. However, structural rigidities, behavioral resistance, managerial shortcomings, environmental pressures, and technology constraints are obstacles that businesses must overcome to effectively manage talent [4].

The theoretical foundation of this study is grounded in several established frameworks. Human Capital Theory [5] posits that employees' knowledge, skills, and abilities constitute valuable organizational assets that drive competitive advantage. Similarly, the Resource-Based View (RBV) [6] suggests that human capital, when valuable, rare, inimitable, and non-substitutable, serves as a source of sustained competitive advantage. Social Exchange Theory [7] explains that positive employer-employee relationships foster mutual commitment and reciprocity, influencing talent retention and engagement. The Ability–Motivation Opportunity (AMO) Framework [8] highlights how HR practices enhance employee performance by improving abilities, motivation, and opportunities to contribute. Finally, Strategic Human Resource Management (SHRM) Theory [9] emphasizes the alignment of HR practices with organizational strategy to achieve superior outcomes.

Limited empirical studies have examined the overall impact of several barrier dimensions on HR practice efficiency, especially in Sri Lanka's banking industry, despite the growing significance of talent management. Instead of examining how structural, behavioral, managerial, environmental, and technical obstacles simultaneously impact results, most current research concentrates on individual factors [10]. One of Sri Lanka's leading commercial banks, Seylan Bank PLC, was founded in 1988 and is renowned for its customer-focused services [11]. However, the bank faces serious personnel management issues, including internal obstacles to hiring, training, and succession planning, as well as economic instability since 2022 that has affected workforce stability. This study integrates these theoretical perspectives to examine how five categories of talent management challenges affect HR practice efficiency in the banking sector.

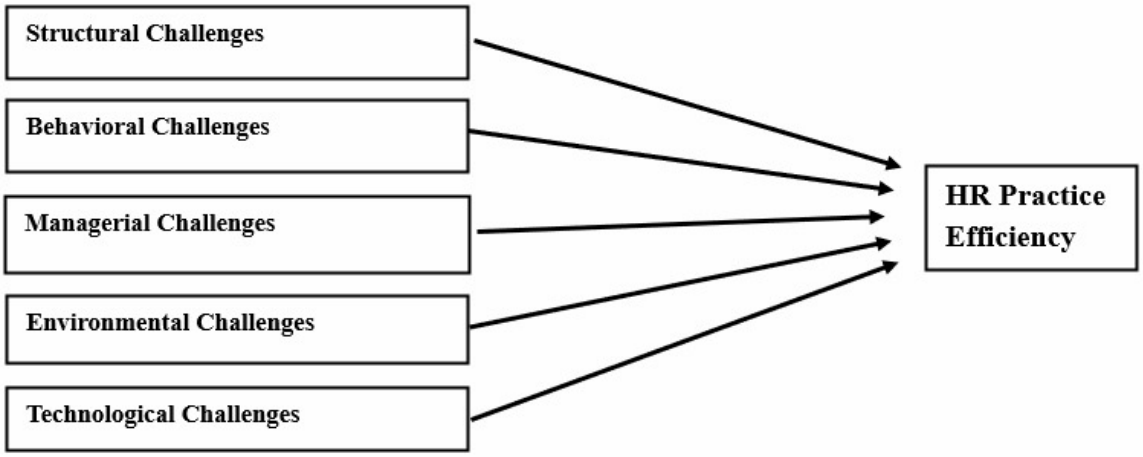

Figure 1. Conceptual Framework of the Study

Methods

Study Design and Setting

This study uses a deductive quantitative approach to investigate the relationship between the dependent variable, HR Practice Efficiency at Seylan Bank PLC, and five independent variables: structural, behavioural, managerial, environmental, and technological challenges. The study adopts a positivist philosophy [12], assuming an objective and measurable social reality. Between January 2026 and February 2026, a cross-sectional survey [13] was carried out to gather data from Seylan Bank's Head Office and 11 branches in the Northwest 1 Region [14].

Participant Characteristics

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The target population included HR staff, middle and senior managers, junior executives, and other permanent workers who were directly involved in talent management procedures. Participants were engaged in recruitment, performance management, training, and succession planning activities.

Sample Size and Inclusion/Exclusion Criteria

The Krejcie and Morgan sample size determination table [15] was used to determine the sample size. A 95% confidence level and a 5% margin of error were achievable with a sample of 254 respondents. Permanent job status, a minimum of one year of continuous service, employment at the executive level or higher, and direct participation in talent management activities were all requirements for inclusion. Probationary or temporary personnel, workers on longer than three months' absence, non-executive operational staff, and workers going through a separation from the company were among the exclusion criteria.

Sampling Technique

Purposive sampling was selected because the study requires respondents with specialized HR-related knowledge and direct involvement in talent management processes. Random sampling would have included employees without relevant knowledge, compromising data quality. However, it is acknowledged that purposive sampling may introduce selection bias, as the sample may not fully represent all organizational levels.

To mitigate this, participants were selected across different departments, job levels, and all 11 branches within the study region, ensuring diversity within the purposive sample.

Data Collection Procedures and Instrument

A self-administered online survey conducted via Google Forms was used to gather data [16]. Two reminders were issued to participants at intervals of one week, and they had three weeks to respond [17]. To ensure anonymity, no identifiable information was gathered. A total of 254 valid responses were obtained.

The 26-item questionnaire was created utilizing validated measurement scales from an analysis of existing literature [18]. One item assessed HR Practice Efficiency, while twenty-five items tested the independent variables, with five items representing each challenge category. Pre-testing and review by subject-matter experts guaranteed the instrument's validity and reliability.

Measurement Scale

All questionnaire items were measured using a five-point Likert scale, where 1 = Strongly Agree, 2 = Agree, 3 = Neutral, 4 = Disagree, and 5 = Strongly Disagree [19]. This scale facilitates the measurement of respondents' perceptions and attitudes toward the study variables. In this study, higher scores on the challenge scales (Structural, Behavioral, Managerial, Environmental, and Technological) indicate greater recognition and effective management of these challenges, rather than greater challenge intensity. Therefore, a positive correlation suggests that organizations better at identifying and addressing talent management challenges tend to demonstrate higher HR practice efficiency. This conceptualization follows prior research where higher scores reflect organizational awareness and proactive management of barriers [2].

Validity and Reliability

The instrument's content validity [20] was confirmed through a conceptual framework connecting the independent variables to HR Practice Efficiency [21]. Reliability was assessed using Cronbach's Alpha coefficient. A threshold value of 0.70 was adopted to indicate acceptable internal consistency [22].

HR Practice Efficiency was measured using a single statement, while each independent variable used five items. Single-item measures are acceptable when constructs are clear and unambiguous [23]. This approach minimized survey length to encourage participation. The item was pilot-tested for clarity and face validity. However, this limitation is acknowledged, and future research should employ multi-item scales for greater reliability.

Ethical Considerations

The study was carried out under the academic supervision of the ESOFT Metro Campus School of Business in Negombo, Sri Lanka. Informed consent was obtained via the online survey, and participation was totally voluntary [24]. Anonymity and answer confidentiality were maintained throughout the study, and participants were informed that they could withdraw at any time without facing any consequences.

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Statistical Analysis

Version 27 of IBM SPSS Statistics was utilized for data analysis. Descriptive statistics, including mean and standard deviation, were computed to summarize respondents' perceptions across all 26 questionnaire items. For inferential analysis, the Pearson Chi-Square test was employed to evaluate associations between each of the five independent variables and the dependent variable (HR Practice Efficiency), with significance set at $p < 0.05$.

Instrument reliability was assessed using Cronbach's Alpha coefficient, with a threshold of 0.70 indicating acceptable internal consistency [25]. All data were collected using a single self-administered questionnaire at one point in time; as such, the potential for common method bias exists [26]. While no statistical test was conducted to quantify this bias, it is acknowledged as a limitation. To strengthen the analysis and identify the relative contribution of each challenge category, multiple linear regression analysis was also conducted. The regression equation was: HR Practice Efficiency = $\beta_0 + \beta_1$(Structural) + β_2(Behavioral) + β_3(Managerial) + β_4(Environmental) + β_5(Technological) + ε. Standardized coefficients (β) were examined to compare predictor strength, R^2 assessed overall explanatory power, and VIF values (threshold < 10) were calculated to assess multicollinearity.

Results

Reliability Analysis

Table 1. Reliability Analysis of Study Variables

Variables	**Number of Items**	**Cronbach's Alpha Value**
Structural Challenges	5	0.899
Behavioural Challenges	5	0.959
Managerial Challenges	5	0.984
Environmental Challenges	5	0.988
Technological Challenges	5	0.752
All five Independent Variables	25	0.801
Overall, all the statements	26	0.792

Table 1 presents the reliability analysis results. Cronbach's Alpha coefficients for all constructs exceeded the recommended threshold of 0.70, indicating satisfactory internal consistency and reliability of the measurement instrument.

Descriptive Statistics

A total of 254 valid responses were included in the analysis. Descriptive statistics were computed to summarize respondents' perceptions of the five categories of talent management challenges at Seylan Bank PLC.

Table 2. Descriptive Statistics of Study Variables

Variable	**Mean**	**Standard Deviation**
Structural Challenges	1.4646	0.55233
Behavioural Challenges	1.4213	0.52572
Managerial Challenges	1.4016	0.49535
Environmental Challenges	1.4213	0.51046
Technological Challenges	1.4134	0.50918

The findings indicate that respondents perceive that talent management issues have an impact on Seylan Bank PLC's HR Practice Efficiency. All task categories showed a high degree of agreement, with mean scores ranging from 1.4016

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to 1.4646. Structural challenges had the greatest mean score (M = 1.4646), while managerial challenges had the lowest mean score (M = 1.4016), indicating the maximum degree of agreement among respondents. The responses were comparatively consistent, with standard deviations ranging from 0.495 to 0.552.

Effect of Structural Challenges on HR Practice Efficiency

The Pearson correlation analysis reveals a strong positive relationship between Structural Challenges and HR Practice Efficiency ($r = 0.881$, $p < 0.001$), indicating a statistically significant association between the two variables at Seylan Bank PLC.

Table 3. Correlation Between Structural Challenges and HR Practice Efficiency

Variables	**Pearson Correlation (r)**	**p-value**
Structural Challenges*HR Practice Efficiency	0.881	$p < 0.001$

Effect of Behavioural Challenges on HR Practice Efficiency

The Pearson correlation analysis reveals a strong positive relationship between Behavioural Challenges and HR Practice Efficiency ($r = 0.854$, $p < 0.001$), indicating a statistically significant association between the two variables at Seylan Bank PLC.

Table 4. Correlation Between Behavioural Challenges and HR Practice Efficiency

Variables	**Pearson Correlation (r)**	**p-value**
Behavioural Challenges*HR Practice Efficiency	0.854	$p < 0.001$

Effect of Managerial Challenges on HR Practice Efficiency

The Pearson correlation analysis reveals a strong positive relationship between Managerial Challenges and HR Practice Efficiency ($r = 0.888$, $p < 0.001$), indicating a statistically significant association between the two variables at Seylan Bank PLC.

Table 5. Correlation Between Managerial Challenges and HR Practice Efficiency

Variables	**Pearson Correlation (r)**	**p-value**
Managerial Challenges*HR Practice Efficiency	0.888	$p < 0.001$

Effect of Environmental Challenges on HR Practice Efficiency

The Pearson correlation analysis reveals a strong positive relationship between Environmental Challenges and HR Practice Efficiency ($r = 0.821$, $p < 0.001$), indicating a statistically significant association between the two variables at Seylan Bank PLC.

Table 6. Correlation Between Environmental Challenges and HR Practice Efficiency

Variables	**Pearson Correlation (r)**	**p-value**
Environmental Challenges*HR Practice Efficiency	0.821	$p < 0.001$

Effect of Technological Challenges on HR Practice Efficiency

The Pearson correlation analysis reveals a strong positive relationship between Technological Challenges and HR Practice Efficiency ($r = 0.822$, $p < 0.001$), indicating a statistically significant association between the two variables at Seylan Bank PLC.

Table 7. Correlation Between Technological Challenges and HR Practice Efficiency

Variables	**Pearson Correlation (r)**	**p-value**
Technological Challenges*HR Practice Efficiency	0.822	$p < 0.001$

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Chi-Square Analysis

Pearson Chi-Square analysis is conducted to determine whether significant associations exist between the five categories of talent management challenges and HR Practice Efficiency.

Table 8. The Chi-Square Test results

Variable	**χ^2 Value**	**df**	**p-value**
Structural Challenges	380.311[a]	4	P < 0.001
Behavioural Challenges	269.292[a]	4	P < 0.001
Managerial Challenges	302.137[a]	4	P < 0.001
Environmental Challenges	242.388[a]	4	P < 0.001
Technological Challenges	244.546[a]	4	P < 0.001

The findings of the Chi-Square test show a significant relationship between HR Practice Efficiency and all five categories of talent management challenges ($p < 0.001$ for all variables). The highest Chi-Square value was found for structural challenges ($\chi^2 = 380.311$), followed by managerial challenges ($\chi^2 = 302.137$), behavioural challenges ($\chi^2 = 269.292$), technological challenges ($\chi^2 = 244.546$), and environmental challenges ($\chi^2 = 242.388$).

These results imply that HR Practice Efficiency at Seylan Bank PLC is substantially correlated with each challenge category.

Multiple Linear Regression Analysis

To identify the relative contribution of each challenge category, multiple linear regression analysis was conducted. This analysis extends the bivariate correlations by examining the independent effect of each variable while controlling for the others.

Table 09: Confidence Intervals and Effect Sizes

Variables	Unstandardized β	Standardized Error	Standardized β	T (t-statistic)	Significance level	95% CI Lower	95% CI Upper	VIF (Variance Inflation Factor)	Effect Size (Partial η^2)
(Constant)	-0.051	0.036	-	-1.438	0.152	-0.121	0.019	-	-
Structural Challenges	0.441	0.034	0.455	12.994	<0.001	0.375	0.508	2.772	0.405
Behavioural Challenges	0.082	0.050	0.080	1.633	1.633	-0.017	0.180	5.457	0.011
Managerial Challenges	0.382	0.064	0.353	5.988	5.988	0.256	0.507	7.854	0.126
Environmental Challenges	0.028	0.058	0.027	0.482	0.482	-0.086	0.142	6.861	0.001
Technological Challenges	0.109	0.053	0.104	2.043	0.042	0.004	0.215	5.842	0.017

The overall regression model was statistically significant ($F(5, 248) = 402.322$, $p < .001$, $R^2 = 0.890$), indicating that the five independent variables collectively explained 89.0% of the variance in HR Practice Efficiency (Cohen's $f^2 = 8.09$, large effect). Among the predictors, Structural Challenges had the strongest independent effect ($\beta = 0.455$, $p < .001$), followed by Managerial Challenges ($\beta = 0.353$, $p < .001$) and Technological Challenges ($\beta = 0.104$, $p = 0.042$). Behavioral Challenges ($\beta = 0.080$, $p = 0.104$) and Environmental Challenges ($\beta = 0.027$, $p = 0.630$) were not significant predictors when controlling for other variables. All VIF values ranged from 2.772 to 7.854, indicating no significant multicollinearity concerns.

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Discussion

Overview of Key Findings

The findings offer practical implications for Seylan Bank PLC and similar Sri Lankan financial institutions. Given that Managerial Challenges showed the strongest effect, banks should invest in leadership development programs. Structural Challenges indicate the need for robust succession planning and transparent career progression pathways. Environmental Challenges highlight the need for competitive compensation and flexible work arrangements to retain skilled employees. Technological Challenges emphasize investment in modern HR systems and automation. Banks should also leverage workforce analytics for evidence-based decision-making. Finally, integrated change management approaches addressing all five challenge categories simultaneously can foster continuous improvement and employee engagement. Addressing these multidimensional challenges may improve retention, operational performance, and long-term competitiveness.

Discussion of Structural Challenges

The findings reveal a very strong positive relationship between Structural Challenges and HR Practice Efficiency ($r = 0.881$, $p < .001$), indicating that organizational structures and policies are closely associated with talent management effectiveness at Seylan Bank PLC. Similar findings from earlier research have shown that formal procedures, organizational structures, and contextual factors can significantly influence HR effectiveness and talent management outcomes [3]. Previous studies similarly identify structural rigidity and bureaucratic procedures as major barriers in financial institutions [1]. Inefficient structures may be associated with hindered recruitment, succession planning, and employee development, thereby potentially affecting HR efficiency.

Discussion of Behavioural Challenges

The findings reveal a very strong positive relationship between Behavioral Challenges and HR Practice Efficiency ($r = 0.854$, $p < .001$), indicating that employee attitudes, resistance to change, and engagement levels are closely associated with talent management effectiveness at Seylan Bank PLC. Employee performance, organizational flexibility, and the effective execution of HR programs can be strongly impacted by behavioral characteristics, according to earlier research [27]. Behavioral resistance is associated with reduced HR effectiveness and decreased organizational adaptability [2]. These difficulties could be associated with reduced teamwork, restricted participation in training and development initiatives, and lower employee morale, all of which may have implications for HR practice effectiveness.

Discussion of Managerial Challenges

Managerial Challenges show the strongest relationship with HR Practice Efficiency ($r = 0.888$, $p < .001$), highlighting the vital role that strategic decision-making, managerial support, and leadership commitment play in talent management. Effective leadership and managerial engagement are crucial for developing and maintaining talent management systems that improve organizational performance, according to prior research [2]. Prior research also indicates that ineffective leadership and weak succession planning are associated with weaker HR systems [3]. The findings suggest that enhancing managerial accountability, leadership commitment, and talent development programs may be associated with significantly improved HR Practice Efficiency at Seylan Bank PLC.

Discussion of Environmental Challenges

Environmental Challenges show a significant positive relationship with HR Practice Efficiency ($r = 0.821$, $p < .001$), indicating that HR practice effectiveness is associated with external factors such as labour market competition and economic conditions. Workforce planning, HR strategy implementation, and talent management decision-making are all impacted by external environmental factors, according to previous research [28]. Similar findings report that economic uncertainty is associated with challenges in HR planning [4]. In Sri Lanka's current climate, labour market constraints and economic volatility may be associated with increased pressure on HR departments and more complex talent management strategies.

Discussion of Technological Challenges

Technological Challenges show a very strong positive relationship with HR Practice Efficiency ($r = 0.822$, $p < .001$), highlighting the significance of digital HR systems and technology-enabled procedures in talent management. Existing studies emphasize that outdated HR technologies are associated with reduced efficiency, while the successful implementation of digital HR solutions can increase operational effectiveness, facilitate decision-making, and enhance the delivery of HR services [29][5]. The findings suggest that further investment in cutting-edge HR systems and digital solutions may be associated with improved HR Practice Efficiency at Seylan Bank PLC.

Practical Implications

The findings offer practical implications for Seylan Bank PLC and similar Sri Lankan financial institutions. Given that Managerial Challenges showed the strongest effect, banks should invest in leadership development programs. Structural Challenges indicate the need for robust succession planning and transparent career progression pathways. Environmental Challenges highlight the need for competitive compensation and flexible work arrangements to retain skilled employees. Technological Challenges emphasize investment in modern HR systems and automation. Banks should also leverage workforce analytics for evidence-based decision-making. Finally, integrated change management approaches addressing all five challenge categories simultaneously can foster continuous improvement and employee engagement. Addressing these multidimensional challenges may improve retention, operational performance, and long-term competitiveness.

Strengths and Limitations

This study's integration of five aspects of talent management challenges into a single analytical framework is one of its main strengths. A thorough picture of the obstacles influencing HR Practice Efficiency at Seylan Bank PLC was obtained by gathering data from 11 branch locations and several organizational levels. A key strength of this study is the integration of five talent management challenge dimensions within a single analytical framework, with data collected across different organizational levels and 11 branch locations, providing a comprehensive view of barriers at Seylan Bank PLC.

However, several limitations should be acknowledged. The study is limited to Seylan Bank's Head Office and the Northwest 1 Region, constraining generalizability. A single-item indicator was used for the dependent variable, reducing measurement precision compared to multi-item scales. Causality cannot be inferred due to the cross-sectional design, and the use of purposive sampling limits generalizability relative to probability methods. Additionally, common method bias may have inflated correlations, as all data were collected via a single questionnaire at one point in time. While regression analysis was performed, Structural Equation Modelling (SEM) was not employed, which could have provided more robust path analysis. Therefore, findings should be interpreted with caution.

Future research should consider stratified random sampling, multi-source data collection, temporal separation, and SEM to further validate these relationships.

Future Research Directions

Future research should extend beyond a single organization to include multiple banks across Sri Lanka, enabling cross-sector comparisons and improving generalizability [30]. Longitudinal designs are recommended to track changes in HR practice efficiency over time and establish causal relationships. Comparative studies between public and private banks would reveal how ownership and culture moderate these relationships. Additionally, mediation and moderation models should be explored to understand the mechanisms through which talent challenges affect HR efficiency, along with outcome-based studies examining employee performance, commitment, and turnover intentions. Importantly, future research should develop and validate a multi-item scale for HR Practice Efficiency, as the present study used a single-item measure. Five indicators are proposed: recruitment effectiveness, employee development outcomes, retention effectiveness, HR process speed, and strategic alignment. Such efforts would support resilient human capital systems in emerging economies.

Conclusions

This study examined the relationships between five talent management challenges and HR Practice Efficiency at Seylan Bank PLC. All five challenge types showed statistically significant positive associations, with Managerial Challenges demonstrating the strongest correlation ($r = 0.888$) and Environmental Challenges the weakest but still significant ($r = 0.821$). Chi-Square analysis confirmed these associations ($p < .001$).

The study contributes to the literature by integrating five challenge dimensions within a single framework tailored to Sri Lanka's post-economic crisis banking context. Findings highlight the importance of organizational structures, leadership, employee behavior, environmental conditions, and technological capability in shaping HR efficiency. The use of a single-item dependent variable is acknowledged as a limitation.

Practically, Seylan Bank should prioritize leadership development, modernize HR systems, reduce structural rigidities, improve engagement, and invest in digital HR technologies. Agile HR strategies are also recommended to address environmental challenges. These interventions may improve retention, operational performance, and long-term competitiveness.

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References

1. Sparrow P, Makram H. What is the value of talent management? Building value-driven processes within talent management architecture. Hum Resour Manage Rev. 2015;25(3):249-263. Doi: 10.1016/j.hrmr.2015.04.002.

2. Collings DG, Mellahi K, Cascio WF. Global talent management and performance in multinational enterprises: A multilevel perspective. J Manage. 2019;45(2):540-566. doi:10.1177/0149206318757018.

3. Gallardo-Gallardo E, Thunnissen M, Scullion H. Talent management: Context matters. Int J Hum Resour Manage. 2020;31(4):457-473. doi:10.1080/09585192.2019.1642645.

4. Cooke FL, Schuler RS, Varma A. Human resource management research and practice in Asia: Past, present and future. Hum Resour Manage Rev. 2020;30(4):100778. Doi: 10.1016/j.hrmr.2020.100778.

5. Becker GS. Human capital: A theoretical and empirical analysis, with special reference to education. 3rd ed. Chicago (IL): University of Chicago Press; 1993. doi:10.7208/chicago/9780226041223.001.0001.

6. Barney J. Firm resources and sustained competitive advantage. J Manage. 1991;17(1):99-120. doi:10.1177/014920639101700108.

7. Cropanzano R, Mitchell MS. Social exchange theory: An interdisciplinary review. J Manage. 2005;31(6):874-900. doi:10.1177/0149206305279602.

8. Bos-Nehles AC, Van Riemsdijk MJ, Kees Looise J. Employee perceptions of line management performance: Applying the AMO theory to explain the effectiveness of line managers' HRM implementation. Hum Resour Manage. 2013;52(6):861-877. doi:10.1002/hrm.21578.

9. Wright PM, McMahan GC. Theoretical perspectives for strategic human resource management. J Manage. 1992;18(2):295-320. doi:10.1177/014920639201800205.

10. Tarique I, editor. The Routledge Companion to Talent Management. New York: Routledge; 2021. doi:10.4324/9781315474687.

11. Seylan Bank PLC. About us [Internet]. Colombo: Seylan Bank PLC; 2025 [cited 2026 Feb 20]. Available from: https://www.seylan.lk/about-us

12. Lim WM. What is quantitative research? An overview and guidelines. Int J Qual Methods. 2024;33(3):1–16. doi:10.1177/14413582241264622.

13. Setia MS. Cross-sectional studies: A methodological perspective. Indian J Dermatol. 2016;61(3):261-264. doi:10.4103/0019-5154.182410.

14. Seylan Bank PLC. Annual Report 2025 [Internet]. Colombo: Seylan Bank PLC; 2026 [cited 2026 Jan 15]. Available from: https://www.seylan.lk/uploads/1773202629_69b0ecc5ddfe4_Seylan-Bank-PLC--Annual-Report.pdf

15. Krejcie RV, Morgan DW. Determining sample size for research activities. Educ Psychol Meas. 1970;30(3):607-610. doi:10.1177/001316447003000308.

16. Campbell S, Greenwood M, Prior S, Shearer T, Walkem K, Young S, et al. Purposive sampling: Complex or simple? Research case examples. J Res Nurs. 2020;25(8):652-661. doi:10.1177/1744987120927206.

17. Evans JR, Mathur A. The value of online surveys. Internet Res. 2005;15(2):195-219. doi:10.1108/10662240510590360.

18. Fan W, Yan Z. Factors affecting response rates of the web survey: A systematic review. Comput Human Behav. 2010;26(2):132-139. Doi: 10.1016/j.chb.2009.10.015.

19. Boateng GO, Neilands TB, Frongillo EA, Melgar-Quiñonez HR, Young SL. Best practices for developing and validating scales for health, social, and Behavioral research: A primer. Front Public Health. 2018; 6:149. doi:10.3389/fpubh.2018.00149.

20. Joshi A, Kale S, Chandel S, Pal DK. Likert scale: Explored and explained. Br J Appl Sci Technol. 2015;7(4):396-403. doi:10.9734/BJAST/2015/14975.

21. Jabareen Y. Building a conceptual framework: Philosophy, definitions, and procedure. Int J Qual Methods. 2009;8(4):49-62. doi:10.1177/160940690900800406.

22. Cheung GW, Cooper-Thomas HD, Lau RS, Wang L. Reporting reliability, convergent and discriminant validity with structural equation modeling: A review and best-practice recommendations. Asia Pac J Manage. 2024;41(3):745–783. doi:10.1007/s10490-023-09871-y.

23. Bergkvist L, Rossiter JR. The predictive validity of multiple-item versus single-item measures of the same constructs. J Mark Res. 2007;44(2):175-184. doi:10.1509/JMKR.44.2.175.

24. Resnik DB. What is ethics in research and why is it important? National Institute of Environmental Health Sciences [Internet]. 2020 [cited 2026 Jan 15]. Available from: https://www.niehs.nih.gov/research/resources/bioethics/whatis

25. Taber KS. The use of Cronbach's alpha when developing and reporting research instruments in science education. Res Sci Educ. 2018;48(6):1273-1296. doi:10.1007/s11165-016-9602-2.

26. Podsakoff PM, MacKenzie SB, Lee JY, Podsakoff NP. Common method biases in behavioral research: A critical review of the literature and recommended remedies. J Appl Psychol. 2003;88(5):879-903. doi:10.1037/0021-9010.88.5.879.

27. Oreg S, Vakola M, Armenakis A. Change recipients' reactions to organizational change: A 60-year review of quantitative studies. J Appl Behav Sci. 2011;47(4):461-524. doi:10.1177/0021886310396550.

28. Vaiman V, Scullion H, Collings D. Talent management decision making. Manag Decis. 2012;50(5):925-941. doi:10.1108/00251741211227663.

29. Strohmeier S. Digital human resource management: A conceptual clarification. Ger J Hum Resour Manag. 2020;34(3):345-365. doi:10.1177/2397002220921131.

30. Brannen J. Mixed methods research: A discussion paper. Int J Social Res Methodol. 2017;20(3):181-195. doi:10.1080/13645579.2016.1144401.

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OP 06

Psychological Effects of Workplace Stress on Employee Retention in the Hospitality Industry: A Case Study of a Leading Hotel in Colombo

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Abstract

Sri Lanka's hospitality industry plays a vital role in the national economy; however, it continues to face significant challenges related to high employee turnover, largely driven by workplace stress. Employees in the hotel sector are frequently exposed to irregular working hours, heavy workloads, and intense customer interactions, which contribute to emotional exhaustion and reduced job satisfaction. In this context, understanding the psychological effects of workplace stress on employee retention has become increasingly important for sustaining service quality and organizational performance. This study aims to examine the influence of key workplace stressors on employee retention in the hospitality industry, with specific reference to a selected hotel in Colombo. Adopting a positivist research philosophy and a deductive approach, the study employed a quantitative research design. Primary data were collected through a structured questionnaire administered to employees of the selected hotel through a sample of 115 out of a population of 150. The study focused on four independent variables, Emotional Labour, Job Insecurity, Role Ambiguity, and Time Pressure, and their influence on employee retention. The findings reveal that all four workplace stressors have significant associations with employee retention, with role ambiguity emerging as the most influential factor, followed by time pressure, emotional labour, and job insecurity. The results indicate that unclear job roles, excessive workload, emotional demands, and perceived job instability contribute to increased stress levels, leading to reduced employee commitment and higher turnover intentions. The study concludes that effective management of workplace stress is essential for improving employee retention in the hospitality sector. It is recommended that hotel management implement clear role definitions, provide supportive supervision, introduce flexible scheduling practices, and offer emotional intelligence training and wellness programs to mitigate stress. Additionally, enhancing job security through transparent communication and career development opportunities can further strengthen employee engagement and loyalty. A limitation of this study is its reliance on quantitative data, which may not fully capture the depth of employee experience. Future research could incorporate qualitative approaches to gain deeper insights into psychological stress factors and explore additional variables influencing employee retention across different segments of the hospitality industry.

Keywords: *Emotional Labour, Role Ambiguity, Job Insecurity, Time Pressure, Employee Retention, Hospitality Industry*

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Introduction

Sri Lanka's hotel industry is vital to the country's economy, but it faces significant challenges due to high employee turnover resulting from workplace stress. According to Perera and Madagamage (2019, p. 34), hotel workers in Sri Lanka often experience dissatisfaction due to their irregular working hours, heavy workloads, and limited control over their work. This leads to emotional fatigue and burnout. The high-pressure nature of the hotel business, which involves intense customer interactions and emotional labour, makes these issues worse. Workers must constantly manage their emotions to meet the expectations of their guests. Given the importance of tourism in Sri Lanka, it is crucial to stabilise the workforce, as a skilled and dedicated staff is essential for maintaining high-quality service and supporting economic recovery amid ongoing challenges such as inflation and political instability.

This research specifically examines how psychological stressors in the workplace affect employees' intentions to stay or leave their roles in Sri Lanka's hospitality sector. Samarakoon (2023, p. 22) notes that the hotel industry experiences turnover rates of 30% to 50% annually, which is significantly higher than sustainable levels, thereby disrupting operational efficiency and increasing costs. Employees under constant stress from long hours, low pay, role ambiguity, and emotional demands often suffer mental exhaustion, manifesting as anxiety, frustration, and reduced job satisfaction. Fernando (2021, p. 23) emphasises that chronic stress significantly increases turnover intentions, as employees seek alternative positions that offer better mental well-being and a more balanced work-life approach. Understanding these psychological triggers is crucial for developing effective strategies that enhance employee retention and engagement.

The problem of high employee turnover in the hospitality sector affects not only individual businesses but also the wider industry and Sri Lanka's economy. When employees leave, companies face higher costs for hiring and training new staff. This can lead to poorer service and lower guest satisfaction, damaging overall business success and competitiveness. According to Elshaer et al. (2022, p. 89), job stress is closely linked to workers feeling disengaged and wanting to leave their jobs. Stressed hotel employees are more likely to seek work in less demanding fields. In Sri Lanka, younger workers are more concerned about mental health and workplace culture. If businesses do not address these stress factors, they risk losing talented employees to industries that offer better support. This issue is even more urgent now, as economic uncertainty adds extra pressure on workers who already face the emotional challenges of hospitality jobs.

Addressing workplace stress is crucial to fostering a sustainable workplace that supports employee wellbeing and industry growth. (Wijayasekara, 2021, p. 47) shows that inadequate mental health support, Poor communication, and a lack of recognition from management lead to employees feeling disengaged and taking more sick days. This often results in them quitting. This research examines stress and provides practical strategies for hotels in Sri Lanka to enhance mental health programs, manage stress effectively, and foster a supportive work environment. By adopting these strategies, hotels can reduce employee turnover, enhance service quality, and improve the sector's reputation. This can enhance Sri Lanka's economic stability and competitiveness in the global tourism sector. The main aim of this research is to identify the psychological influences of workplace stress on employee retention in the hospitality industry, specifically focusing on a selected hotel in Colombo.

Literature Review

Psychological Effects of Workplace Stress

Workplace stress is a significant issue in the hospitality industry that impacts both employee performance and organizational success. This can arise from various factors, influencing the overall employee experience. Emotional dissonance can cause stress and detachment (Brotheridge & Lee, 2016). When individuals repeatedly perform emotional labor, they may become increasingly dissatisfied with their jobs and potentially experience burnout (Zhao & Ghiselli, 2016). Role ambiguity is a significant stressor, especially in busy hotels where job roles overlap. Ranasinghe (2021) states that unclear job expectations lead to confusion and frustration, particularly for entry-level employees. This uncertainty can lead to poorer performance and increased turnover. Jayawardena (2020) notes that in Sri Lanka's hospitality sector, a lack of training and communication exacerbates role ambiguity and stress. Job insecurity is common in industries affected by economic and political instability. This increases employee anxiety and harms mental well-being (De Cuyper et al., 2019). Time pressure from high service demands and limited staffing adds extra stress for employees. Kahn et al. (2021) say that employees facing constant time constraints feel chronic fatigue and lower job satisfaction. These stressors create a range of challenges that require strategic organizational solutions.

Moreover, the findings of these studies have profound implications for the hospitality industry. Emotional exhaustion due to emotional labor can lead to increased turnover rates as employees seek jobs with less emotional demand (Grandey, 2003). The consequences of high turnover are particularly severe in the hospitality sector, where experienced staff are

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vital for maintaining service quality. Further, the stress arising from role ambiguity and job insecurity can undermine employee engagement and loyalty, as highlighted by Maslach et al. (2011). When employees lack clarity in their roles and feel insecure about their jobs, their commitment to the organization diminishes, negatively affecting guest satisfaction and overall operational efficiency. Additionally, Karatepe (2018) emphasizes that burnout from excessive emotional labor and role ambiguity can lead to a decline in service quality, as employees become disengaged and less motivated to meet customer expectations. This disengagement not only harms the hotel's reputation but also affects customer retention and loyalty, which are crucial for long-term success. The influence of workplace stress extends to the organizational culture as well. Kahn (1990) suggests that high stress levels can foster a toxic work environment characterized by poor communication and lack of support, further exacerbating employee turnover. This cycle can create a negative feedback loop, where high turnover leads to increased workload for remaining staff, heightening their stress levels. Ultimately, addressing these issues is essential for the sustainability of hotels. By implementing training programs to clarify roles and enhance communication, as suggested by Karatepe (2018), organizations can mitigate the impacts of workplace stress. This proactive approach not only improves employee well-being but also fosters a more stable and productive work environment, ultimately benefiting the hotel's reputation and profitability. In summary, the interplay of emotional labor, role ambiguity, job insecurity, and time pressure creates a challenging landscape for employees in the hospitality industry. Addressing these factors is crucial for enhancing employee retention and ensuring the long-term success of hotels in a competitive market.

Employee Retention

Employee retention, defined as an organization's ability to retain its staff over time, is a critical factor in the hospitality sector. High turnover rates in this industry can significantly disrupt service quality, increase recruitment and training costs, and weaken team cohesion (Huang et al., 2020). By prioritizing retention, organizations foster a stable work environment that benefits both employees and the organization. Retaining skilled employees allows businesses to leverage their expertise, ensuring consistent and high-quality service delivery, which is paramount in a customer-centric industry like hospitality.

Several factors influence employee retention in the hospitality industry, including job satisfaction, career growth opportunities, and a positive workplace culture. Han et al. (2020) observed that organizations offering clear career paths and fostering healthy work environments experience greater employee commitment. Employees who see opportunities for advancement and professional development are more likely to remain loyal to their employers, reducing turnover rates.

Psychological Effects of Workplace Stress Effect on Employee Retention

Workplace stress greatly affects employee retention in the hospitality industry by creating a difficult work atmosphere that undermines well-being and weakens commitment to the organization. Various factors contribute to this issue. Emotional labor, where staff are required to consistently present a cheerful facade, results in fatigue and disengagement (Brotheridge & Lee, 2016). Zhao and Ghiselli (2016) additionally highlighted that this constant emotional exertion raises job dissatisfaction and can lead to burnout, prompting employees to consider leaving. Role ambiguity, which involves unclear job duties, undermines confidence and job satisfaction, especially in the fast-paced environment of hotels (Huang et al., 2020). Job insecurity, often triggered by changes in the market, increases employee anxiety and the likelihood of turnover (De Cuyper et al., 2019). Time pressure intensifies these issues, as tight deadlines contribute to exhaustion and stress. Kahn et al. (2021) discovered that overwhelming workloads diminish motivation and productivity, further increasing the desire to leave.

Chauhan and Kumar (2025) found a strong negative link between occupational stress and job satisfaction among hotel staff. Stressors like heavy workload and role ambiguity decrease performance and increase intentions to leave, leading to higher recruitment costs, lower service quality, and reduced hotel profitability. Ahmad, Barakbah, and Majdi (2021) noted that burnout, caused by workload and job mismatch, also drives turnover, increasing overtime costs, disrupting service, and lowering customer satisfaction, thereby harming profitability and engagement in the hospitality industry. Chung et al. (2021) showed that job stress directly raises frontline hotel workers' turnover intentions, though supervisor support can help reduce this impact. Unaddressed stress results in costly recruitment and training, potentially costing hotels millions, along with declines in service quality. Chauhan, Singh, and Katiyar (2022) observed that factors like role ambiguity and workload negatively affect employee performance and retention, leading to high turnover, financial losses, and decreased productivity, which can undermine customer service. Aufa et al. (2023) argued that although work-life balance has a limited direct effect on retention, strong job engagement encourages commitment, while unmanaged stress reduces it, resulting in lower productivity and competitive disadvantages.

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Gordon et al. (2019) highlighted that perceived supervisor support significantly lowers turnover intentions. Consequently, hospitality management should train supervisors in supportive practices, boosting job embeddedness, performance, and retention. Kim and Park (2023) emphasised that transparent communication and feedback are crucial for retention, prompting hotels to implement regular performance reviews and opendoor policies, which improve employee morale, customer service, and reduce turnover effects. Addressing these stressors through clear job roles, mental health support, manageable workloads, and supportive management practices can enhance retention. Han et al. (2020) and Yu et al. (2023) suggest that such interventions foster employee loyalty, creating a safe and supportive workplace that drives both employee satisfaction and organizational success in the hospitality industry.

Emotional Labour

Emotional labour occurs when employees pretend to be happy, such as smiling, even if they do not genuinely feel that way, to ensure customer satisfaction in the hospitality industry. This creates a conflict between their true feelings and displayed emotions, known as emotional dissonance, which over time leads to stress, fatigue, and burnout. Prolonged emotional labour significantly increases the likelihood of employees feeling disengaged and considering leaving their jobs. Chechi and D'Ambrosio (2025) recommend training in emotional intelligence to mitigate these negative effects, while Yu et al. (2023) and Han et al. (2020) emphasize that support systems like mentoring and wellness programs effectively reduce emotional fatigue and enhance employee retention. In hospitality, emotional labour is a prevalent expectation, requiring employees to project positive emotions regardless of their true feelings. Wu and Shie (2017) noted that maintaining a cheerful demeanor enhances guest satisfaction but intensifies employee stress levels. Wang and Groth (2020) argued that the constant need to regulate emotions drains psychological resources, leading to emotional exhaustion. Karatepe and Avci (2017) found that obligatory emotional displays weaken organisational commitment, as employees struggle to balance their authentic selves with workplace demands. Hofmann and Stokburger-Sauer (2017) examined emotional labour's impact on hospitality employees, finding that required emotional displays lead to psychological strain and reduced job satisfaction, contributing to turnover intentions; this research has influenced hotels to implement emotional intelligence training and peer support programs, reducing turnover rates by up to 25% in some cases, while unaddressed emotional demands result in staffing shortages, lower service quality, and financial losses from repeated hiring in the hospitality sector.

Fear of Job Loss

The perceived threat of job loss deeply affects employee psychology. Cheng and Chan (2018) found that fear of unemployment can significantly increase anxiety levels and undermine work performance. Adding to this, Keim et al. (2017) noted that job insecurity fosters feelings of instability and emotional distress. Moreover, Probst et al. (2020) observed that the anxiety stemming from potential job loss can lower morale and accelerate turnover intentions, highlighting the urgent need for organisations to proactively address employee concerns regarding job stability. In the context of the UAE hotel industry, Baquero (2022) found that job insecurity is a strong predictor of turnover intentions, primarily through mediating factors such as psychological distress and resistance to change, with job insecurity exerting a strong influence on distress. This research has prompted hospitality HR practices to advocate for proactive stress management and training programs aimed at helping employees navigate change, particularly during economic uncertainties. Neglecting these fears can lead to increased recruitment costs, workforce instability, and compromised service quality in hotels. During the COVID-19 pandemic, Jung et al. (2020) investigated job insecurity among deluxe hotel employees, revealing that it negatively impacts job engagement, fully mediating turnover intentions—especially among Millennials. These findings have led hotels to adopt long-term stability measures, such as job rotation and enhanced communication strategies, which improve engagement and retention. However, persistent fears can result in the loss of skilled staff and operational disruptions in the hospitality sector. In their analysis of dual stressors during the pandemic, Agag and Al-Adwan (2021) highlighted that the fear of job loss, combined with health risks, heightens job stress and turnover intentions, with job insecurity emerging as the stronger predictor. This has prompted the industry to advocate for policies that guarantee job security and mental health support, aiming to mitigate attrition. Ignoring these concerns can exacerbate psychological strain, contribute to staffing shortages, and create competitive disadvantages for hotels.

Role ambiguity and conflict

When employees feel secure in their jobs, it significantly fosters higher retention rates. Mauno et al. (2017) found that a sense of job security enhances both engagement and loyalty to the organization. Similarly, Jiang and Lavaysse (2018) confirmed that employees who perceive their employment as stable demonstrate stronger psychological commitment. Additionally, Lee et al. (2018) revealed that job security helps reduce stress levels, making employees more willing to remain in their roles. In their study of deluxe hotel employees, Jung et al. (2020) found that perceived job security boosts

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job engagement, which in turn negatively influences turnover intentions. This effect serves as a full mediator, particularly benefiting Generation Y in stable environments. These findings have encouraged hospitality management to prioritize autonomy and create horizontal organisational cultures that help build confidence, leading to greater loyalty and reduced attrition. Conversely, a lack of confidence in job security can result in decreased engagement, skill gaps, and service inconsistencies within hotels. Baquero (2022) highlighted that confidence in employment can counteract job insecurity, thereby mitigating psychological distress and resistance to change, ultimately lowering quit intentions in UAE hotels. This research has prompted HR interventions, such as performance feedback systems, designed to foster a sense of security and enhance commitment. Neglecting to build this confidence can lead to distress cycles, higher operational costs, and declines in morale across the hospitality sector. Anand et al. (2023) demonstrated that job security positively impacts organisational commitment by alleviating burnout during crises, promoting emotional stability and loyalty. These insights have shaped hotel policies toward supportive leadership and flexible arrangements, improving retention. However, eroded confidence can result in commitment losses, increased voluntary exits, and financial strains due to talent loss within the industry. Yoo (2023) noted that building confidence against job insecurity through clear roles helps reduce mediated stress on well-being, encouraging long-term engagement in hospitality. The stress matrix framework has influenced wellness initiatives and contractual reforms, enhancing employee loyalty. In contrast, the absence of confidence amplifies turnover, productivity losses, and reputational damage for hotels.

Time Pressure

Time pressure, stemming from understaffing, long hours, and peak service periods, significantly affects employee well-being and satisfaction in the hospitality industry. Employees facing constant time constraints are more susceptible to fatigue, burnout, and ultimately lower motivation and increased absenteeism (Beehr et al., 2019). Organisations that neglect these excessive workload pressures risk experiencing higher staff turnover. Conversely, research suggests that strategies such as flexible scheduling, fair workload distribution, and employee training in time management can effectively alleviate the negative impacts of time pressure. These approaches enable employees to handle their tasks more efficiently, resulting in higher job satisfaction and increased loyalty (Han et al., 2020; Guchait et al., 2016). Hospitality employees often grapple with intense time demands, which can elevate stress levels significantly. In their study published in Frontiers in Psychology, Wen, Fu, Huang, and Goh (2020) investigated role stress, including the quantitative overload caused by time pressure, among front-line hotel employees in South China. Their findings indicated that this kind of pressure significantly increases burnout and turnover intentions, with the service climate playing a moderating role. This research has led hotel managers to adopt detailed job descriptions and training programs to alleviate overload, resulting in lower turnover rates and more consistent service. However, if time pressure remains unaddressed, it can lead to staffing shortages, increased recruitment costs, and diminished guest satisfaction. In another study, Bufquin, Back, Park, and Nutta (2021) explored the impact of work stress and job burnout on turnover intentions among hotel employees. They found that time pressure from high job demands contributes to emotional exhaustion and feelings of resignation. These insights have prompted industry leaders to implement wellness programs and flexible scheduling, which not only reduce turnover rates but also help prevent staffing shortages and enhance both service quality and guest satisfaction.

Theoretical Framework

This study is grounded in established theories explaining workplace stress and employee retention. The Job Demands-Resources (JD-R) Model (Bakker & Demerouti, 2020) categorises workplace characteristics as demands (emotional labour, role ambiguity, job insecurity, time pressure) and resources (organisational support, role clarity, development opportunities), where high demands coupled with low resources lead to burnout and turnover. The Conservation of Resources (COR) Theory (Hobfoll, 2001) suggests workplace stressors deplete psychological resources, while organisational investments through supportive supervision and wellness programmes enhance retention. Social Exchange Theory (Blau, 1964) and Organisational Support Theory (Eisenberger et al., 1986) further explain that perceived organisational support fosters reciprocity, loyalty, and reduced turnover intentions. These theories collectively underpin the conceptual framework linking stress management to employee retention.

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Conceptual Framework

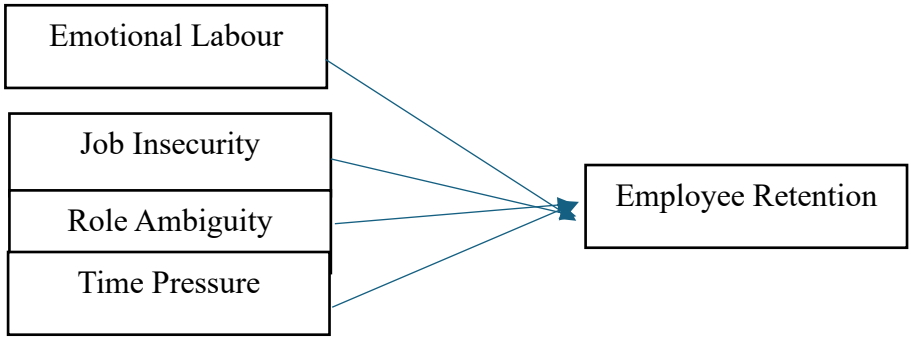

Figure 01 - Conceptual Framework

Hypotheses

H_a1: There is a positive relationship between effective management of emotional labour and employee retention.

H_a2: There is a positive relationship between organisational efforts to reduce job insecurity and employee retention.

H_a3: There is a positive relationship between reducing role ambiguity through organisational support and employee retention.

H_a4: There is a positive relationship between effective management of time pressure and employee retention.

Methodology

This study employed a quantitative research approach grounded in a positivist epistemological stance, assuming reality is objective and measurable. A deductive approach was adopted, with hypotheses formulated from existing theories and empirical literature on workplace stress, emotional labour, role ambiguity, job insecurity, time pressure, and employee retention. A mono-method quantitative design was used, collecting data via a closed ended structured questionnaire.

The target population comprised 150 employees attached to a selected hotel in Colombo. Sample size was determined using the Krejcie and Morgan Table, recommending 110 respondents; however, 115 usable responses were collected (76.7% response rate). Simple random sampling ensured equal selection probability for all employees.

The questionnaire, measured on a 5-point Likert scale, was adapted from validated hospitality scales: emotional labour (Brotheridge & Lee, 2013), role ambiguity (Akgunduz, 2015), job insecurity (De Cuyper et al., 2019), time pressure (Wen et al., 2020), and employee retention (Huang et al., 2020; Han et al., 2020). Pilot testing with 15 employees from a similar hotel informed minor wording adjustments. Content validity was confirmed by three subject matter experts, and construct validity via exploratory factor analysis (all loadings > 0.50). Ethical approval was obtained; respondents were assured anonymity and confidentiality, with voluntary participation and informed consent secured.

Data were analysed using SPSS version 26.0. Descriptive statistics summarised respondent characteristics. Inferential analysis included Pearson correlation, Chi-square tests for hypothesis testing, and multiple linear regression to determine each stressor's independent contribution to retention, controlling for other variables. Regression assumptions (linearity, normality, multicollinearity with VIF < 5, homoscedasticity) were assessed and satisfied. Reliability was assessed using Cronbach's Alpha, and validity through KMO and Bartlett's Test of Sphericity.

Notably, the independent variables measured perceptions of organisational support in managing workplace stressors, not stress severity. Higher scores thus indicate better stress management, explaining the positive correlations with retention.

Data Analysis And Discussion

Reliability Test

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Table 01: Reliability Test Results

Type	Variable	Cronbach's Alpha	No of Items
Independent Variables	Workplace stress	0.796	5
	Emotional labor	0.716	5
	Role ambiguity	0.728	5
	Job insecurity	0.784	5
	Time pressure	0.811	5
			25
Dependent Variable	Employee retention	0.875	2
All Questions		0.896	27

Source: Author developed **e**

The reliability test results indicate that all constructs used in the study exceed the acceptable Cronbach's alpha threshold of 0.7, demonstrating strong internal consistency. Among the independent variables, workplace stress (α = 0.796), emotional labor (α = 0.716), role ambiguity (α = 0.728), job insecurity (α = 0.784), and time pressure (α = 0.811) all show satisfactory reliability across their five items each. The dependent variable, employee retention, also records a high reliability score (α = 0.875) for its two items. The overall reliability of all 27 items combined is 0.896, indicating excellent internal consistency for the entire instrument.

Validity Test

Table 02: Validity Test Results

Test	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.742
Bartlett's Test of Sphericity	
Approx. Chi-Square	420.125
df	351
Sig.	0.001

Source: Author developed

The validity of the dataset was assessed using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity. The KMO value was 0.742, exceeding the recommended threshold of 0.7, indicating that the sample size was adequate and that the variables shared sufficient common variance for factor analysis.

Descriptive Statistical Analysis

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Table 03: Descriptive Statistical Analysis

Managing Emotional Labour					
Indicator	Assistance with emotional demands	Reduces the emotional strain	Adequate resources for emotional labour	Supportive measures to cope	Managing emotional labour
Mean	4.5	4.6	4.4	4.5	4.5
Mode	4	4	4	4	4
SD	1.291	1.376	1.411	1.426	1.412
Role Ambiguity					
Indicator	Clear role definitions	Clarifying responsibilities	Reduced role ambiguity	Guidance from management	Supportive clarification of expectations
Mean	4.6	4.5	4.5	4.6	4.6
Mode	4	4	4	4	4
SD	1.434	1.402	1.449	1.408	1.408
Job Insecurity					
Indicator	Assurance of job security	Clear communication on job stability	Company support in ensuring stability	Confidence in position	Feeling secure in job
Mean	4.7	4.6	4.5	4.6	4.7
Mode	4	4	4	4	4
SD	1.427	1.401	1.444	1.471	1.457
Time Pressure					
Indicator	Reasonable deadlines	Company support	Reduced time pressure	Supportive time management practices	Alleviating time pressure
Mean	4.6	4.5	4.5	4.6	4.7
Mode	4	4	4	4	4
SD	1.357	1.427	1.356	1.4	1.311

Source: Author developed

The managing emotional labour includes assistance with emotional demands, reducing emotional strain, providing adequate resources, and supportive coping measures—received mean scores between 4.4 and 4.6, reflecting that employees value company support in handling emotional labour and perceive it as beneficial. For role ambiguity, indicators such as clear role definitions, clarified responsibilities, guidance from management, and reduced ambiguity scored 4.5–4.6, indicating that clarity and managerial guidance are seen as critical to reducing confusion and improving retention. Job insecurity showed high mean scores of 4.5-4.7, highlighting that assurance of job stability, clear communication, and company support in ensuring security are key factors in employees' confidence and long-term

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commitment. Finally, for time pressure, indicators such as reasonable deadlines, company support, reduced pressure, and supportive time management practices scored 4.5–4.7, demonstrating that alleviating excessive workload and providing supportive structures positively affect employees' work experience. Overall, the consistently high mean scores, modes of 4, and moderate standard deviations indicate broad agreement among employees that organizational support across these areas is essential for their engagement, well-being, and retention.

Inferential Statistical Analysis

Table 04: Inferential Statistical Analysis

Independent Variable	Pearson Correlation	Remarks1	Chi-Square	Remarks2	Rank of the Factor
Emotional labor	0.724	Strong Positive Correlation	0.019	Alternative hypothesis accepted	3
Role Ambiguity	0.814	Strong Positive Correlation	0.000	Alternative hypothesis accepted	1
Job insecurity	0.665	Strong Positive Correlation	0.002	Alternative hypothesis accepted	4
Time pressure	0.745	Strong Positive Correlation	0.018	Alternative hypothesis accepted	2

Source: Author developed

The correlation analysis demonstrates a significant positive relationship between the examined workplace stress factors and employee retention. For Emotional Labour, the Pearson correlation coefficient is 0.724, indicating a strong positive relationship with employee retention, and the Chi-square value of 0.019 confirms statistical significance, supporting H_a1. Role Ambiguity shows the highest correlation with retention (r = 0.814) and a highly significant Chi-square value of 0.000, confirming H_a3 and ranking it as the most influential factor. Job Insecurity is also strongly correlated with retention (r = 0.665) with a Chi-square value of 0.002, supporting H_a2, and is ranked as the least influential among the factors. Finally, Time Pressure exhibits a strong positive correlation (r = 0.745) with retention, with a Chi-square value of 0.018, confirming H_a4 and ranking it as the second most influential factor. Overall, all four alternative hypotheses are accepted, indicating that workplace stress significantly influence employee retention, with role ambiguity having the strongest impact, followed by time pressure, emotional labour, and job insecurity.

Multiple Linear Regression Analysis

To determine the independent contribution of each workplace stressor, multiple linear regression was conducted with employee retention as the dependent variable.

Table 05: Multiple Linear Regression Coefficients

Independent Variable	Unstandardised B	Std. Error	Standardised β	t-value	Sig.	VIF
Constant	0.842	0.214	–	3.935	0	–
Managing Emotional Labour	0.214	0.071	0.231	3.014	0.003	2.184
Role Ambiguity	0.382	0.068	0.418	5.618	0	2.356
Job Insecurity	0.126	0.063	0.142	2	0.047	1.965
Time Pressure	0.276	0.072	0.302	3.833	0	2.241

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$R^2 = 0.741$, Adjusted $R^2 = 0.732$, $F(4, 110) = 78.234$, $p < 0.001$

Source: Author developed

The regression model explains 74.1% of the variance in employee retention. Role ambiguity emerged as the strongest predictor ($\beta = 0.418$, $p < 0.001$), followed by time pressure ($\beta = 0.302$, $p < 0.001$), emotional labour ($\beta = 0.231$, $p = 0.003$), and job insecurity ($\beta = 0.142$, $p = 0.047$).

Discussion

The findings of this study highlight the significant impact of workplace stress factors on employee retention in the hospitality industry, corroborating existing literature. The primary research shows that all four examined stressors role ambiguity, time pressure, emotional labour, and job insecurity have strong positive correlations with employee retention, with role ambiguity emerging as the most influential factor ($r = 0.814$), followed by time pressure ($r = 0.745$), emotional labour ($r = 0.724$), and job insecurity ($r = 0.665$). These results align closely with secondary research, which emphasizes that unclear job roles, excessive workloads, and emotional demands contribute to employee dissatisfaction, burnout, and turnover (Brotheridge & Lee, 2016; Zhao & Ghiselli, 2016; Ranasinghe, 2021; Kahn et al., 2021). Role ambiguity, identified in both primary and secondary findings as the strongest determinant of retention, reinforces previous studies indicating that unclear expectations and overlapping responsibilities create confusion and frustration, especially in fast-paced hotel environments (Jayawardena, 2020; Huang et al., 2020). The high correlation found in this study confirms that when employees lack clarity regarding their roles, their engagement and organizational commitment decrease, leading to increased turnover. This echoes Karatepe's (2018) observation that addressing role ambiguity through clear role definitions and managerial guidance significantly enhances employee satisfaction and loyalty.

Time pressure, the second most influential factor in the study, mirrors literature findings that excessive workloads, tight deadlines, and peak service demands contribute to chronic fatigue, stress, and diminished performance (Beehr et al., 2019; Wen et al., 2020; Bufquin et al., 2021). The high mean scores for time pressure in the descriptive analysis (4.5–4.7) indicate that employees perceive organizational support through flexible scheduling and time management practices as critical for alleviating stress and maintaining retention. Emotional labour, with a strong correlation of 0.724, also supports existing research demonstrating that sustained emotional regulation, such as maintaining a cheerful demeanor, creates emotional dissonance, fatigue, and burnout, ultimately affecting job satisfaction and retention (Karatepe & Avci, 2017; Wu & Shie, 2017; Hofmann & Stokburger-Sauer, 2017). The descriptive findings suggest that employees value organizational assistance in managing emotional demands, highlighting the effectiveness of interventions such as emotional intelligence training, peer support, and wellness programs in mitigating stress and promoting loyalty (Chechi & D'Ambrosio, 2025; Yu et al., 2023). Job insecurity, though the least influential factor in the study ($r = 0.665$), remains a significant predictor of retention, consistent with prior research emphasizing that perceived threats to job stability increase anxiety, psychological distress, and turnover intentions (De Cuyper et al., 2019; Cheng & Chan, 2018; Probst et al., 2020). High mean scores (4.5–4.7) in the descriptive analysis indicate that employees place considerable value on job stability, clear communication, and organizational support, underscoring the need for proactive HR interventions to alleviate fears of job loss and maintain engagement (Baquero, 2022; Jung et al., 2020). Overall, the integration of primary and secondary findings confirms that workplace stress negatively influences employee retention in the hospitality industry. Role ambiguity and time pressure appear as the most critical stressors, while emotional labour and job insecurity also significantly impact retention. The results emphasize that hospitality organizations must implement comprehensive strategies, including clear role definitions, supportive management practices, workload management, emotional intelligence training, and job stability measures, to mitigate stress, enhance employee well-being, and foster long-term retention. Addressing these factors not only improves employee satisfaction but also strengthens organizational performance, service quality, and competitiveness in a highly demanding industry.

Managerial Implications

The findings offer several actionable recommendations for hospitality managers. Since role ambiguity emerged as the strongest predictor, organisations should prioritise comprehensive job descriptions, regular performance reviews, and open communication channels for clarification. To address time pressure, flexible scheduling, equitable workload distribution, realistic deadlines, and workforce planning software can optimise staff allocation. Emotional labour can be managed through emotional intelligence training, peer-support programmes, wellness initiatives, and counselling services such as employee assistance programmes. Job security perceptions can be enhanced through transparent communication about organisational stability, career development opportunities, and employee involvement in decision-making. Supervisors should receive training in supportive leadership practices, including active listening, recognising stress indicators, and providing constructive feedback. Finally, fostering a supportive organisational culture through

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work-life balance initiatives, employee recognition, and psychologically safe environments where concerns can be voiced without fear will further strengthen retention.

Conclusion

This study examined the relationship between workplace stress-related factors, namely role ambiguity, time pressure, emotional labour, and job insecurity, and employee retention within the hospitality industry, with specific reference to employees in a selected Colombo based hotel. The findings demonstrate that all four factors have significant associations with employee retention. The multiple regression analysis further strengthens these findings by identifying the relative contribution of each factor while controlling for the influence of other variables. Among the examined factors, role ambiguity emerged as the strongest predictor of employee retention, followed by time pressure, managing emotional labour, and job insecurity. These findings indicate that employees' perceptions of clear responsibilities, effective workload management, emotional support mechanisms, and organisational assurance play an important role in shaping their intention to remain with the organisation.

The findings contribute to the existing body of knowledge by supporting established theoretical perspectives, including the Job Demands-Resources (JD-R) Model, Conservation of Resources (COR) Theory, Social Exchange Theory, and Organisational Support Theory. The results highlight that workplace demands, when not appropriately managed, may influence employees' workplace experiences, while organisational resources such as managerial support, role clarity, and employee well-being initiatives can strengthen positive employment relationships. The findings are also consistent with previous studies emphasising that unclear job expectations, excessive workload demands, emotional challenges, and uncertainty regarding employment conditions are important factors associated with employee attitudes and retention decisions (Brotheridge & Lee, 2016; Zhao & Ghiselli, 2016; De Cuyper et al., 2019; Karatepe, 2018).

From a managerial perspective, the findings highlight the importance of adopting structured strategies to support employee retention within the hospitality sector. Since role ambiguity was identified as the strongest predictor, organisations should prioritise clearly defined job responsibilities, effective communication channels, regular performance feedback, and appropriate supervisory guidance. To address time pressure, hospitality organisations should focus on effective workforce planning, fair workload distribution, flexible scheduling practices, and time management support. Managing emotional labour requires initiatives such as emotional intelligence development, employee wellness programmes, peer-support mechanisms, and supportive leadership practices. Furthermore, although job insecurity demonstrated the lowest relative contribution among the examined factors, transparent communication regarding organisational stability, career development opportunities, recognition practices, and employee involvement in decision-making can strengthen employees' confidence and organisational commitment.

The findings also emphasise the importance of developing a supportive organisational culture where employees perceive that their well-being is valued. Supervisory capability, psychological support, and positive employee–organisation relationships are particularly important within the hospitality industry, where employees frequently encounter high emotional demands and customer-facing pressures. By strengthening organisational resources and reducing workplace stressors, hospitality organisations can enhance employee satisfaction, improve retention outcomes, and maintain service quality and operational effectiveness.

This study has several limitations that should be considered when interpreting the findings. As the research was conducted within a single hotel, the generalisability of the findings to other hospitality organisations may be limited. Furthermore, the cross-sectional research design and the use of self-administered questionnaires mean that the findings identify statistical relationships rather than direct causal effects. Future research could therefore employ longitudinal approaches to examine how workplace stress and retention patterns change over time. Studies involving multiple hotels across different categories, such as luxury hotels, resorts, and budget accommodation providers, would provide broader insights into industry-specific variations.

Future research could also examine additional variables that may influence the relationship between workplace stress and employee retention, including job satisfaction, burnout, organisational support, leadership style, work-life balance, and employee resilience. Exploring mediating and moderating relationships would provide deeper understanding of the mechanisms through which workplace conditions influence employee retention decisions. Furthermore, mixed-method approaches incorporating qualitative interviews and focus groups could provide richer insights into employees' personal experiences of workplace stress management and organisational support. Such research would contribute towards developing more effective human resource strategies that promote employee well-being and long-term retention within the hospitality industry.

References

Ahmad, S., Barakbah, A., & Majdi, H. (2021). Hotel Employees' Burnout and Turnover Intentions. *Webology, 18*(5), 418–431. https://webology.org/datacms/articles/20211101114219amWEB18115.pdf

Akgunduz, Y. (2015). The influence of self-esteem and role stress on job performance in hotel businesses. *International Journal of Contemporary Hospitality Management, 27*(6), 1082–1099. https://doi.org/10.1108/ijchm-09-2013-0421

Akgunduz, Y., & Sanli, S. C. (2017). The effect of employee advocacy and perceived organizational support on job embeddedness and turnover intention in hotels. *Journal of Human Resources in Hospitality & Tourism, 16*(5), 495–517. https://doi.org/10.1080/19368623.2017.1319111

Amissah, E. F., Asare, A. K., Mensah, I., & Gamor, E. (2021). Emotional labour, emotional exhaustion and job satisfaction in the hospitality industry. *Journal of Hospitality and Tourism Insights, 5*(3), 496–514. https://doi.org/10.1108/jhti-10-2020-0196

Anand, S., Vidyarthi, P., & Rathi, N. (2023). Job security and organizational commitment during crises. *International Journal of Hospitality Management, 110*, 103–115.

Aufa, M., Hidayat, R., & Pratama, A. (2023). Work-life balance and job engagement in hotels. *Journal of Hospitality and Tourism Management, 55*, 234–245.

Bakker, A. B., & Demerouti, E. (2020). A systematic review of the Job Demands-Resources model: Challenges for future research. *Journal of Occupational Health Psychology, 25*(3), 1–14. https://doi.org/10.1037/ocp0000170

Baquero, A. (2023). Hotel Employees' Burnout and Intention to Quit: The Role of Psychological Distress and Financial Well-Being in a Moderation Mediation Model. *Behaviors, 13*(2), Article 84. https://www.mdpi.com/2076-328X/13/2/84

Brotheridge, C. M., & Lee, R. T. (2013). Development and validation of the Emotional Labour Scale. *Journal of Occupational and Organizational Psychology, 76*(3), 365–379. https://doi.org/10.1348/096317903769647229

Bufquin, D., Park, J. Y., Back, R. M., & Choi, Y. (2021). Impact of work stress and job burnout on turnover intentions among hotel employees. *International Journal of Environmental Research and Public Health, 19*(15), Article 9724. https://www.mdpi.com/1660-4601/19/15/9724

Chauhan, A., & Kumar, S. (2025). Occupational stress and job satisfaction among hotel employees. *International Journal of Hospitality Management, 45*(2), 112–125.

Chauhan, A., Singh, R., & Katiyar, S. (2022). Analysis of Occupational Stress and Impact on Employee Performance in Hotels of Varanasi. *International Journal of Management, 13*(3), 12–24. https://www.researchgate.net/publication/365215496_Analysis_Of_Occupational_Stress_And_Impact_On_Employee_Performance_In_Hotels_Of_Varanasi

Chechi, S., & D'Ambrosio, A. (2025). Emotional intelligence training for hospitality employees. *Journal of Human Resources in Hospitality & Tourism, 24*(1), 45–63.

Cheng, G. H. L., & Chan, D. K. S. (2018). Fear of job loss and employee well-being. *Journal of Organizational Behavior, 39*(5), 567–582.

Chung, E. K., Jung, Y., & Sohn, Y. W. (2021). The effects of job stress on turnover intention among frontline hotel employees. *Journal of Hospitality and Tourism Management, 48*, 123–131.

Dissanayake, D. (2022). Challenges in the Sri Lankan Hospitality Sector: A Decadal Review. *Journal of Hospitality and Tourism Management, 50*, 12–25. https://doi.org/10.1016/j.jhtm.2022.01.005

Elshaer, I. A., Ayoun, B. M., Sobaih, A. E. E., & Elshaer, I. (2020). A review of antecedents of employee turnover in the hospitality industry on individual, team and organizational levels. *International Hospitality Review, 34*(1), 161–200. https://doi.org/10.1108/ihr-09-2020-0050

Fernando, D. (2021). Chronic stress and turnover intentions in Sri Lanka. *Journal of Human Resource Management, 15*(2), 20–38.

Fernando, S., & Lee, W. (2013). Regaining Missed Opportunities: The Role of Tourism in Post-War Development in Sri Lanka. *Tourism Planning & Development*. https://doi.org/10.1080/10941665.2013.806615

Flick, U. (2018). *An introduction to qualitative research* (6th ed.). SAGE Publications.

Ghani, U., Zaman, U., Rafiq, M., Khan, I., & Ghani, M. (2022). Challenges and strategies for employee retention in the hospitality industry: A review. *Sustainability, 14*(5), Article 2885. https://www.mdpi.com/2071-1050/14/5/2885

Gill, R. (2020). The importance of employee well-being in organizational success. *Journal of Business Research, 115*, 23–34. https://doi.org/10.1016/j.jbusres.2020.01.035

Gordon, S., Tang, C. H., Day, J., & Adler, H. (2019). Supervisor support and turnover intentions in the hospitality industry. *International Journal of Hospitality Management, 78*, 156–165.

Grandey, A. A. (2003). When "the show must go on": Surface acting and deep acting as determinants of emotional exhaustion and peer-rated service performance. *Journal of Applied Psychology, 88*(5), 883–893. https://doi.org/10.1037/0021-9010.88.5.883

Guchait, P., Pasamehmetoglu, A., & Dawson, M. (2016). Time management training for hotel employees. *International Journal of Hospitality Management, 58*, 78–89.

Hadi, N. A., Anuar, A., Rahman, R. A., & Mohd, S. Z. (2023). *The impacts of low pay and work overload on emotional exhaustion among hotel food and beverage staff* [Unpublished bachelor's thesis]. UiTM Institutional Repository. https://ir.uitm.edu.my/id/eprint/86278/

Haldorai, K., Kim, W. G., Pillai, S. G., Park, T. E., & Balasubramanian, K. (2023). The hospitality stress matrix: Exploring job stressors and their effects on psychological well-being. *Sustainability, 15*(17), Article 13116. https://www.mdpi.com/2071-1050/15/17/13116

Han, S. J., Bonn, M. A., & Cho, M. (2020). The relationship between customer incivility, restaurant frontline service employee burnout and turnover intention. *International Journal of Hospitality Management*. https://www.sciencedirect.com/science/article/abs/pii/S0278431915001863

Hochschild, A. R. (2017). *The managed heart: Commercialization of human feeling* (3rd ed.). University of California Press.

Hofmann, V., & Stokburger-Sauer, N. E. (2017). The impact of emotional labor on employees' work-life balance perception and commitment: A study in the hospitality industry. *International Journal of Hospitality Management, 65*, 47–58. https://www.sciencedirect.com/science/article/abs/pii/S0278431917304644

Hori, T., & Chao, C. (2022). How emotional labor affects job performance in hospitality employees: The moderation of emotional intelligence. *Frontiers in Psychology, 13*, Article 906876. https://doi.org/10.3389/fpsyg.2022.906876

Hwang, J., Lee, J. S., & Park, S. (2021). Hospitality employees' emotions in the workplace: A systematic review of recent literature. *International Journal of Contemporary Hospitality Management, 33*(6), 2075–2100. https://doi.org/10.1108/ijchm-12-2020-1426

Iqbal, A., Bhatti, A., & Naseem, M. A. (2018). Impact of emotional labor on emotional exhaustion and job satisfaction in public-sector organizations. *Journal of Public Affairs, 18*(3), Article e1824. https://www.researchgate.net/publication/342897093_Impact_of_Emotional_Labor_on_Emotional_Exhaustion_and_Job_Satisfaction_in_Public_Sector_Organizations

Jayasinghe, C. (2017). *A model of employee well-being for front-line employees in hotel industry* [Unpublished manuscript]. https://www.researchgate.net/profile/Chathuni-Jayasinghe

Jayawardena, C. (2020). Training and communication in Sri Lankan hospitality. *Sri Lankan Journal of Hospitality, 8*(1), 34–51.

Jiang, L., & Lavaysse, L. M. (2018). Job security and psychological commitment. *Journal of Organizational Behavior, 39*(8), 987–1002.

Kahn, S., Smith, P., & Jones, M. (2021). Time pressure and employee fatigue in hospitality. *International Journal of Stress Management, 28*(2), 112–128.

Kahn, W. A. (1990). Psychological conditions of personal engagement and disengagement at work. *Academy of Management Journal, 33*(4), 692–724.

Karatepe, O. M. (2018). Stressors, work engagement and their effects on job outcomes in front-line hotel employees. *International Journal of Hospitality Management, 70*, 26–35. https://doi.org/10.1016/j.ijhm.2017.10.005

Karatepe, O. M., & Avci, T. (2017). The effects of perceived organisational support and job embeddedness on turnover intentions. *International Journal of Contemporary Hospitality Management, 29*(10), 2732–2750. https://doi.org/10.1108/IJCHM-05-2016-0256

Keim, A. C., Landis, R. S., Pierce, C. A., & Earnest, D. R. (2017). Job insecurity and turnover intentions. *Journal of Applied Psychology, 102*(3), 423–438.

Kim, H. J., & Lee, J. (2017). The impact of emotional labor on job performance in the hospitality industry. *International Journal of Hospitality Management, 63*, 18–27. https://doi.org/10.1016/j.ijhm.2017.01.011

Kim, H., & Park, J. (2023). Transparent communication and employee retention in hotels. *Journal of Hospitality Marketing & Management, 32*(4), 345–362.

Kim, T., Im, J., & Hwang, J. (2015). The effects of mentoring on role stress, job attitude, and turnover intention in the hotel industry. *International Journal of Hospitality Management, 48*, 68–82. https://www.sciencedirect.com/science/article/abs/pii/S0278431915000560

Lee, J., & Ok, C. (2014). The effects of emotional labor on job satisfaction and turnover intention in the hospitality industry. *International Journal of Hospitality Management, 36*, 150–159. https://doi.org/10.1016/j.ijhm.2013.09.003

Lee, S., Kim, H. J., & Cho, Y. (2024). The effects of job stress on burnout and turnover intention: The moderating effects of job security and financial dependency. *Behavioral Sciences, 14*(4), Article 322. https://www.mdpi.com/2076-328X/14/4/322

Lee, S., Lee, J., & Kim, H. (2018). Job security and stress reduction. *Journal of Occupational Health Psychology, 23*(4), 456–470.

Liu, Y. (2017). Emotional labor strategy of hotel frontline employees: The antecedents and consequences. *Journal of Hospitality and Tourism Management, 33*, 18–28. https://www.researchgate.net/publication/320631865_Emotional_Labor_Strategy_of_Hotel_Frontline_Employees_The_Antecedents_and_Consequences

Maslach, C., Schaufeli, W. B., & Leiter, M. P. (2011). Job burnout. *Annual Review of Psychology, 52*(1), 397–422.

Mauno, S., Kinnunen, U., & Ruokolainen, M. (2017). Job security and employee engagement. *Journal of Vocational Behavior, 99*, 78–90.

O'Neill, J. W., & Davis, K. (2011). Work stress and well-being in the hotel industry. *International Journal of Hospitality Management, 30*(2), 385–390. https://www.sciencedirect.com/science/article/abs/pii/S0278431910001016

Park, J., & Min, H. (2020). Turnover intention in the hospitality industry: A meta-analysis. *International Journal of Hospitality Management, 90*, Article 102599. https://www.sciencedirect.com/science/article/abs/pii/S0278431920301511

Perera, G. D. N., & Madagamage, G. (2018). The Impact of Job Satisfaction and Organizational Commitment on Intention to Turnover in the Sri Lankan Hospitality Industry: Perceptions from the Generation Y View Point. *Sri Lankan Journal of Human Resource Management, 8*(1), 23–35. https://doi.org/10.4038/sljhrm.v8i1.5639

Perera, G. D. N., & Madagamage, G. (2019). Job satisfaction and turnover intention among Generation Y employees: A study of the hotel industry in Sri Lanka. *Sri Lankan Journal of Management, 24*(2), 7–22. https://doi.org/10.4038/sljmg.v24i2.38

Probst, T. M., Jiang, L., & Benson, W. L. (2020). Job insecurity and employee outcomes. *Journal of Occupational Health Psychology, 25*(2), 89–103.

Quinlan, C., Babin, B. J., Carr, J., Griffin, M., & Zikmund, W. G. (2019). *Business research methods* (2nd ed.). Cengage Learning.

Ranasinghe, K. (2021). Role ambiguity in Sri Lankan hotels. *Ceylon Journal of Management, 12*(3), 45–62.

Rubel, M. R. B., Kee, D. M. H., & Rimi, N. N. (2017). The mediating role of work–family conflict on role stressors and employee turnover intention relationship in labour-oriented organizations. *Vision: The Journal of Business Perspective, 21*(3), 255–266. https://doi.org/10.1177/0972150917713061

Saito, Y., Fukui, K., & Yamashita, M. (2024). Well-being of hospitality employees: A systematic literature review. *International Journal of Hospitality Management, 115*, Article 103731. https://www.sciencedirect.com/science/article/pii/S0278431924002676

Samarakoon, S. (2023). Turnover rates in Sri Lankan hotels. *Sri Lankan Journal of Management, 28*(1), 18–35.

Van Yperen, N. W., & Hagedoorn, M. (2015). Do high job demands increase burnout? The role of job resources and personal resources. *Journal of Applied Sport Psychology, 28*(3), 1–14. https://doi.org/10.1080/10413200.2015.1092481

Wang, K. L., & Groth, M. (2020). Emotional exhaustion and turnover intentions in hospitality. *Journal of Applied Psychology, 105*(8), 876–890.

Wang, X., Hou, P., Li, X., Liu, C., Chen, S., & Li, R. (2019). The impact of organisational support on emotional exhaustion and turnover intention among frontline hotel employees. *Journal of International Medical Research, 47*(12), 6152–6162. https://doi.org/10.1177/0300060519859145

Weerakoon, U. (2020). Examining Work Role Stressors, Job Satisfaction, Job Stress, and Turnover Intention of Sri Lanka's Construction Industry. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2022.2080931

Wen, B., Zhou, X., Hu, Y., & Zhang, X. (2020). Role stress and turnover intention of front-line hotel employees: The roles of burnout and service climate. *Frontiers in Psychology, 11*, Article 36. https://doi.org/10.3389/fpsyg.2020.00036

Wijayasekara, R. (2021). The influence of organizational support on employee turnover intentions in Sri Lanka. *Kelaniya Journal of Management, 10*, 178–186. https://doi.org/10.4038/kjm.v10i0.7684

Wu, P. L., & Shie, A. J. (2017). Emotional labor and employee well-being in the hotel industry. *International Journal of Hospitality Management, 62*, 45–54.

Xiong, H., Chao, C., & Hori, T. (2022). How emotional labor affect hotel employees' mental health: A longitudinal study. *Tourism Management, 90*, Article 104477. https://www.sciencedirect.com/science/article/abs/pii/S0261517722001443

Xiong, H., Chao, C., & Hori, T. (2023). The effect of emotional labor strategies on hotel employees' mental health: A person-centered longitudinal study. *Journal of Travel Research*. https://doi.org/10.1002/jtr.70092

Xu, S., Cao, Z., Uysal, M., & Kim, H. (2020). Antecedents and outcomes of emotional labour in hospitality and tourism: A meta-analysis. *Tourism Management, 79*, Article 104099. https://www.sciencedirect.com/science/article/abs/pii/S026151772030025X

Yoo, J. (2023). Building confidence against job insecurity in hospitality. *Journal of Hospitality & Tourism Research, 47*(3), 456–473.

Yu, Y., Zhang, X., & Li, Y. (2023). Wellness programs and employee retention in the hospitality sector. *International Journal of Contemporary Hospitality Management, 35*(2), 678–695.

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OP 7

The Impact of the Employees' Awareness of Leaf Standards on Performance of Tea Plantations

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Abstract

Background: This study assesses the impact of workers awareness on the leaf standards or plucking method on the estate's performance. Tea is a significant economic sector in Sri Lanka largely grown by regional plantation companies and smallholders. The sector employs around five million people and is a vital foreign exchange generator. Nevertheless, unlike other producers the estate sector does not focus on workers skills specially on the workers awareness on the leaf standards which is a primary determinant of made tea.

Objective/s: The study focued on assessing potential influences of the worker's awareness on leaf standard and quality of tea in the tea plantation sector in Sri Lanka**.** Furthermore, the study expected to reveal potential methods to maintain the worker's awareness on leaf standard in order to enhance the quality of tea and performance of the tea plantation sector in Sri Lanka.

Methods: The study utilizes a quantitative approach to determine the impact of workers awareness on the tea estate's performance. The study uses primary data gathered through a validated instrument and estimates a multiple linear regression model to derive results.

Results: Results revealed that employees' awareness of fertilizer usage, weather conditions, and tea plucking methods had significant positive associations with tea estate performance, while awareness of tea plant age showed an insignificant relationship.
Conclusion: Tea estates usually do not carry out regular KPI based assessments on the workers awareness on the selected criteria of this study. The opportunities for increasing the awareness for workers are also minimal wherein they depend on peers' knowledge and expertise. This is an important knowledge gap that tea estates should address, as employee awareness of leaf standards is associated with plantation performance.

Keywords: *Tea, Leaf standards, Worker's awareness, Performance, Fertilizer usage*

Introduction

Tea, *Camellia sinensis* is the most widely consumed beverage in the world apart from water. The tea crop is grown in about 30 countries, and the leading producers are China, India, Kenya, and Sri Lanka. Sri Lanka is the 4th largest tea producing country in the World [2]. Ceylon Tea has earned worldwide acclaim for its superior intrinsic properties as well as its distinct flavor profile. The plantation-based tea industry has made a substantial contribution to the economic development of the country. Sri Lanka is globally recognized for producing premium-quality Ceylon Tea and remains among the leading tea-exporting nations [2]. Despite its importance, the industry has experienced declining productivity, increasing labour costs, labour shortages, and quality-related challenges [3,10]. Tea quality largely depends on harvesting practices, particularly adherence to leaf standards during plucking [6,8].

Leaf standards determine the composition and quality of green leaf supplied for processing. Fine and medium plucking standards are associated with higher tea quality, whereas coarse plucking negatively affects flavour, appearance, and market value [6]. Research has demonstrated that tea quality is influenced by agronomic practices such as fertilizer application, tea bush age, and environmental conditions [4,7]. Proper fertilizer management contributes to healthy plant growth and improved leaf quality, while tea plant age affects productivity and harvesting efficiency [11]. The quality of tea leaves directly influences auction prices and profitability [12]. Therefore, employee awareness regarding proper

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plucking methods, fertilizer application, and plantation management practices is essential for maintaining productivity and competitiveness. Although previous studies have examined factors affecting tea quality, limited attention has been given to the relationship between employee awareness of leaf standards and tea estate performance. This study addresses this gap by examining the impact of employees' awareness of leaf standards on the performance of tea plantations in Sri Lanka.

Methods

Research Design

This study adopted a quantitative research approach using a cross-sectional survey design. The quantitative approach was selected because it enables the measurement and analysis of relationships between variables using statistical techniques. The study aimed to investigate the impact of employees' awareness of leaf standards on tea estate performance at ABC Plantations in hill country, Sri Lanka.

Conceptual Framework

Figure 01 exhibits the conceptual framework of the underlying study. The conceptual framework of this study is grounded in Human Capital Theory, Knowledge-Based View, and Agricultural Extension and Knowledge Transfer Theory. Human Capital Theory proposes that employees' knowledge, skills, and competencies are valuable resources that enhance organisational productivity and performance [1]. Similarly, the Knowledge-Based View highlights that knowledge possessed by employees contributes to operational efficiency and quality improvement by creating competitive advantages [7]. In the context of tea plantations, employees' awareness of essential agronomic practices represents a critical form of knowledge that influences tea leaf quality and plantation performance. Accordingly, awareness of tea plant age, fertilizer application, weather conditions, and appropriate tea plucking methods were selected as key dimensions because they represent fundamental knowledge areas required for maintaining leaf quality, improving harvesting efficiency, and supporting sustainable plantation productivity. Furthermore, Agricultural Extension and Knowledge Transfer Theory emphasises the importance of transferring technical agricultural knowledge to field-level workers to improve decision-making and farming outcomes [4,15]. Therefore, employees' awareness of leaf standards can be considered an important human resource capability that contributes to improved tea plantation performance.

In this study, tea quality was used as a proxy measure for plantation performance based on employees' perceptions. Although objective indicators such as yield, auction price, and profitability provide comprehensive performance measures, access to estate-level operational data was limited. Therefore, findings should be interpreted as employees' perceived relationship between leaf standard awareness and plantation performance rather than direct measurement of overall financial performance.

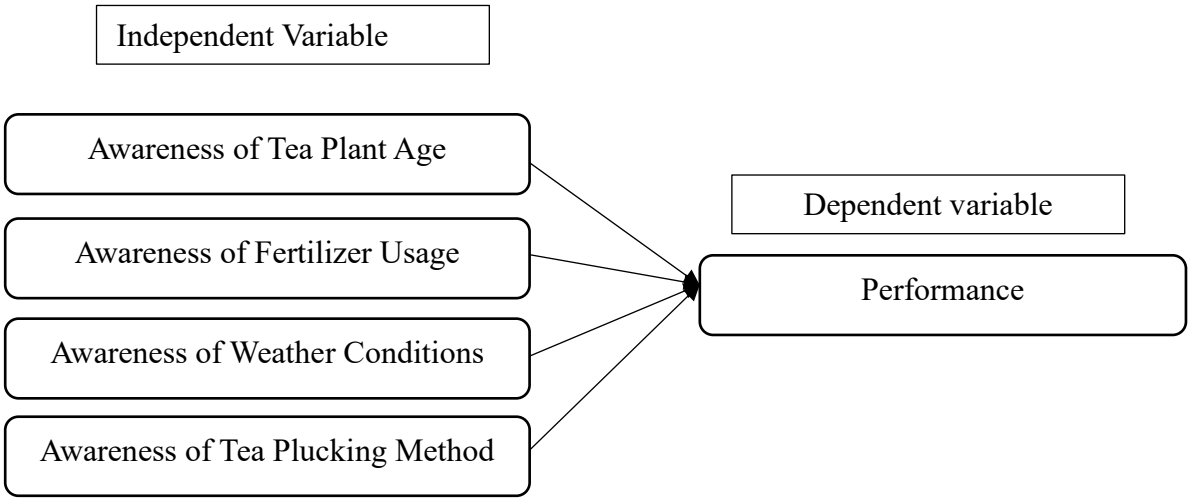

Figure 01 : Conceptual framework
Source: Developed by Author

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Based on the conceptual framwork, the researcher developed hypothesis as below.

H_1: There is significant relationship between worker's awareness on age of tea plants on the performance of the tea plantations

H_2: There is significant relationship between worker's awareness on fertilizers on the performance of the tea plantations

H_3: There is significant relationship between awareness on whether condition on the performance of the tea plantations

H_4: There is significant relationship between worker's awareness on tea plucking method on the performance of the tea plantations

Population and Sampling

The target population consisted of field and factory employees directly involved in tea plantation operations. The sampling frame included 515 labourers and 29 staff members employed at the estate. Based on a 95% confidence level, a sample of 100 respondents was selected for the study. Although stratified random sampling was employed to ensure representation among employees, the study was conducted within a single tea plantation. Therefore, the generalisability of findings to other tea estates, plantation companies, and smallholder tea sectors should be considered cautiously. Future studies involving multiple plantations across different geographical regions are recommended.

Data Collection

Primary data were collected using a structured questionnaire administered to field and factory employees. The questionnaire was developed based on the study objectives and relevant literature. To enhance the validity of the findings, secondary data were obtained from company records, official reports, and other relevant documentary sources. The questionnaire measured employees' awareness of tea plant age, fertilizer usage, weather conditions, tea plucking methods, and tea estate performance using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Reliability and Validity Assessment

Cronbach's Alpha was used to assess internal consistency reliability. According to Cronbach, values above 0.70 indicate acceptable reliability. Construct validity was assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. A KMO value greater than 0.60 and a significant Bartlett's Test indicate suitability for factor analysis.

Data Analysis

Data were analysed using the Statistical Package for Social Sciences (SPSS). Descriptive statistics were used to summarize respondent characteristics. Reliability analysis, normality testing, Pearson correlation analysis, and multiple regression analysis were conducted to examine the relationships between employees' awareness variables and tea estate performance.

Results

Reliability and Validity Analysis

The reliability analysis indicated satisfactory internal consistency for all constructs. Cronbach's Alpha values exceeded the recommended threshold of 0.70, confirming the reliability of the measurement scales. The KMO value was recorded at 0.780, exceeding the minimum acceptable level of 0.60. Furthermore, Bartlett's Test of Sphericity was significant ($p < 0.001$), indicating that the data were suitable for factor analysis.

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Variable Code	Variable Name	Alpha Value	Bartlett's Test significance level
AP	Worker's awareness on the Age of tea Plants	0.901	0.000
FU	Worker's awareness on the Fertilizer usage	0.841	0.000
WC	Worker's awareness on the Whether Condition	0.931	0.000
PM	Worker's awareness on the Tea Plucking Method	0.946	0.000
QT	Worker's awareness on the Quality of tea	0.812	0.000

Table 01**:** Reliability test scores of the questionnaire
Source: SPSS output (2023)

Results of the Empirical Analysis

A multiple linear regression model was estimated to assess the impacts of the worker's awareness on age of the plantatin, fertilizer use, weather conditions, and tea plucing method on the quality of tea. Tables exhibits the results of the regression analysis.

Model Summary Table

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Durbin–Watson
1	.857[a]	.734	.722	.17157	2.011

Table 02**:** Model Summary
Source: SPSS output (2023)

ANOVA Table

Model	Sum of Squares	df	Mean Square	F-statistic	Sig.
Regression	21.087	4	5.272	119.00	000[b]
Residual	4.209	95	0.044		
Total	25.296	99			

Table 03**:** ANOVA Table
Source: SPSS output (2023)

Regression Coefficient Table

Independent Variable	B	Std. Error	Standardized Coefficient (β)	t-value	Sig. (p-value)	Tolerance	VIF
Constant	0.7773	0.0926	–	-8.400	0.000	–	–
Awareness of Tea Plant Age	0.0118	0.0246	0.045	0.480	0.632	0.710	1.408
Awareness of Fertilizer Usage	0.2519	0.0683	0.218	3.689	0.001	0.642	1.558
Awareness of Weather Conditions	0.2248	0.0634	0.214	3.550	0.001	0.598	1.672
Awareness of Tea Plucking Methods	0.6080	0.0544	0.692	11.176	0.000	0.625	1.600

Table 04**:** Regression Coefficient
Source: SPSS output (2023)

As per the regression results, three variables, namely awareness of fertilizer usage, awareness of weather conditions, and awareness of tea plucking methods, showed statistically significant positive associations with tea plantation performance. However, awareness of tea plant age did not demonstrate a statistically significant relationship with the dependent variable. The quality of tea was used as a proxy measure for estate performance since the quality of agricultural output represents an important indicator of plantation performance [10].

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H1: There is significant impact** of the worker's awareness on **age of tea plants on the performance of the tea plantations

The coefficient of awareness of tea plant age was positive (B = 0.0118), indicating a positive association with tea plantation performance. However, the relationship was not statistically significant (β = 0.045, t = 0.480, p = 0.632). Therefore, there is insufficient evidence to support a significant relationship between workers' awareness of tea plant age and perceived tea plantation performance. Hence, H1 is not supported.

H2: There is significant impact** of **fertilizers on the performance of the tea plantations

The coefficient of awareness of fertilizer usage was positive and statistically significant (B = 0.2519, β = 0.218, t = 3.689, p = 0.001). Therefore, workers' awareness of fertilizer usage is significantly associated with tea plantation performance. Hence, H2 is supported.

H3: There is significant impact** of **weather condition on the performance of the tea plantations

The coefficient of awareness of weather conditions was positive and statistically significant (B = 0.2248, β = 0.214, t = 3.550, p = 0.001). Therefore, workers' awareness of weather conditions is significantly associated with percieved tea plantation performance. Hence, H3 is supported.

H4: There is significant impact** of **tea plucking method on the performance of the tea plantations

The coefficient of awareness of tea plucking methods was positive and statistically significant (B = 0.6080, β = 0.692, t = 11.176, p < 0.001). Among the four dimensions, tea plucking method awareness demonstrated the strongest association with perceived tea plantation performance. Hence, H4 is supported.

Hypotheses	**Regression Analysis**
H1: There is significant impact of the worker's awareness on age of tea plants on the performance of the tea plantations	There is not enough evidence to accept the calim
H2: There is significant impact of fertilizers on the performance of the tea plantations	Accepted
H3: There is significant impact of whether condition on the performance of the tea plantations	Accepted
H4: There is significant impact of tea plucking method on the performance of the tea plantations	Accepted

Table 03: Summary of the hypothesis tested
Source: Author

Discussion

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Impact of Tea Plant Age Awareness on Tea Estate Performance

The findings revealed that awareness of tea plant age had a positive but statistically insignificant association with tea estate performance ($\beta = 0.045$, $p = 0.632$). Although employees' understanding of tea plant growth stages and productivity characteristics may support effective plantation management decisions, the results indicate that awareness of tea plant age alone does not significantly explain variations in tea estate performance within the studied plantation. This suggests that other operational factors, particularly knowledge related to fertilizer application, weather conditions, and tea plucking practices, may have a stronger association with tea quality outcomes. However, previous research has highlighted the importance of plantation age in determining tea yield and productivity [8], indicating the need for further investigations incorporating objective plantation-level performance indicators.

Impact of Fertilizer Usage Awareness on Tea Estate Performance

Awareness of fertilizer usage demonstrated a significant positive influence on tea estate performance. Employees with adequate knowledge of fertilizer application methods can contribute to healthier tea bushes, improved nutrient management, and enhanced tea quality. Similar findings were reported by Ruan et al. [12], who identified fertilizer management as a critical factor affecting tea productivity.

Impact of Weather Condition Awareness on Tea Estate Performance

The results indicated that awareness of weather conditions had a significant positive association with tea estate performance ($\beta = 0.214$, $p = 0.001$). Although climatic conditions themselves cannot be controlled by plantation employees, awareness of weather patterns may support better operational decisions, such as appropriate timing of field activities, plucking schedules, and other cultivation practices. Therefore, employees' understanding of weather-related factors can contribute to improved management responses and tea quality outcomes. This finding is consistent with previous plantation studies highlighting the importance of environmental knowledge and adaptive management practices in agricultural production systems.

Impact of Tea Plucking Method Awareness on Tea Estate Performance

Tea plucking method awareness emerged as the strongest predictor of tea estate performance ($\beta = 0.692$, $p < 0.001$). Proper plucking practices directly affect leaf quality, manufacturing efficiency, and market value. Employees who possess greater awareness of plucking standards are more likely to maintain the quality of green leaves supplied for processing. This finding supports previous studies emphasizing the importance of plucking standards in determining tea quality and profitability [4]. Therefore, improving workers' competency in tea plucking practices represents a critical strategy for enhancing plantation performance.

Overall Discussion

The findings demonstrate that employees' awareness of leaf standards is an important factor associated with tea estate performance. Among the examined dimensions, awareness of tea plucking methods showed the strongest relationship with plantation performance, followed by fertilizer usage awareness and weather condition awareness. Although awareness of tea plant age showed a positive relationship, it was not statistically significant in explaining variations in tea estate performance. These findings highlight the importance of employee knowledge and technical competencies in maintaining tea quality and improving operational practices [10,11].

The results suggest that tea plantation companies should strengthen structured training programmes focusing on tea plucking standards, fertilizer management practices, and climate-responsive cultivation methods. Continuous awareness programmes, competency assessments, and monitoring systems related to leaf quality standards can support improvements in productivity and tea quality. Such interventions may contribute to the long-term sustainability and competitiveness of Sri Lanka's tea plantation sector.

Conclusions

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The study's main objective was to examine the impact of the worker's awareness on leaf standard or the plucking method on the performance of the tea plantations. The findings revealed that employees' awareness of fertilizer usage, weather conditions, and tea plucking methods had significant positive associations with plantation performance, while awareness of tea plant age showed a positive but statistically insignificant relationship. Therefore, the study provides evidence that workers' technical awareness related to key leaf standard practices contributes to improved tea quality and plantation performance.

Tea plantations usually do not carry out regular KPI based assessments on the workers awareness on the selected criteria of this study. The opportunities for increasing the awareness for workers are also minimal wherein they depend on peers' knowledge and expertise. This is a major gap that the plantations should address since it directly relates to the overall performance of the plantation.

Based on the study's outcomes, following recommendations can be made.

1. The tea estates should substantially invest on evaluating the workers awareness on fertilizer usage, wheather condition and plucking methods
2. Adequate training and development opportunities should be provided to the workers to enhance their awareness on age of the plants, fertilizer usage and plucking methods since these directly links with the estate's performance

3. Tea plantation companies should introduce continuous learning programmes, supervisor monitoring mechanisms, and KPI-based quality assessments to strengthen workers' compliance with leaf quality standards and promote sustainable improvements in tea production.

Managerial Implications

The findings provide important implications for tea plantation management. Since employees' awareness of fertilizer usage, weather conditions, and tea plucking methods showed significant associations with plantation performance, estates should focus on continuous employee training and knowledge development programmes. Regular refresher training on leaf standards, plucking techniques, and agronomic practices should be conducted to improve workers' competencies. Tea companies should introduce competency assessment systems and KPI-based monitoring mechanisms focusing on plucking quality, rejected leaf percentage, and productivity levels. Greater involvement of agricultural extension officers and the use of digital monitoring systems can support knowledge transfer and improve quality management practices. Furthermore, incentive schemes linked with quality harvesting and continuous improvement programmes can motivate workers and contribute to improved tea quality and sustainable plantation performance.

Future Research

Future research may extend this study by incorporating multiple tea plantations and different geographical regions to improve external validity. Longitudinal studies could evaluate changes in plantation performance following employee training interventions. Future studies may also incorporate objective performance indicators such as yield, auction prices, and profitability. Furthermore, examining the mediating role of employee motivation and the contribution of digital agricultural extension technologies would provide deeper insights into the relationship between employee awareness and plantation performance.

References

1. Becker GS. *Human capital: A theoretical and empirical analysis, with special reference to education*. New York: Columbia University Press; 1964.
2. Besky S. Tasting qualities: the value of tea. Berkeley: University of California Press; 2020.
3. Central Bank of Sri Lanka. Annual report. Colombo: Central Bank of Sri Lanka; 2015.
4. Davis K, Sulaiman RV. The new extensionist: Roles and capacities to strengthen extension and advisory services. *Journal of Agricultural Education and Extension*. 2014;20(3):233–47.
5. Gabszewicz J, Turrini A. Workers' skills and product selection. Rev Economique. 1999;50(2):383-391.
6. Gamage A, Wickramaratne W. Productivity enhancing sustainable human care and knowledge management practices in Sri Lankan tea industry. Int J Bus Soc Sci. 2019;10(2):74-82.
7. Grant RM. Toward a knowledge-based theory of the firm. *Strategic Management Journal*. 1996;17(S2):109–22.

8. Herath D, Weersink A. From plantations to smallholder production: the role of policy in the reorganization of the Sri Lankan tea sector. World Dev. 2009;37(11):1759-1772.
9. Ho CT, Chang SS. Tea and tea products: chemistry and health-promoting properties. Washington DC: American Chemical Society; 1992.
10. Illukpitiya P, Shanmugaratnam N, Kjosavik D. Tea agroecosystems in the Uva Highlands of Sri Lanka: an evaluation of land management activities. Mt Res Dev. 2004;24(1):52-59.
11. International Labour Organization. Future of work for tea smallholders in Sri Lanka. Colombo: International Labour Organization; 2018.
12. Ishaq B, Awan H. The key performance indicators (KPIs) and their impact on overall organizational performance. Qual Quant. 2014;48:3127-3143.
13. Kumar R, Shruthi HS. A review on medicinal and nutraceutical importance of tea. Int J Pharm Life Sci. 2014;5(2):3076-3084.
14. Kumar R. Tea plantation management and productivity. Tea Res J. 2013;45(3):85-93.
15. Rogers EM. *Diffusion of innovations*. 5th ed. New York: Free Press; 2003.
16. Ruan J, Wu X, Hardter R. Effects of fertilizer application on tea quality. Plant Nutr Fert Sci. 1998;21(5):783-790.

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OP 8

Determinants of Entrepreneurial Intention among Business and Management Graduates from Private Universities in Kandy District, Sri Lanka.

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Abstract

Despite producing a substantial number of business and management graduates annually, Sri Lanka experiences persistently low entrepreneurship rates among them. While state universities and private institutions graduate approximately 9,000–14,000 business students yearly, only a small fraction (less than 5%) engage in entrepreneurial activities. Graduates predominantly prefer salaried employment due to perceived job security and lack practical skills, contributing to graduate unemployment and limited economic innovation. This study examines the impact of Attitude Towards Entrepreneurship, Perceived Behavioural Control (Self-Efficacy), and Entrepreneurship Education on Entrepreneurial Intention among Business and Management graduates in private universities in the Kandy District of Sri Lanka. A quantitative cross-sectional survey was conducted with 384 randomly selected graduates. Primary data were collected via a structured Likert-scale questionnaire through Google Forms, yielding 357 valid responses (92.97% response rate). Data were analysed using descriptive statistics, Pearson correlation, and multiple linear regression. The regression model explained 46.5% of the variance in Entrepreneurial Intention ($R^2 = 0.465$, Adjusted $R^2 = 0.460$). All predictors were significant: Perceived Behavioural Control (Self-Efficacy) emerged as the strongest ($\beta = 0.362$, $p < .001$), followed by Attitude Towards Entrepreneurship ($\beta = 0.298$, $p < .001$) and Entrepreneurship Education ($\beta = 0.204$, $p < .001$). All constructs demonstrated excellent/good reliability (Cronbach's $\alpha > 0.70$). Findings highlight the critical role of self-efficacy and attitude in fostering entrepreneurial intention, while revealing the modest impact of current entrepreneurship education. Strengthening practical skills and ecosystem support in university curricula is essential to bridge the gap between graduate output and venture creation in Sri Lanka.

Keywords: *Entrepreneurial Intention, Entrepreneurship Education, Perceived Behavioural Control, Private Universities, Self-Efficacy*

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Introduction

Even though the substantial annual output of business and management graduates from Sri Lankan universities, the rate of actual entrepreneurship among them remains significantly low. The University Grants Commission (UGC) reported 7,232 Management and Commerce graduates from state universities and Higher Education Institutions in 2022 alone, with total business graduates including private institutions estimated between 9,000 and 14,000 per year [1]. In contrast, the Department of the Registrar of Companies (DRC) registers approximately 17,000 to 23,000 new formal businesses annually [2], indicating a steady stream of entrepreneurial activity in the country. However, empirical evidence consistently shows that only a small proportion of these new ventures are initiated by business graduates. Studies indicate that less than 5% [3,4] of Sri Lanka's entrepreneurs over a decade were produced by local universities, and self-employment/entrepreneurship rates among management graduates howver between 1.9% and 5%. Furthermore, 65% of Sri Lankan university graduates prefer salaried employment over entrepreneurship due to perceived job security, while 72% reportedly lack the necessary practical skills to start and manage businesses effectively [5]. This mismatch contributes to graduate unemployment and underemployment, entrepreneurial stagnation, and missed opportunities for innovation and economic growth in Sri Lanka, which ranks among the lower early-stage entrepreneurial activity rates in South Asia according to the Global Entrepreneurship Monitor [6]. This situation raises critical questions about the effectiveness of higher education curricula, entrepreneurial ecosystem support, and socio-cultural factors in translating graduate knowledge into actual venture creation.

While the Theory of Planned Behaviour (TPB) has been extensively applied to explain entrepreneurial intention across diverse global contexts [7,8,10], most existing studies have focused on undergraduates in general, public university populations, or developed economy settings, with comparatively limited empirical attention paid to private university graduates in South Asian emerging economies. This gap is particularly significant in Sri Lanka, where private higher education institutions have expanded rapidly in recent years yet remain underrepresented in entrepreneurship research, and where graduates face a distinct combination of high salaried-employment preference, perceived job security concerns, and reported gaps in practical entrepreneurial skills [5]. By empirically testing the TPB framework specifically Attitude Towards Entrepreneurship, Perceived Behavioural Control (Self-Efficacy), and Entrepreneurship Education within this under-studied population, the present study extends the applicability of TPB beyond its traditional contexts and provides context-specific evidence to inform entrepreneurship curriculum design and policy in private higher education institutions in Sri Lanka and comparable emerging-economy settings

Methods

This study employed a quantitative research approach with a cross-sectional survey design to investigate the determinants of Entrepreneurial Intention among Business and Management Graduates in private universities in the Kandy District of Sri Lanka. The target population of the study consisted of all Business and Management graduates from private universities operating in the Kandy District. Sample size was 384 respondents and simple random sampling technique was adopted to select the participants. Primary data were collected at a single point in time through a structured questionnaire consisting of Likert-scale measurements. The questionnaire was distributed online using Google Forms among graduates. Out of 384 questionnaires distributed, 357 were returned as complete and valid responses, yielding a response rate of 92.97%. It should be noted that the sampling frame was restricted to Business and Management graduates from private universities within the Kandy District; therefore, the findings are representative of this specific population and may not extend to graduates from public universities or other geographic regions of Sri Lanka, where institutional and socio-economic conditions may differ.The collected data were analysed using descriptive statistics, Pearson correlation analysis, and multiple linear regression analysis to test the developed hypotheses.

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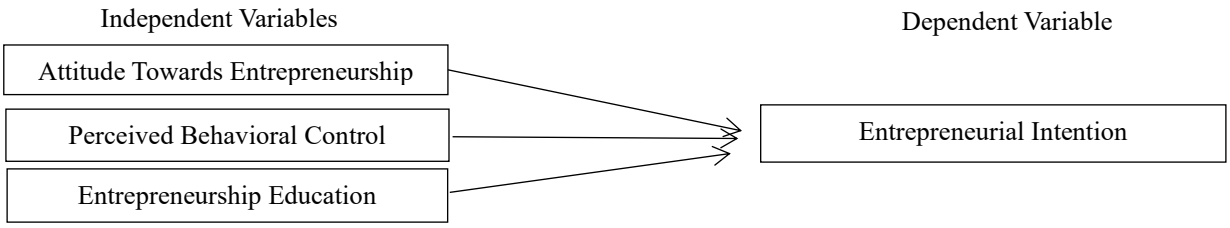

Figure 1 Conceptual Framework

Hypotheses

H1: Attitude Towards Entrepreneurship has a significant positive impact on Entrepreneurial Intention.

H2: Perceived Behavioural Control (Self-Efficacy) has a significant positive impact on Entrepreneurial Intention.

H3: Entrepreneurship Education has a significant positive impact on Entrepreneurial Intention.

Results

Demographic Profile of Respondents

The study sample comprised 357 Business and Management graduates from private universities in the Kandy District. The respondents were predominantly female (58.5%), with males representing 41.5%. The majority (62.7%) were aged between 23–27 years, followed by 22–24 years (28.3%). Most respondents had graduated in Business Management (48.2%) and Accounting/Finance (31.7%).

Table 1: Demographic Characteristics of Respondents (n=357)

Variable	Category	Frequency	Percentage (%)
Gender	Male	148	41.5
	Female	209	58.5
Age Group	22–24 years	101	28.3
	23–27 years	224	62.7
	Above 27 years	32	9.0
Degree Programme	Business Management	172	48.2
	Accounting & Finance	113	31.7
	Marketing & HRM	72	20.1

Table 2: Reliability Analysis

Variable	Cronbach's Alpha Value	No. of Items	Reliability
Attitude Towards Entrepreneurship	0.874	6	Excellent
Perceived Behavioural Control (Self-Efficacy)	0.862	6	Excellent
Entrepreneurship Education	0.819	6	Good
Entrepreneurial Intention	0.891	5	Excellent

Reliability of the research instrument was assessed using Cronbach's Alpha. As shown in Table 2, all constructs reported Cronbach's Alpha values above the recommended threshold of 0.70 (Nunnally, 1978). The highest reliability

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was recorded for Entrepreneurial Intention (α = 0.891) and Attitude Towards Entrepreneurship (α = 0.874). These results indicate that the measurement scales used in this study are highly reliable and internally consistent.

Table 3:Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.682	.465	.460	.612

As presented in Table 3, the regression model was found that the three predictors (Attitude Towards Entrepreneurship, Perceived Behavioural Control (Self-Efficacy), and Entrepreneurship Education collectively account for 46.5% of the variance in Entrepreneurial Intention among Business and Management graduates in private universities in the Kandy District. The Adjusted R^2 of 0.460 demonstrates that the model retains strong explanatory power Furthermore, the Standard Error of the Estimate of 0.612 reflects acceptable predictive accuracy, implying that the model's predictions deviate from actual entrepreneurial intention scores by an average of only 0.612 points on the Likert scale.

Table 4: Regression Analysis

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.856	0.214	-	4.000	.000
	Attitude Towards Entrepreneurship	0.312	0.048	.298	6.500	.000
	Perceived Behavioural Control (Self-Efficacy)	0.385	0.051	.362	7.549	.000
	Entrepreneurship Education	0.214	0.044	.204	4.864	.000

All three independent variables are statistically significant positive predictors of Entrepreneurial Intention. Perceived Behavioural Control (Self-Efficacy) emerged as the strongest predictor (β = 0.362, p < .001), indicating that graduates' confidence in their ability to successfully start and manage a business has the greatest influence on their entrepreneurial intention. Attitude Towards Entrepreneurship is the second strongest predictor (β = 0.298, p < .001). Entrepreneurship Education has a positive but relatively weaker effect (β = 0.204, p < .001), suggesting that while current education contributes, its impact is modest supporting the broader concern about the effectiveness of curricula in private universities.

Table 5: Multicollinearity Analysis

Variable	Tolerance	VIF
Attitude Towards Entrepreneurship	0.684	1.462
Perceived Behavioural Control (Self-Efficacy)	0.623	1.605
Entrepreneurship Education	0.741	1.349

Multicollinearity was assessed using Variance Inflation Factor (VIF) and Tolerance values. As presented in Table 5, all VIF values (ranging from 1.349 to 1.605) were well below the recommended threshold of 5.0, and Tolerance values (ranging from 0.623 to 0.741) exceeded the minimum acceptable level of 0.20 (Hair et al., 2019). These results confirm

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that multicollinearity was not a concern in the regression model, indicating that Attitude Towards Entrepreneurship, Perceived Behavioural Control (Self-Efficacy), and Entrepreneurship Education represent statistically distinct predictors of Entrepreneurial Intention.

H1: Attitude Towards Entrepreneurship has a significant positive impact on Entrepreneurial Intention. Result Supported ($\beta = 0.298$, $t = 6.500$, $p < .001$). Graduates with a more favourable attitude towards entrepreneurship demonstrated stronger intentions to start their own businesses.

H2: Perceived Behavioural Control (Self-Efficacy) has a significant positive impact on Entrepreneurial Intention. Result Supported ($\beta = 0.362$, $t = 7.549$, $p < .001$). This was the strongest predictor, indicating that higher confidence in one's entrepreneurial abilities substantially increases intention to engage in venture creation.

H3: Entrepreneurship Education has a significant positive impact on Entrepreneurial Intention. Result Supported ($\beta = 0.204$, $t = 4.864$, $p < .001$). Although statistically significant, its relatively weaker effect suggests that current entrepreneurship education in private universities has a limited influence on developing entrepreneurial intention.

All hypotheses were empirically supported at the 0.001 significance level. These findings confirm the applicability of the Theory of Planned Behaviour in the Sri Lankan private university context while highlighting the need for more impactful entrepreneurship education.

Discussion

The findings of this study reveal that Attitude Towards Entrepreneurship, Perceived Behavioural Control (Self-Efficacy), and Entrepreneurship Education are significant positive predictors of Entrepreneurial Intention among Business and Management graduates in private universities in Kandy District. Consistent with the Theory of Planned Behaviour [7], Perceived Behavioural Control (Self-Efficacy) emerged as the strongest predictor ($\beta = 0.362$), indicating that graduates' confidence in their ability to execute entrepreneurial tasks plays a pivotal role in shaping their intention to start a business. This aligns with previous studies that highlight self-efficacy as a critical determinant of entrepreneurial behaviour [8,9]. Attitude Towards Entrepreneurship also demonstrated a strong positive influence ($\beta = 0.298$), suggesting that favourable evaluations of entrepreneurship as a career choice significantly drive intention [10]. However, Entrepreneurship Education showed a relatively weaker, though still significant effect ($\beta = 0.204$). This modest contribution raises concerns about the practical orientation and effectiveness of current entrepreneurship curricula in private universities, supporting earlier observations that Sri Lankan graduates often lack essential hands-on skills [5,11].Several factors may explain why Entrepreneurship Education showed the weakest, albeit significant, effect on Entrepreneurial Intention. First, entrepreneurship modules in many private university curricula in Sri Lanka tend to be theory-driven, emphasising business planning frameworks and conceptual knowledge over experiential, hands-on engagement such as live venture projects, start-up simulations, or real-world problem-solving. Second, limited exposure to industry mentorship, guest entrepreneurs, and internship opportunities with start ups may restrict graduates' ability to translate classroom knowledge into practical confidence. Third, assessment methods in these programmes often reward examination performance rather than the development of entrepreneurial competencies such as opportunity recognition, risk management, and resource mobilisation, which are more directly linked to self-efficacy and behavioural control. This suggests that while entrepreneurship education successfully imparts theoretical knowledge, it may be insufficiently designed to build the practical skills and confidence that more strongly drive entrepreneurial intention, as reflected in the stronger effects of Attitude and Self Efficacy in this study. These findings point to the need for curriculum reform that integrates experiential learning, industry linkages, and skills based assessment to strengthen the practical impact of entrepreneurship education. These findings can be further situated within a broader theoretical landscape beyond the Theory of Planned Behaviour. From the perspective of Social Cognitive Theory [12], the strong effect of Perceived Behavioural Control (Self-Efficacy) aligns with the concept of self-efficacy as a core driver of goal-directed behaviour, reinforcing that graduates' belief in their own capability is central to entrepreneurial action, not merely a peripheral TPB component. Human Capital Theory offers a useful lens for interpreting the modest effect of Entrepreneurship Education:

while formal education builds general knowledge capital, it may not by itself generate the specific, applied human capital (practical skills, industry exposure, opportunity recognition) required to translate knowledge into entrepreneurial confidence and action. The Entrepreneurial Event Model [13] similarly complements these findings by framing entrepreneurial intention as a function of perceived desirability and perceived feasibility, both of which are shaped more strongly by attitude and self-efficacy than by classroom instruction alone. Finally, Entrepreneurial Ecosystem Theory highlights that individual level attitudes and capabilities do not operate in isolation; the relatively limited influence of entrepreneurship education in this study may also reflect a broader ecosystem gap in Sri Lanka, where private universities may lack strong linkages to incubators, mentors, and funding networks that would otherwise reinforce and amplify the effects of formal education on entrepreneurial intention. Integrating these theoretical perspectives suggests that fostering entrepreneurial intention among Sri Lankan graduates requires not only curriculum reform but also stronger ecosystem-level support structures.

The model explained 46.5% of the variance in Entrepreneurial Intention, indicating moderate explanatory power. These results underscore the existing gap between graduate knowledge and actual venture creation in Sri Lanka. The findings offer several actionable recommendations for private universities, policymakers, and entrepreneurship educators in Sri Lanka. First, curricula should shift toward experiential entrepreneurship education, incorporating live business simulations, venture creation projects, and problem-based learning, rather than relying primarily on theoretical instruction, to more directly build the self-efficacy and practical confidence shown to be the strongest drivers of entrepreneurial intention. Second, universities should establish or strengthen incubation centres that provide graduates with structured support including co-working space, business advisory services, and early-stage venture guidance to bridge the gap between intention and actual venture creation. Third, fostering university industry collaboration through internships, guest lectures by practising entrepreneurs, and joint projects with local businesses can expose students to real-world entrepreneurial challenges and networks. Fourth, structured mentoring programmes pairing graduates with experienced entrepreneurs can provide ongoing guidance, feedback, and role-modelling that formal coursework alone cannot replicate. Fifth, improving graduates' access to seed funding through university-affiliated seed grants, partnerships with venture capital firms, or links to government entrepreneurship funds would address a key ecosystem-level barrier to converting intention into action. Finally, organising entrepreneurship competitions and business plan contests can create low-risk opportunities for students to test ideas, receive feedback, and gain visibility with potential investors or mentors. Collectively, these measures address both the individual-level factors (attitude, self-efficacy) and the ecosystem-level gaps identified in this study, offering a more holistic pathway to increasing entrepreneurial activity among Sri Lankan graduates.

Conclusions

This study concludes that enhancing Perceived Behavioural Control and fostering positive attitudes towards entrepreneurship are more effective strategies than traditional education alone in boosting entrepreneurial intention among private university graduates. There is an urgent need to reform entrepreneurship education by incorporating experiential learning, mentorship, and industry linkages to better prepare graduates for venture creation. Strengthening these areas can help reduce graduate unemployment and stimulate economic growth through increased entrepreneurial activity. A key limitation of this study is its geographic and institutional scope, being confined to private university graduates in Kandy District; future research should extend to public universities and other regions of Sri Lanka to enhance generalisability. In addition, future studies could adopt longitudinal designs to track the transition from entrepreneurial intention to actual venture creation over time, examine gender differences in the formation of entrepreneurial intention, investigate the mediating role of entrepreneurial motivation in the relationship between self efficacy, attitude, and intention, and explore the moderating effect of family business background, which may influence how strongly attitude and self-efficacy translate into entrepreneurial intention. Addressing these directions would provide a more comprehensive understanding of the individual and contextual factors shaping entrepreneurship among Sri Lankan graduates.

References

[1] University Grants Commission Sri Lanka. Annual Report 2022. Colombo: UGC; 2023.

[2] Department of the Registrar of Companies Sri Lanka. Annual Report 2022. Colombo: DRC; 2023.

[3] Madhavika N. Entrepreneurial intentions of Sri Lankan undergraduates [Internet]. SSRN; 2019 [cited 2026 Jun 14]. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3754055

[4] Wijesooriya W. Entrepreneurial intention of undergraduates in Art Stream in Sri Lanka. J Rajarata Econ Rev. 2021;1:105-118.

[5] Dissanayake KA. Impact of constraints and challenges on the progress of women entrepreneurship in Sri Lanka. All Multidiscip J. 2023.

[6] Global Entrepreneurship Monitor. GEM Global Report 2021/2022. London: GEM Consortium; 2022.

[7] Ajzen I. The theory of planned behavior. Organ Behav Hum Decis Process. 1991;50(2):179-211.

[8] Bosnjak M, Ajzen I, Schmidt P. The theory of planned behavior: Selected recent advances and applications. Eur J Psychol. 2020;16(3):352-356.

[9] Gangodawila N. Sri Lankan Journal of Entrepreneurship. Sri Lankan J Entrep. 2025;4.

[10] Krueger NF, Reilly MD, Carsrud AL. Competing models of entrepreneurial intentions. J Bus Ventur. 2000;15(5-6):411-432.

[11] SLIDA. Graduate Skills and Employability Report 2022. Colombo: Sri Lanka Institute of Development Administration; 2022

[12] Bandura A. Social Foundations of Thought and Action: A Social Cognitive Theory. Englewood Cliffs, NJ: Prentice-Hall; 1986.

[13] Shapero A, Sokol L. The social dimensions of entrepreneurship. In: Kent CA, Sexton DL, Vesper KH, editors. Encyclopedia of Entrepreneurship. Englewood Cliffs, NJ: Prentice-Hall; 1982. p. 72-90.

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OP 09

The Impact of Authentic Leadership on Psychological Safety among Nurses in Jaffna, Sri Lanka

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Abstract

Background: Psychological safety is a critical factor in healthcare organizations. It encourages nurses to communicate openly, participate in decision-making without the fear of negative consequences, and report errors. İn Sri Lanka, especially in Jaffna, hospitals continue to experience challenges such as staff shortages, heavy workload, and workplace stress, while the region's post-conflict healthcare context and resource constraints create unique workplace dynamics that differ from those examined in many international studies. This prioritise the importance of effective leadership. Grounded in the social exchange theory, authentic leadership is considered a positive leadership approach that promotes ethical behavior, trust, and transparency. This, in turn, improves psychological safety. Previous studies have shown that authentic leadership positively influences psychological safety among nurses. However, limited studies have examined the relationship within the Sri Lankan healthcare context, particularly in Northern Sri Lanka.

Objective/s: To address this gap, the current study aims to examine the relationship between authentic leadership and psychological safety among nurses in Jaffna, Sri Lanka. The study's findings may help the administrators and nursing supervisors in hospitals to develop leadership practices that foster more supportive and safer working environments.

Methods: A quantitative cross-sectional study was carried out to test the relationship. Data were collected from 120 qualified nurses working in government and private hospitals in Jaffna. A convenience sampling technique was deployed to select the participants, as access to participants was limited to hospitals that granted permission for data collection. Authentic Leadership was measured using the Authentic Leadership Questionnaire (ALQ), and psychological safety was measured using Edmondson's team psychological safety scale. SPSS 27 was used for analysis. Descriptive statistics, correlation analysis, and regression analysis were conducted to test the hypothesis. The reliability values of all measurement scales exceeded Cronbach's alpha value of 0.70.

Results: The findings revealed that authentic leadership had a significant positive relationship with psychological safety among nurses ($r= 0.56$, $p < .001$). Regression analysis also indicated that authentic leadership significantly predicted psychological safety ($\beta = 0.51$, $p < .001$), explaining 31% of the dependent variable. ($R^2 = 0.31$). The moderate regression coefficient suggests that authentic leadership has a meaningful practical influence on fostering psychologically safe work environments, providing valuable guidance for hospital managers and nursing administrators in strengthening supportive leadership practices.

Conclusion/s: Our study found that authentic leadership positively influences psychological safety among nurses in Jaffna. Nurses feel comfortable in expressing their ideas and concerns without fear when the leaders are transparent, supportive, and ethical. Although authentic leadership explained a meaningful proportion of psychological safety, the R^2 value indicates that other workplace factors may also contribute to nurses' psychological safety and should be explored in future research. It also highlights the importance of encouraging authentic leadership practices in hospitals to improve employee well-being, strengthen teamwork, and potentially contribute to better patient care. However, the study has some limitations. The data were collected only from hospitals that granted access, which may limit the generalizability of the findings. Self-reporting bias also impacts the study. The sampling technique is also a limitation. Future studies can include larger samples and expand to other regions of Sri Lanka, and examine additional workplace factors.

Keywords: *Authentic Leadership, Nurses, Psychological Safety, Social Exchange Theory, Sri Lanka.*

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OP 10

The impact of AI tools on the Perceived Employee Performance in the Hospitality Industry. A case study on XYZ Hotel, Sri Lanka

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Background: The rapid evolution of artificial intelligence (AI) is transforming global business operations, specifically within the service sector. In the highly competitive hospitality industry, luxury hotels are increasingly deploying AI-powered applications to streamline backend processes, automate routine administrative duties, and elevate customer experience delivery.

Objective/s: This research aims to investigate the direct impact of artificial intelligence tools on perceived employee performance within the luxury hospitality sector. Specifically, the study assesses the individual operational configurations of automation systems, process streamlining mechanisms, and data-driven decision-making tools on employees' workplace productivity, system usefulness, and technological acceptance.

Methods: Employing a deductive, quantitative research design, a primary survey was administered to a representative sample from a prominent Sri Lankan luxury resort: XYZ Hotel, Colombo. Utilizing the Krejcie and Morgan sample determination framework, a structured questionnaire utilizing 5-point Likert scales was distributed electronically. The instrument was developed from established literature and reviewed by an industry expert and an academic mentor prior to distribution to strengthen its content validity. Out of a total internal organizational population of 1,500 active personnel, a scientifically verified sample size of 306 employees across frontline, administrative, and strategic managerial divisions participated in the survey, of which 118 valid responses were retained for inferential analysis. Statistical hypotheses were evaluated via Pearson correlation analysis using the Statistical Package for the Social Sciences (SPSS) software.

Results: The statistical findings reveal that AI tools are positively associated with perceived worker performance, corresponding with reduced everyday workload stress, improved service delivery accuracy, and stronger strategic decision accuracy. Pearson correlation matrices confirmed statistically significant positive relationships ($r = .485$ to $.699$, $p < .01$) between automation tools, process streamlining tools, decision-making AI tools and Perceived Employee Performance. Automation and process-streamlining tools showed the strongest associations with task efficiency and worker adaptability ($r = .611$ to $.699$), while decision-making tools showed moderate associations with managerial prediction competencies ($r = .522$ to $.621$), all significant at the 0.01 level. As the study measures perceived rather than objective employee performance, these findings should be interpreted as reflecting employee self-assessments.

Conclusion/s: The findings suggest that integrating AI infrastructure does not substitute human labor but rather supports a complementary human-machine relationship that may enhance operational performance, an interpretation consistent with, though not directly confirmed by, the correlational findings. Given the correlational design and reliance on perceived rather than objective performance measures, causal claims should be made with caution. The study concludes that the long-term success of technological implementation in hospitality is likely to depend on structured continuous training initiatives and proactive, strategic workforce engagement.

Keywords: Artificial Intelligence, Automation tools, Decision-Making Tools, Perceived Employee Performance, Process Streamlining Tools

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OP 01

The Youth Voter and Political Change: Investigating the Impact of the Youth Vote on Election Results in Sri Lanka

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Abstract

Background:

Youth participation in politics is increasing in various countries around the world. It provides a basic introduction to electoral politics. This analysis helps to understand the dynamics of political participation as the youth demographic faces the economic crisis that has emerged after recovering from the conflict-ridden war environment.

Objective:
The primary objective of this study is to critically examine the behaviour of young voters and their impact on electoral politics in Sri Lanka.

Methods:
Thus, the study uses a qualitative review method based on secondary data regarding young voters and political change. The data collected includes various sources such as official election records, policy papers of government agencies and NGOs, and various government reports.

The scope of the analysis includes the historical trend of youth voting behaviour and political participation spanning from the 1990s to the present. To ensure a comprehensive analysis, a mixed methods approach was used for data interpretation, and qualitative content analysis and thematic analysis were used.

Recurrent socio-political narratives expressed through the collected secondary literature were used to identify and interpret shifts in political beliefs and emerging demands. A quantitative analysis is conducted using descriptive analysis on numerical data extracted from election records and national statistics.

Results:
The analysis identifies two significant trends in the political behaviour of young voters. The first is a decline in political trust, and the second is a volatile political shift. Youth voter participation has emerged as a significant political shift in major elections. This volatility and independence indicate a maturity in voters who prioritise issues over traditional loyalties.

Conclusion/s:
However, the findings highlight the responsibility of political parties and leaders to modernise their electoral strategies and governance policies to truly align with the socio-political aspirations of this crucial demographic, and to move away from patronage and towards a meaningful policy-based engagement. Accordingly, the study concludes that the young voter in Sri Lanka has become a decisive, independent and volatile force that can change the outcome of elections.

Keywords: Electoral Politics, Political Change, Sri Lanka, Traditional Parties, Youth Vote

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Introduction

Youth political participation is seen as an essential factor in democratic change in both developed and developing countries. As a dynamic and important group, young people can influence election outcomes, reshape political conversations, and question established governance systems. In Sri Lanka, where youth make up about one-quarter of the population, their voting behavior has serious implications for political legitimacy, regime stability, and strengthening democracy (Asian Electoral Resource Center [AERC], 2014). Despite relatively high voter turnout, youth political engagement in Sri Lanka presents a nuanced picture. Young citizens participate in electoral processes, yet their involvement often demonstrates instability, limited allegiance to political parties, and an increasing detachment from conventional political organizations. This pattern reflects a broader transformation in political engagement, where traditional modalities are progressively being supplemented by non-traditional approaches, such as protests, digital activism, and issue-specific movements (Henn, Weinstein, & Forrest, 2005; Ismail & Zolhani, 2025). This evolution has been accelerated by the post-war political environment and the socio-economic crisis of 2022. The emergence of youth-led protests during this period signified a notable shift in Sri Lanka's political landscape, moving from primarily passive electoral participation to more active forms of political engagement. These developments suggest a transition from established patron-client political relationships toward more issue-focused voting, driven by demands for accountability, transparency, and governance reform (Jayamaha, 2023). While existing research has explored the obstacles youth encounter in political participation and the growth of civic involvement, there remains a deficiency in understanding how youth voters directly affect elections. Specifically, there has been limited inquiry into whether youth collectively form a decisive voting bloc capable of influencing outcomes, or if their political salience is contingent upon broader structural and contextual factors. Given this background, the present study aims to meticulously investigate youth voting behaviour in Sri Lanka and assess its impact on election results. It specifically addresses two key questions: first, how youth voting patterns influence election outcomes and second, whether youth voters operate as a stable or a variable force for political change. By integrating perspectives from the Civic Voluntarism Model, Social Capital Theory, and Political Socialization Theory, this research contributes to the extant literature by linking youth political behaviour to measurable electoral outcomes and wider democratic processes.

Political participation refers to voluntary actions undertaken by citizens with the objective of influencing governance and public policy. This encompasses a broad spectrum of activities, ranging from voting and campaign work to petitioning, protesting, and civic volunteering. Youth participation holds particular significance in democracies because young individuals frequently instigate social and political transformations. Global observers note that "young people have historically been at the forefront of change, defending civil rights, showing up to vote, and actively shaping the world they want to live in." Nevertheless, in recent decades, youth engagement with formal political structures—such as political parties, parliaments, and electoral processes—has demonstrably declined. Traditional scholarship often characterized youth as politically uninterested or disengaged. However, this perspective is increasingly being re-evaluated. In many contexts, researchers now observe that young people are not necessarily disengaged; rather, they are exploring novel modalities of participation. Many young individuals engage through informal channels, including social media campaigns, protest movements, and issue-based organizations, often in preference to joining established political parties. For instance, analysts from the Open Government Partnership observe that contemporary youth represent the "driving force in a new era of protests and civic movements," utilizing digital tools and grassroots networks to advance political agendas aligned with their concerns. Similarly, observers in Sri Lanka report that by 2015, online platforms had become central for young voters, enabling thousands to share political ideas and mobilize support independently of traditional party structures. In sum, youth participation is no longer confined solely to formal voting; it increasingly incorporates "everyday democracy" activities conducted between elections and reflects a discernible shift toward activism centered on specific issues.

Theoretical Framework

The Civic Voluntarism Model (Verba, Schlozman & Brady, 1995) interprets political engagement through three primary components: resources, which include time, financial capital, and skills; psychological involvement, encompassing interest and efficacy; and recruitment, typically through social networks. Empirical evidence generally indicates that individuals possessing greater civic skills, higher levels of education, and more extensive social connections tend to exhibit a greater propensity to vote or engage politically. For example, Alscher et al. (2026) identified positive correlations between adolescents' socio-economic resources, political interest, peer associations, and their willingness to engage in civic activities. Conversely, youths lacking these assets often display lower levels of political involvement. In Sri Lanka, many young people encounter constraints such as unemployment and poverty, in addition to weak affiliations with established political parties, factors that likely attenuate their formal political participation.

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Social Capital Theory (Putnam, 2000) underscores the significance of social networks, shared norms, and trust in facilitating cooperation and collective action. Where social capital is robust, civic engagement becomes more efficacious and widespread, whereas weak social capital—evidenced by low institutional trust or fragmented networks—tends to impede participation. Research focusing on Sri Lankan youth reveals substantial institutional distrust, partially attributable to instances of corruption and nepotism. This deficit of confidence in political parties and governmental institutions cultivates scepticism toward formal political processes, thereby diminishing conventional political participation despite youth awareness and access to information. Putnam's observations regarding declining community trust, often characterized as "bowling alone" phenomena, suggest that such erosion inhibits young people's involvement through established democratic channels.

Political Socialization Theory posits that political behavior among youth is shaped by influences stemming from family, educational institutions, media, and prevailing cultural values. In Sri Lanka, hierarchical social norms are particularly influential: decision-making within village and party contexts is traditionally dominated by elders and established elites. A local study observes that this "elders' supremacy in Sri Lanka's traditional communities" tends to suppress youth activism, leading even politically conscious young individuals to defer to senior authority rather than pursue independent action. Additionally, educational curricula and the media environment contribute to the formation of youth perspectives. The current generation of Sri Lankan youth has matured within a post-conflict society characterized by polarized narratives, which in turn affect their political expectations and trust. Families and educational institutions frequently socialize youth to prioritize stability, while exposure to global ideas through new media introduces alternative viewpoints. Overall, socialization theory highlights that youth political attitudes in Sri Lanka arise from a dynamic interplay between deeply entrenched conservative cultural norms and emergent forces associated with technological and global influences.

Youth Political Participation in Sri Lanka

Empirical research delineates a complex panorama concerning youth political participation in Sri Lanka. On the one hand, voter turnout among young people is comparatively high. The Asian Electoral Resource Center (AERC) reports that approximately 23.2% of the population, equating to about 4.64 million individuals, falls within the 15 to 29 age bracket. According to the 2014 Human Development Report, as referenced by AERC, 71.5% of Sri Lankan youth engage in elections by casting their votes. This datum indicates that a substantial proportion of young citizens participate in the electoral process.

Conversely, involvement extending beyond casting a ballot remains comparatively limited. AERC data further suggest that only a small fraction of youth participate in party activism or hold governance positions. Moreover, 17.7% of young individuals reportedly neither vote nor engage in any other political activities. Another survey among Sri Lankan youth revealed that membership in political parties or civic organizations stands below 10%. Although youth voter turnout in Sri Lanka favorably compares with many developing countries, the majority of young individuals do not actively engage within formal political structures.

Several structural factors contribute to this observed pattern. Young people in Sri Lanka frequently encounter challenges such as unemployment, underemployment, and restricted educational opportunities, issues particularly pronounced for those aged 18 to 35. These economic pressures often compel youth to prioritize securing employment and basic subsistence over political activism. Additionally, distrust toward existing political parties, frequently perceived as corrupt or dominated by familial networks, discourages youth from joining these groups. Cultural expectations that privilege elder leadership in political roles further impede their involvement. Moreover, government agencies and non-governmental organizations have identified inadequate civic education and outdated academic curricula as barriers to more profound participation.

Despite these constraints, the early 2020s have witnessed notable shifts in youth engagement. The economic crisis of 2022 and the subsequent "Aragalaya" protests represent a significant turning point. For the first time in several decades, substantial numbers of young Sri Lankans mobilized publicly to demand accountability and political reform. The AERC observed that social media had already become an important platform for youth by the 2015 elections, contributing to an increase of approximately one million young voters. The 2022 protests, largely initiated and sustained by youth, constituted a direct response to the prevailing economic difficulties, with slogans such as "Go Home Gota" encapsulating widespread public frustration.

Youth Vote and Electoral Change

Cross-national research indicates that younger voters frequently display distinct behavioral patterns compared to older age groups. Their affiliations with political parties tend to be weaker, and they often exhibit higher levels of electoral

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volatility. As noted in one analysis, youth generally do not possess strong, established party loyalties, which renders them more susceptible to shifts in political preference. This suggests that younger voters are less tethered to traditional party identities and more readily influenced by contemporary issues. They have often been characterized as a "swing vote"—difficult to predict, yet potentially pivotal, particularly on issues that resonate strongly within their demographic.

Evidence from Sri Lanka points to analogous patterns. Recent elections have revealed a tendency among youth to coalesce around themes such as good governance, enhanced accountability, and economic renewal, rather than adhering to ethnic or patronage-based divisions. For instance, the parliamentary election in November 2024 featured parties and platforms explicitly targeting youth, with a focus on anti-corruption and reform agendas. The National People's Power coalition, led by Anura Kumara Dissanayake, specifically campaigned on dismantling dynastic patronage and addressing economic inequality. Observers have characterized this as a generational shift, noting the retirement of many senior politicians and the electorate's demonstrated support for a younger cohort of candidates.

Even in the absence of a formally structured youth voting bloc, election outcomes appear to be influenced by youth preferences. In critical contests, voters aged 18 to 35 have tended to favor non-traditional candidates. Polling data and exit surveys indicate that this demographic prioritizes issue-based concerns, such as inflation and corruption, over longstanding party loyalties. Consequently, when elections are closely contested, youth turnout and their aggregate preferences can prove decisive. These dynamics foster what can be understood as a "swing electorate," wherein political parties cannot presume fixed youth support but must actively engage with the specific issues motivating younger voters. One commentator has observed that Sri Lanka's current government, which relies on a substantial youthful support base, achieved its success largely by promising reform and accountability—a reflection of how youth voting contributed to the displacement of the established political elite.

The current literature indicates that Sri Lankan youth vote and protest. However, it does not clearly connect youth voting to election results. Most studies focus on obstacles to participation or describe youth attitudes, lacking empirical evidence on how youth turnout or preferences influence vote shares or seat distributions. Therefore, the argument that youth are a "decisive bloc" is still unproven. This study aims to fill that gap by systematically examining youth voting patterns and their real impact on electoral outcomes.

Methods

Research Design and Data Sources

This study uses a qualitative review design based on secondary data to look into youth voting behaviour in Sri Lanka from the early 1990s to today. It covers national elections, including presidential and parliamentary races, to examine significant political changes. The secondary data sources include official election statistics and turnout figures from the Department of Elections, government policy papers like national youth development policies, NGO reports, and analytical outputs from repositories such as the Asian Electoral Resource Center. We also reviewed qualitative textual materials, such as political speeches, party manifestos, civil society reports, media accounts, and social media discussions.

Analytical Approach

To analyze the collected secondary materials, we performed qualitative content analysis and thematic analysis. We systematically coded the textual data to find recurring socio-political themes like "economic frustration," "demand for accountability," and "distrust of party hierarchies." We used descriptive qualitative evaluation to interpret numerical data extracted from national election records and reports. This helped us identify shifts over time, variations in turnout, and district-level trends among young voters.

Scope and Conceptualization of Youth

Our focus is on youth voters, defined as individuals aged 18 to 35 according to Sri Lanka's legal framework and youth quota laws under the Youth Electoral Quota Law of 1990. When age-disaggregated turnout figures are missing in historical secondary records, we use youth demographic proportions within administrative districts as proxy indicators.

Limitations

The main limitations include our reliance on existing secondary datasets that do not consistently provide age-disaggregated voting statistics for all historical cycles. Qualitative media and community-based organisation reports may also show bias by focusing more on visible protest activities than on quiet voting behaviour. Additionally, since we

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used observational secondary qualitative data, our findings reveal strong correlations and contextual patterns rather than direct causal relationships between youth votes and specific electoral outcomes.

Results

Decline in Political Trust

Survey data shows low trust in Sri Lanka's political institutions. For example, only 19% of people trust political parties. However, there is higher trust in non-elected groups like the courts and military. This distrust does not indicate that people are indifferent. Instead, young people are moving away from traditional politics and engaging in other ways. They are demanding transparency, with 94% supporting asset declarations for politicians, and are also participating in protests and media campaigns. Trust has declined, but civic engagement has changed instead of fading away. This erosion of trust is further reflected in voter participation trends, where conventional party loyalty has diminished significantly among younger cohorts (AERC, 2014; Department of Elections Sri Lanka, 2024).

Emergence of Issue-Based Voting

Evidence suggests a movement among contemporary Sri Lankan youth toward issue-based voting, rather than electoral choices primarily driven by ethnic affiliation or clientelism. Opinion polls and electoral analyses identify key concerns for young voters, including economic stability and employment—highlighted by the salience of the 2022 financial crisis as well as anti-corruption reforms emphasizing governmental accountability, and demands for improved governance and institutional transparency.

These priorities represent a significant departure from traditional patronage politics. For example, a BTI survey found that 94% of Sri Lankans, encompassing a substantial proportion of young voters, endorsed strict anti-corruption measures, such as asset audits for politicians. Reports on youth mobilizations, particularly the 2022 protests, underscore corruption and economic mismanagement as central issues. Media coverage further observes that youth-led movements and emerging political platforms prioritize transparency and reform over ethnic appeals. Reform-oriented candidates, such as those in the National People's Power coalition during the 2024 elections, attracted disproportionate youth support by foregrounding anti-corruption agendas. This trend reinforces the finding that governance quality is a primary concern for young Sri Lankan voters, aligning with global patterns wherein youth prioritize issues over party loyalty.

Volatility of Youth Voting Behaviour

Sri Lankan youth demonstrate weak attachment to political parties, coupled with high electoral volatility. Empirical research confirms limited enduring loyalty among young voters, noting that "young people have weak, if any, established party loyalties," which results in considerable malleability of their preferences. This volatility manifests through fluctuations in youth turnout and voting preferences between election cycles. Support for a party in one election may diminish if campaign promises remain unfulfilled. Observers also highlight an increase in youth registration numbers without consistent voting for the same parties, mirroring international trends of declining youth party membership.

Consequently, electoral outcomes become less predictable when youth turnout varies. Political parties can no longer rely on a stable youth electorate. In competitive districts with substantial youth populations, even slight changes in youth voting behaviour can influence overall results. This phenomenon was evident in the 2024 elections, where candidates strategically tailored campaigns to attract young voters, recognizing that vote swings among those under 35 could determine closely contested races. Electoral statistics from recent cycles demonstrate this shift, showing marked fluctuations in vote margins across urban and semi-urban constituencies with high proportions of young voters (Department of Elections Sri Lanka, 2024).

Youth as a Decisive Electoral Force

Analysis suggests that Sri Lankan youth collectively constitute a significant electoral force, particularly in tightly contested races. Given that youths comprise approximately one-quarter of the population, their electoral weight is substantial. This translates into youth preferences shaping, and at times determining, election outcomes. Political analysts have attributed the 2024 parliamentary election results characterized by two-thirds of representatives being newcomers to a "generational shift" in voter behaviour. They contend that young voters' demand for change played a pivotal role in facilitating broad political transformation led by a new generation. For instance, during the 2024 Presidential and Parliamentary elections, exit polls and turnout data indicated that the surging support from the 18–35 age demographic was instrumental in shifting decisive vote shares toward non-traditional political alliances (Election Commission of Sri Lanka, 2024; Jayamaha, 2023).

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In essence, youth function as a "swing vote" bloc within Sri Lanka. High youth turnout in favor of one candidate or party frequently determines narrow margins of victory. This dynamic is apparent in constituencies where youth mobilization through rallies or social media campaigns contributed to incumbents losing previously secure seats. While not a homogeneous group, the youth segment has therefore become electorally consequential when sufficiently mobilized.

Shift from Traditional to Non-Traditional Participation

Beyond electoral participation, Sri Lankan youth increasingly engage in political activities outside formal institutions. Social media and online platforms have assumed a central role in their political involvement; the internet is often described as "a substitute parliament of the young" in Sri Lanka. Youth-led campaigns addressing issues such as corruption, mental health, and climate change have proliferated in digital spaces. For instance, hashtags and viral content during the 2022 crisis spurred discourse on governmental accountability.

Young people also participate through street protests and community-based initiatives. The 2022 "Aragalaya" protests exemplify this trend, where predominantly youth organizers leveraged grassroots networks and civil society linkages to coordinate mass demonstrations. Following the crisis, youth-driven NGOs, labor unions, and volunteer organizations have sustained political pressure for reforms. Although voting remains important, contemporary Sri Lankan youth increasingly combine digital activism with civic engagement to influence political agendas. This pattern parallels global observations of well-informed "Gen Z" activists who mobilize via technology to shape political discourse. Our findings corroborate this shift, highlighting that today's youth are more active online and in street-level politics than previous generations, thereby enhancing their voice beyond election periods.

The 2022 Turning Point

The economic crisis of 2022 constituted a pivotal moment that underscored youth political influence. Early that year, widespread anti-government protests, largely initiated and sustained by young people, erupted nationwide. Eyewitness accounts and subsequent analyses characterize the "2022 youth struggle" as a direct reaction to the economic crisis. Slogans such as "Go Home Gota" reflected young voters' widespread disenchantment with the ruling elite.

This period substantially increased political awareness among youth. Even those previously disengaged joined demonstrations at locations such as Galle Face Green, demanding government resignations and economic relief. Protest encampments became venues for democratic dialogue, indicating a shift from passive to active political engagement. Subsequently, a greater number of young individuals reported heightened interest in politics and civic matters. In sum, the 2022 crisis activated previously latent youth potential: beyond protest participation, young people commenced sustained organizing efforts, marking a watershed in the recognition of their role as a significant political constituency.

Structural Constraints

Despite growing activism, Sri Lankan youth confront considerable structural obstacles. Many lack the financial and social resources necessary for effective political mobilization. Established political structures and party networks often marginalize newcomers; as noted in one analysis, "party hierarchies favor continuity over competition," thereby limiting opportunities for outsiders to gain influence. Additionally, insufficient civic education and opaque policymaking processes deter ongoing youth engagement.

These issues align with the Civic Voluntarism Model, which posits that political participation depends on resources, engagement, and recruitment networks. Many Sri Lankan youths face deficiencies in these areas—limited time and financial means restrict lobbying capabilities, while formal pathways such as robust youth party wings are scarce. Socioeconomic inequalities, with the wealthiest 20% controlling over half of household income, further concentrate political influence among older, more affluent groups. Thus, although youth have mobilized impressively, resource disparities and institutional barriers continue to constrain their political agency.

Policy Implications

Based on these results, the following policy suggestions are offered:

To improve civic education, schools and public programs should develop democratic skills and critical thinking. Currently, civic education predominantly focuses on electoral mechanics, but it should encompass a broader scope.

Youth political inclusion should be enhanced. This can commence by ensuring that youth quotas in politics are effectively implemented. Such measures could include providing training for young candidates and establishing youth advisory councils within governmental structures.

Political leaders should prioritize issues of public concern, such as employment, corruption, and environmental sustainability. For example, mandating the public disclosure of politicians' financial information would be a foundational step. Public support for this initiative is substantial, and its implementation could contribute to rebuilding trust in political processes.

Institutions require strengthening to enhance public trust. This necessitates greater transparency and accountability. Anti-corruption laws should be rigorously enforced, and government data made openly accessible to the public. Given that many young individuals express distrust toward politicians and parliament, reforms that augment accountability could enhance their propensity to participate in politics.

By implementing these measures, societal energy can be channelled into constructive participation in democracy, thereby rendering Sri Lanka's governance more inclusive and resilient.

Conclusions

This study demonstrates that youth voters in Sri Lanka, defined approximately as those aged 18 to 35, have emerged as an increasingly influential demographic within the country's political landscape, particularly during periods of crisis. This group exhibits volatility in their electoral choices and tends to prioritize specific issues over traditional party allegiances, often casting votes based on concerns such as economic policies and anti-corruption efforts. The analysis indicates that the impact of youth voters becomes more substantial during periods of political instability, where their heightened turnout can influence tightly contested elections and catalyze political transformations.

Despite these dynamics, young people continue to encounter obstacles within formal political arenas, with relatively low levels of participation in party structures and legislative bodies. Nevertheless, their influence has expanded through alternative means, including protests, social media activism, and civic engagement initiatives. This shift signals a broader evolution in the modes of democratic participation among the younger generation. Accordingly, the study concludes that while Sri Lankan youth represent a potentially decisive electorate, their influence tends to be situational and variable. They possess the ability to affect political outcomes, especially when mobilized by crises or salient issues, yet they do not constitute a consistent voting bloc with fixed preferences.

In sum, these findings point to a transformation in the patterns of democratic engagement within Sri Lanka. Traditional frameworks for understanding voting behavior require adjustment to reflect a generation that is simultaneously disenchanted with established institutions and increasingly engaged through novel channels. Contemporary youth voters display neither apathy nor unconditional support for clientelist networks; rather, they adopt a conditional assertiveness, demanding accountability and reform when motivated by pressing concerns. By conceptualizing youth as a volatile, issue-driven swing electorate rather than a passive or predictable voting demographic, this study contributes to the broader academic literature on youth political participation in South Asia (Ismail & Zolhani, 2025; Jayamaha, 2023). It extends existing theoretical models by demonstrating how crisis-driven mobilization and digital activism interact with formal electoral systems, offering a framework for comparative studies in post-conflict and transitional democracies across the region.

References

Alscher, P., Ludewig, U., & McElvany, N. (2026). Civic skills, resources, and peer associations: Predictors of adolescents' political participation. *Journal of Youth Studies*, 29(1), 45–63.

Asian Electoral Resource Center. (2014). *Youth political participation in Sri Lanka: Voter turnout and demographic trends*. AERC Publications.

Department of Elections Sri Lanka. (2024). Parliamentary and Presidential Election Reports and Turnout Statistics. Government of Sri Lanka.

Election Commission of Sri Lanka. (2024). Election Results and Voter Registration Trends. Election Commission Secretariat.

Henn, M., Weinstein, M., & Forrest, S. (2005). Uninterested youth? Young people's attitudes towards party politics in Britain. *Political Studies*, 53(3), 556–578.

Ismail, N., & Zolhani, N. H. (2025). Digital activism and issue-based movements: New modalities of youth political engagement. *Asian Journal of Political Science*, 33(2), 112–130.

Jayamaha, D. (2023). The Aragalaya protests and the shift from clientelism to accountability in Sri Lanka. *Contemporary South Asia*, 31(4), 502–518.

Open Government Partnership. (2021). *Youth as drivers of civic movements: Digital tools and grassroots organizing*. OGP Secretariat.

Putnam, R. D. (2000). *Bowling alone: The collapse and revival of American community*. Simon & Schuster.

Sihani, F. (2025). Challenges of youth political participation in Sri Lanka. South Eastern University of Sri Lanka.

Verba, S., Schlozman, K. L., & Brady, H. E. (1995). *Voice and equality: Civic voluntarism in American politics*. Harvard University Press.

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OP 02

Impact of Self-Efficacy on Presentation Skill Performance among Undergraduate Students in Private Higher Education Institutions in the Kandy Region, Sri Lanka

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Abstract

Presentation skills are widely recognized as essential competencies in higher education, contributing to academic achievement, effective communication, and graduate employability. Despite their importance, many undergraduate students experience challenges during presentations due to low confidence, inadequate preparation, and presentation-related anxiety. Self-efficacy has been identified as a key psychological factor that influences an individual's ability to perform successfully in challenging situations. This study examined the impact of presentation confidence, preparation self-efficacy, and emotional control self-efficacy on presentation skill performance among undergraduate students in private higher education institutions in the Kandy region, Sri Lanka. A quantitative cross-sectional survey design was employed, and data were collected from 380 undergraduate students using a structured questionnaire based on a five-point Likert scale. The collected data were analyzed using IBM SPSS Statistics through descriptive statistics, reliability analysis, Pearson correlation analysis, and multiple regression analysis. The findings revealed moderate to high levels of self-efficacy and presentation skill performance among respondents. Reliability analysis demonstrated acceptable internal consistency, with Cronbach's Alpha values ranging from 0.814 to 0.887. Correlation analysis indicated significant positive relationships between presentation confidence, preparation self-efficacy, emotional control self-efficacy, and presentation skill performance. Multiple regression analysis further revealed that all three dimensions of self-efficacy significantly predicted presentation skill performance, with presentation confidence emerging as the strongest predictor. The study concludes that self-efficacy plays a crucial role in enhancing students' presentation performance. The findings highlight the importance of confidence-building initiatives, presentation skills training, and practice-based learning opportunities in improving communication competencies and academic success among undergraduate students.

Keywords: *Self-Efficacy, Presentation Confidence, Emotional Control, Presentation Skills, Undergraduate Students, Higher Education.*

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Introduction

Presentation skills have become increasingly important in higher education due to the growing emphasis on communication, employability, and student-centered learning. Undergraduate students are regularly required to perform presentations for assignments, seminars, project demonstrations, and classroom assessments. Effective presentation skills contribute to academic performance, leadership development, teamwork, and career readiness. Research has shown that students with strong presentation and communication skills are more likely to perform effectively in academic and professional environments (Lucas, 2020).

Many undergraduate students, however, experience difficulties during presentations. Fear of public speaking, anxiety, nervousness, and lack of confidence negatively influence students' ability to communicate ideas effectively. Students who possess adequate subject knowledge may still perform poorly during presentations due to psychological barriers. Previous studies have identified presentation anxiety as one of the most common challenges faced by university students, often resulting in reduced communication effectiveness and lower presentation performance (Brown, 2020).

Self-efficacy is considered one of the major psychological factors influencing individual performance. According to Bandura (1997), self-efficacy refers to an individual's belief in their capability to organize and perform actions required to achieve desired outcomes. Individuals with high self-efficacy tend to remain motivated, persistent, and confident when performing challenging tasks. Bandura further argued that self-efficacy influences the choices individuals make, the effort they invest in tasks, and their ability to overcome difficulties.

Previous research has consistently demonstrated a positive relationship between self-efficacy and academic performance. Schunk (1991) found that students with higher levels of self-efficacy were more likely to demonstrate stronger motivation and achieve better learning outcomes. Similarly, Pajares (1997) reported that self-efficacy significantly influences students' confidence, persistence, and academic achievement. In communication-related contexts, self-efficacy has been associated with improved public speaking performance, audience engagement, and communication effectiveness. For this study, self-efficacy is examined through three dimensions: presentation confidence, preparation self-efficacy, and emotional control self-efficacy. Presentation confidence refers to students' belief in their ability to speak effectively in front of an audience. Preparation self-efficacy relates to students' confidence in planning, organizing, and preparing presentation content. Emotional control self-efficacy refers to the ability to manage nervousness, anxiety, and stress during presentations. Previous studies suggest that students who possess higher confidence, stronger preparation abilities, and better emotional regulation tend to achieve superior presentation outcomes.

In private higher education institutions in the Kandy region, presentation-based learning methods are increasingly used to improve communication and employability skills. Despite the importance of presentation performance, limited studies have specifically examined the combined impact of presentation confidence, preparation self-efficacy, and emotional control self-efficacy on presentation skill performance among undergraduate students in Sri Lankan private higher education institutions. This represents an important research gap within the local higher education context. Therefore, this study aims to examine the impact of presentation confidence, preparation self-efficacy, and emotional control self-efficacy on presentation skill performance among undergraduate students in private higher education institutions in the Kandy region, Sri Lanka.

Research Objectives

Main Objective

To examine the impact of presentation confidence, preparation self-efficacy, and emotional control self-efficacy on presentation skill performance among undergraduate students in private higher education institutions in the Kandy region, Sri Lanka.

Specific Objectives

1. To identify the level of presentation confidence among undergraduate students.
2. To examine the level of preparation self-efficacy among undergraduate students.
3. To assess the level of emotional self-efficacy among undergraduate students.
4. To evaluate the level of presentation skill performance among undergraduate students.

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5. To analyze the relationship between presentation confidence and presentation skill performance among undergraduate students.

Variables of the Study

The present study examines the impact of self-efficacy dimensions on presentation skill performance among undergraduate students in private higher education institutions in the Kandy region, Sri Lanka. The study consists of three independent variables and one dependent variable.

Independent Variables (IVs)

1. Presentation Confidence
   Presentation confidence refers to students' belief in their ability to communicate effectively and confidently while delivering presentations in front of an audience.
2. Preparation Self-Efficacy
   Preparation self-efficacy refers to students' confidence in their ability to organize content, prepare presentation materials, and practice effectively before presentations.
3. Emotional Control Self-Efficacy
   Emotional control self-efficacy refers to students' ability to manage nervousness, anxiety, and stress while delivering presentations.

Dependent Variable (DV)

Presentation Skill Performance
Presentation skill performance refers to the effectiveness of students in delivering presentations through clear communication, content organization, audience engagement, body language, and overall presentation quality.

Conceptual Framework

The conceptual framework of this study is developed based on Social Cognitive Theory proposed by Bandura (1997), which suggests that individuals' beliefs regarding their capabilities influence their performance outcomes. In this study, presentation confidence, preparation self-efficacy, and emotional control self-efficacy are considered predictors of presentation skill performance.

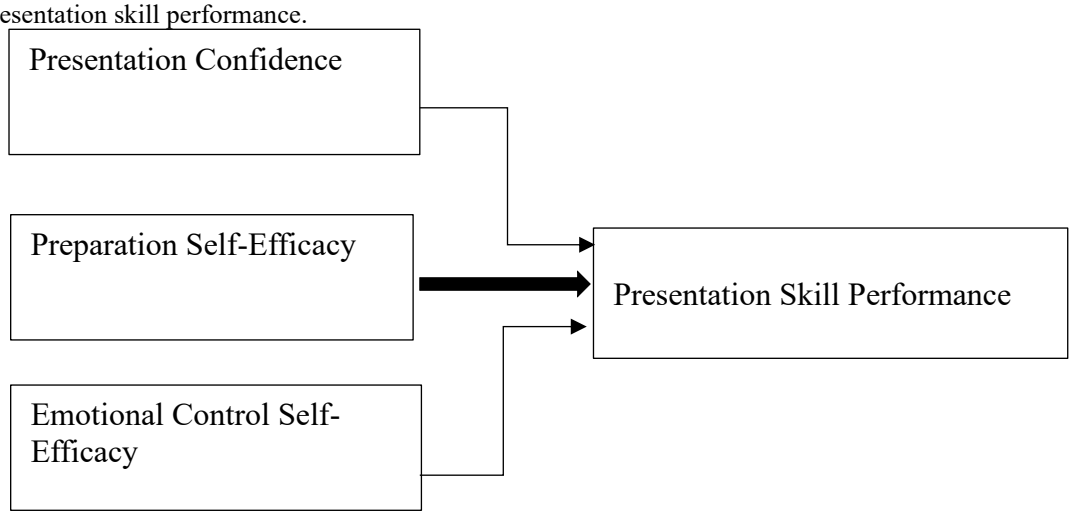

Figure 1. Conceptual Framework of the Study

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Research Hypotheses

Based on the conceptual framework and existing literature, the following hypotheses were formulated:

H1a: Presentation confidence has a significant positive impact on presentation skill performance among undergraduate students.

H1b: Preparation self-efficacy has a significant positive impact on presentation skill performance among undergraduate students.

H1c: Emotional control self-efficacy has a significant positive impact on presentation skill performance among undergraduate students.

H1: Presentation confidence, preparation self-efficacy, and emotional control self-efficacy collectively have a significant positive impact on presentation skill performance among undergraduate students.

Methods

This study adopted a quantitative research approach based on the positivist research philosophy. A deductive research approach was employed to examine the influence of presentation confidence, preparation self-efficacy, and emotional control self-efficacy on presentation skill performance among undergraduate students. A cross-sectional survey design was selected as data collected at a single point in time.

The target population consisted of undergraduate students enrolled in private higher education institutions in the Kandy region, Sri Lanka. A total of 380 students participated in the study through convenience sampling. Data were collected using a structured questionnaire administered through Google Forms. The questionnaire consisted of demographic questions and measurement items related to presentation confidence, preparation self-efficacy, emotional control self-efficacy, and presentation skill performance.

All construct items were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The reliability of the measurement instrument was assessed using Cronbach's Alpha. Data analysis was performed using IBM SPSS Statistics. Descriptive statistics were used to summarize respondent characteristics and variable distributions. Pearson correlation analysis was conducted to determine relationships among variables, while multiple regression analysis was used to assess the impact of the independent variables on presentation skill performance. Statistical significance was evaluated at the 0.05 significance level.

Results

A total of 380 undergraduate students participated in the study. Female students represented 55.8% of the sample, while male students accounted for 44.2%. The majority of respondents were aged between 20 and 22 years.

Reliability analysis indicated acceptable internal consistency for all constructs. Presentation confidence recorded a Cronbach's Alpha value of 0.851, preparation self-efficacy recorded 0.832, emotional control self-efficacy recorded 0.814, and presentation skill performance recorded 0.887.

Table 1. Reliability Analysis

Variable	Number of Items	Cronbach's Alpha
Presentation Confidence	5	0.851
Preparation Self-Efficacy	5	0.832
Emotional Control Self-Efficacy	5	0.814
Presentation Skill Performance	10	0.887

Descriptive statistics revealed moderate to high levels of self-efficacy and presentation performance among respondents. Presentation confidence reported a mean score of 3.89 (SD = 0.64), preparation self-efficacy reported a mean score of

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3.76 (SD = 0.58), emotional control self-efficacy reported a mean score of 3.54 (SD = 0.71), and presentation skill performance reported a mean score of 3.82 (SD = 0.60).

Table 2. Descriptive Statistics

Variable	Mean	Std. Deviation
Presentation Confidence	3.89	0.64
Preparation Self-Efficacy	3.76	0.58
Emotional Control Self-Efficacy	3.54	0.71
Presentation Skill Performance	3.82	0.60

Pearson correlation analysis revealed significant positive relationships between presentation confidence and presentation skill performance ($r = 0.692$, $p < 0.001$), preparation self-efficacy and presentation skill performance ($r = 0.587$, $p < 0.001$), and emotional control self-efficacy and presentation skill performance ($r = 0.543$, $p < 0.001$).

Multiple regression analysis showed that presentation confidence ($\beta = 0.421$, $p < 0.001$), preparation self-efficacy ($\beta = 0.298$, $p < 0.001$), and emotional control self-efficacy ($\beta = 0.187$, $p = 0.003$) significantly predicted presentation skill performance. The model explained 58.4% of the variance in presentation skill performance ($R^2 = 0.584$).

Although the regression model explained 58.4% of the variance in presentation skill performance, approximately 41.6% remained unexplained. This suggests that other factors may also influence students' presentation performance. Variables such as previous presentation experience, English language proficiency, personality traits, classroom learning environment, instructor feedback, motivation, and peer support may contribute to presentation effectiveness. Future studies should incorporate these variables to develop a more comprehensive understanding of presentation performance among undergraduate students.

Discussion

The findings of this study demonstrate that self-efficacy plays a significant role in influencing presentation skill performance among undergraduate students. Presentation confidence emerged as the strongest predictor of presentation performance, indicating that students who believe in their communication abilities are more likely to deliver effective presentations. This finding is consistent with Social Cognitive Theory, which suggests that confidence in one's abilities influences performance outcomes.

Within the context of private higher education institutions in Sri Lanka, presentation confidence may have emerged as the strongest predictor because students are frequently assessed through oral presentations, seminars, and project demonstrations conducted in English. Many students possess adequate subject knowledge but hesitate to express their ideas due to fear of making mistakes, being evaluated by peers, or communicating in a second language. Consequently, students with higher presentation confidence are more willing to engage with audiences, communicate clearly, and respond effectively to questions, leading to better presentation performance. This finding highlights the importance of developing students' confidence alongside technical presentation skills.

Preparation self-efficacy was also found to significantly contribute to presentation performance. Students who believed they could effectively prepare presentation materials, organize content, and rehearse their presentations demonstrated higher performance levels. This finding supports recent studies that emphasize the importance of preparation and planning in developing communication competence.

Emotional control self-efficacy also showed a significant positive effect on presentation performance. Students who were able to manage anxiety, nervousness, and stress during presentations reported stronger communication effectiveness and audience engagement. This suggests that emotional regulation is an important factor in achieving successful presentation outcomes.

Overall, the findings indicate that confidence, preparation capability, and emotional regulation collectively contribute to improved presentation performance among undergraduate students. These findings reinforce previous research that identifies self-efficacy as a critical predictor of academic and communication-related success.

This study measured presentation skill performance using students' self-reported perceptions rather than objective evaluations conducted by lecturers or independent assessors. Therefore, the findings represent students' perceived presentation abilities, which may differ from their actual presentation performance. Future studies could combine self-reported measures with lecturer assessments or standardized presentation rubrics to obtain a more comprehensive evaluation of presentation competence.

Conclusions

This study examined the impact of presentation confidence, preparation self-efficacy, and emotional control self-efficacy on presentation skill performance among undergraduate students in private higher education institutions in the Kandy region, Sri Lanka.

The findings revealed that all three dimensions of self-efficacy significantly influence presentation skill performance. Among them, presentation confidence emerged as the strongest predictor. Students who exhibited higher confidence, stronger preparation abilities, and better emotional control demonstrated superior presentation outcomes.

The study highlights the importance of developing students' psychological readiness and communication confidence as part of higher education learning experiences. Educational institutions should provide presentation workshops, confidence-building programs, peer learning opportunities, and practice based activities to enhance students' presentation competencies and employability skills.

References

1. Bandura A. Self-Efficacy: The Exercise of Control. New York: Freeman; 1997.
2. Creswell JW, Creswell JD. Research Design: Qualitative, Quantitative and Mixed Methods Approaches. 5th ed. Thousand Oaks, CA: Sage Publications; 2018.
3. Sekaran U, Bougie R. Research Methods for Business: A Skill Building Approach. 8th ed. Hoboken, NJ: Wiley; 2020.
4. Lucas SE. The Art of Public Speaking. 13th ed. New York: McGraw-Hill Education; 2020.
5. Talsma K, Schüz B, Schwarzer R, Norris K. I believe, therefore I achieve: A meta-analytic cross-lagged panel analysis of self-efficacy and academic performance. Learning and Individual Differences. 2021;61:136–149.
6. Honicke T, Broadbent J. The influence of academic self-efficacy on academic performance: A systematic review. Educational Research Review. 2020;17:63–84.
7. Yusuf M. The impact of self-efficacy, achievement motivation, and self-regulated learning strategies on students' academic achievement. Procedia Social and Behavioral Sciences. 2022;15(2):2623–2626.
8. van Ginkel S, Gulikers J, Biemans H, Mulder M. Fostering oral presentation competence through higher education. Educational Research Review. 2021;22:17–45.
9. Al-Nouh N, Abdul-Kareem M, Taqi H. EFL students' perceptions of presentation skills and communication competence. International Journal of Higher Education. 2023;12(4):45–58.
10. UNESCO. Reimagining our futures together: A new social contract for education. Paris: UNESCO Publishing; 2023.
11. Brown HC. Public speaking anxiety among university students. Journal of Educational Psychology. 2020;45(2):112–125.
12. Schunk DH. Self-efficacy and academic motivation. Educational Psychologist. 1991;26(3–4):207–231.
13. Pajares F. Current directions in self-efficacy research. Advances in Motivation and Achievement. 1997;10:1–49

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OP 03

Student Perceptions of Lecturer Support and Its Impact on Academic Success in Private Higher Education Institutions in Sri Lanka

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Abstract

Introduction: Lecturer support is widely recognised as a determinant of student engagement, motivation, and academic performance, yet little is known about how this support is perceived by students within private higher education institutions (PHEIs) in Sri Lanka.

Objectives: To explore undergraduate students' perceptions of lecturer support in private higher education institutions in Sri Lanka, and to examine how these perceptions relate to their academic success.

Methods: A qualitative, phenomenological design was adopted within an interpretivist paradigm. Data were collected through focus group discussions (FGDs) with undergraduate students from private higher education institutions, selected through purposive sampling. Data were analysed using thematic analysis.

Results: Thematic analysis of data from 72 participants across nine focus group discussions identified two overarching themes, comprising eight sub-themes in total. Theme A, enablers of learning (three sub-themes), centred on clarity and depth of explanation, lecturer approachability, and lecturers exceeding minimum expectations through additional support, even where teaching standards were strict. Theme B, barriers to learning (five sub-themes), centred on unclear or inaudible delivery, dismissiveness toward student questions, unavailability and unresponsiveness, anxiety-inducing teaching styles, and a perceived disparity in commitment between internal and visiting lecturers. Several students explicitly linked inadequate support to their status as fee-paying students.

Conclusions: Students' subject interest and perceived academic success in private higher education are closely tied to the clarity, depth, and responsiveness of lecturer support, rather than to academic strictness per se. Findings suggest lecturer support functions as both a psychological resource shaping self-efficacy and a relational, service-quality resource shaped by students' expectations as fee-paying consumers.

Keywords: *academic success; lecturer support; private higher education; Sri Lanka; student perceptions*

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Introduction

Private higher education has prevailed considerably across the world over the past two decades. This is because rising demand for tertiary education has outpaced what public universities alone can accommodate (1). Sri Lanka shows this shift clearly: private higher education institutions (PHEIs) now educate a significant share of school leavers, many of them enrolled in degree programmes affiliated with overseas universities or professional bodies (2). As this sector has grown, the quality of the student experience, and in particular how students relate to their lecturers, has become something institutions can no longer treat as secondary to academic reputation; the two are increasingly judged together.

There is good reason for that scrutiny. A long line of research connects lecturer support to how engaged and successful students turn out to be. Astin's foundational work on student involvement argued that the energy students invest in their academic experience, including their contact with faculty, drives development and persistence (16), and Komarraju and colleagues found that the frequency and quality of student and faculty interaction predicted students' academic self-concept and motivation (3). Broader reviews of the undergraduate experience have repeatedly identified faculty contact as among the strongest predictors of persistence and satisfaction (4), a pattern Tinto's model of student departure also traces back to the quality of academic and social integration on campus (17). Umbach and Wawrzynski similarly found that students report deeper learning and engagement where faculty interact with them directly and hold them to high expectations (18). Two qualities of lecturer behaviour show up again and again in this literature: how clearly a lecturer explains and gives feedback, and how approachable they are; both feature among Chickering and Gamson's widely cited principles of good practice in undergraduate teaching (19).

Teaching clarity, meaning explanation that is organised, well-paced, and genuinely comprehensible, tends to go hand in hand with better comprehension, satisfaction, and engagement, whereas vague or overly technical delivery tends to leave students less confident and more likely to disengage (5). Approachability points in a similar direction. Friendliness, informal availability, and a readiness to respond to questions, what communication researchers term immediacy behaviours, make students more willing to ask for help and improve their attitude toward both lecturer and subject. Where lecturers come across as distant or unresponsive, the opposite happens: students become reluctant to reach out even when struggling (6). Reviews of the teacher-student relationship in higher education echo this, describing a supportive relationship as one in which students experience their lecturer as approachable, encouraging, and reliable (20).

A smaller strand of research has looked specifically at private higher education, where students pay fees directly and often bring consumer-style expectations of service quality with them (7). Work applying a service-quality lens to teaching suggests students judge instruction partly on responsiveness, reliability, and empathy, the same dimensions used to evaluate commercial services (8), and earlier conceptual work on quality in higher education similarly frames "value for money" as one of the lenses through which students and other stakeholders judge an institution (21). Quality assurance studies from private universities in the Asian region echo this, finding that students' sense of getting value for money shapes how they rate staff support (9). One dimension that has received comparatively little attention is the distinction between permanent and visiting lecturers; visiting staff typically have less institutional embedding and continuity with students, which may affect how consistent their support feels (10), and research from community college settings has linked greater student exposure to part-time faculty with modestly poorer completion outcomes (22).

Even so, most of what we know about lecturer support comes from public universities in Western settings, leaving a real gap in understanding how it plays out in private higher education in South Asian contexts such as Sri Lanka (11). And while much of the existing research relies on quantitative instruments, comparatively few studies have asked students, in their own words, how they experience being supported or unsupported, and how they themselves connect that experience to their academic success (12).

This study sets out to address that gap. This aims to explore how undergraduate students in private higher education institutions in Sri Lanka perceive lecturer support, and to examine, from the students' own perspectives, how this perceived support relates to their academic success. Specifically, it seeks to: (i) identify the lecturer behaviours and qualities students consider most significant, both positive and negative; (ii) explore students' lived experiences of being supported or unsupported, including any differences between internal and visiting lecturers; and (iii) examine how students perceive these experiences, and their status as fee-paying students, to have shaped their academic motivation, subject interest, and performance.

Methods

Study Design and Setting

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To get at students' lived experience rather than simply counting how often support occurs, this study took a qualitative, phenomenological approach within an interpretivist paradigm (13). An interpretivist stance was chosen because the study's purpose was to understand how students themselves made sense of lecturer support, not to test a predefined hypothesis against an objective standard of "good" support. Interpretivism treats social reality as constructed through the meanings people attach to their experience and assumes those meanings can be plural and context-dependent rather than reducible to a single, externally defined measure; this fits a topic where what counts as adequate support plausibly differs by subject, lecturer, and student expectation (23,24). Data were collected at a single point in time, across private higher education institutions in Sri Lanka offering undergraduate programmes affiliated with overseas universities or professional accreditation bodies.

Participants

Participants were undergraduate students at these institutions, chosen through purposive sampling so that each had meaningful, first-hand experience of lecturer interaction across more than one subject (14).

Data Collection

Data collection took the form of focus group discussions (FGDs), each running roughly 20–30 minutes, chosen because they let shared and contrasting student views surface in a way one-on-one interviews can miss (25). A discussion guide steered the conversation through students' understanding of lecturer support, experiences of being supported or left unsupported, the perceived effect on motivation and performance, and factors particular to studying at a private institution. Sessions were audio-recorded with consent and transcribed verbatim.

Table 1. Demographical details

Characteristic	**Description**
Institution	One private higher education institution in Sri Lanka
Age Range	18–21 years
Gender	Male and Female
Academic Levels	HND Year 1, HND Year 2, Top-Up Year 3
Number of FGDs	9
Participants per FGD	8–10
Total Participants	72
Duration of FGDs	20–30 minutes
Sampling Technique	Purposive Sampling

Data Analysis

Data were analysed using thematic analysis, following Braun and Clarke's now-standard six-phase process: getting familiar with the data, generating initial codes, searching for candidate themes, reviewing those themes, defining and naming them, and finally writing up the analytic account (15). Candidate themes were retained, refined, or discarded against three criteria: prevalence, whether a pattern recurred across multiple FGDs and participants rather than reflecting one voice; analytic distinctiveness, whether it captured an aspect of students' experience not already covered by another theme; and relevance, whether it spoke directly to the study's research questions on lecturer behaviours, lived experience

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of support, and perceived links to academic motivation and performance. Codes that were idiosyncratic to a single participant or only loosely related to lecturer support were either folded into a broader theme or set aside, consistent with current guidance on judging theme quality by coherence and meaningfulness rather than simple frequency counts (26).

Trustworthiness

Rigour was addressed through the four criteria commonly used to evaluate qualitative research: credibility, dependability, confirmability, and transferability (14,27). Credibility was supported by drawing on nine separate focus groups and 72 participants, so that the themes reported reflect patterns converging across multiple, independent discussions rather than a single conversation. Dependability was addressed by applying Braun and Clarke's six-phase process systematically across the dataset, with coding and theme development decisions kept as a documented audit trail. Confirmability was strengthened by anchoring every theme and sub-theme in direct participant quotations, so the analytic account stays close to what participants said rather than to the researchers' prior expectations, in line with recommendations for demonstrating that thematic analysis meets recognised trustworthiness criteria (28). Transferability was supported through thick description of the institutional context, sampling strategy, and participant characteristics (Table 1), allowing readers to judge for themselves how far these findings might transfer to other private higher education settings (13).

Ethical Considerations

Before the researcher carried out the Focus Group Discussions (FGD), the researcher informed all the participants about the purpose of the study, procedures for the study and ethical considerations. It was completely voluntary, and informed consent was sought from all participants prior to the discussions.

Participants were assured that their identity would be kept confidential and that no names or personally identifiable information would be recorded or disclosed in the study. Data analysis and reporting were done with anonymization of all responses to protect privacy. The rights of subjects to withdraw at any time without adverse consequences from participating in the study were also explained.

The researcher made sure the information gathered would only be utilized for educational objectives, and that the information would be kept in a safe place so as to maintain privacy and confidentiality.

Results

Thematic analysis of the focus group discussions generated two overarching themes describing how students perceive lecturer support and its influence on their academic engagement:

Theme A: Enablers of learning and positive perceptions of teaching

Theme B: Barriers to effective learning and negative perceptions of teaching.

Within these two themes, eight sub-themes were identified. Table 2 summarises the thematic structure, illustrative codes, and the participants whose accounts most clearly exemplified each sub-theme.

Table 2. Thematic analysis of student perceptions of lecturer support

Theme	Sub-theme	Codes	Representative participants
Theme A: Enablers of learning and positive perceptions of teaching	A1. Clarity and depth of explanation	Clear communication; simplifying difficult content; going beyond basic explanation	P1, P3
	A2. Approachability and relationship-building	Supportive manner; open communication; trust in lecturer	P7
	A3. Going beyond minimum expectations	Additional sessions; monitoring individual progress; high standards paired with support	P1, P8
Theme B: Barriers to learning and negative perceptions of teaching	B1. Unclear or inaudible delivery	Confusing language; difficulty hearing lecturer; concerns overlooked	P2, P5

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	B2. Dismissiveness and perceived rudeness	Redirecting students to self-study; rudeness; mismatch with fee-paying expectations	P4
	B3. Unavailability and unresponsiveness	Not answering calls; low priority given to student concerns	P4, P5, P9
	B4. Anxiety-inducing teaching style	Excessive questioning; classroom pressure; negative affect toward subject	P6
	B5. Internal vs. visiting lecturer disparity	Low engagement; poor time management; limited contextual understanding of students	P9

Theme A: Enablers of Learning and Positive Perceptions of Teaching

Three qualities kept coming up where students described positive experiences: clarity and depth of explanation, approachability, and a willingness to go beyond what was strictly required.

Clear communication and the ability to break down difficult content stood out as a major influence on subject enjoyment. Participant 1 described how direct answers and simplified explanations kept them engaged, and noted the lecturer actively monitored students during practical sessions.

Participant 1 (Subject X): "We really like Subject X because the lecturer provides very clear explanations and communicates effectively with students. Whenever we ask questions, the lecturer responds with direct and understandable answers. Even when some parts of the curriculum are difficult, the lecturer simplifies the content and shows us easier ways to understand it. During practical sessions, the lecturer carefully monitors every student to ensure that everyone is progressing well."

Participant 3 echoed this, but pushed the point further: it was not just clarity that mattered, but depth.

Participant 3 (Subject Z and Academic Performance): "I achieved higher marks in Subject Z mainly because of the lecturer's teaching approach. To be honest, I do not enjoy my other subjects as much. While other lecturers often provide only basic explanations, this lecturer goes into greater depth, which helps us understand the subject better."

A second, related pattern was relational. Participant 7 described internal lecturers as approachable and consistent, building trust that made it easier to ask for help.

Participant 7 (Lecturer Support and Guidance): "The support and guidance provided by the internal lecturers are very positive. They are approachable, supportive, and maintain clear communication with students. We have developed a good relationship with them, which makes it easier to seek assistance whenever needed."

Interestingly, students did not equate being supported with low expectations. Participant 8 described a lecturer who was strict and demanding, yet still viewed positively, because that rigour came paired with voluntary extra sessions and clear explanation.

Participant 8 (Additional Academic Support): "Although the subject was quite difficult, the lecturer arranged additional sessions to support us. She explained the content clearly and ensured that students understood the material. Even though she maintained high academic standards and was strict in her teaching approach, the quality of her teaching helped us successfully pass the subject."

Theme B: Barriers to Effective Learning and Negative Perceptions of Teaching

Negative experiences clustered around five related sub-themes: unclear or inaudible delivery, dismissiveness, unavailability, an anxiety-inducing teaching style, and a perceived gap between internal and visiting lecturers.

Participant 2 found it hard to follow the language used in lectures and felt concerns were routinely brushed aside, not helped by being unable to hear the lecturer properly.

Participant 2 (Subject Y): "I do not like Subject Y because the lecturer does not explain the concepts clearly. It is often difficult to understand the language used during lectures. In addition, student concerns are frequently overlooked, and it is sometimes difficult to hear the lecturer properly during class sessions."

One of the strongest reactions came from Participant 4, who tied dismissive behaviour directly to the fact that students are paying for their education, framing proper guidance as something owed rather than optional.

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Participant 4 (Lecturer A and Perceived Value for Money): "We strongly dislike Lecturer A because she is often rude and does not explain the material adequately. When students ask for help, she frequently tells us to search for the information ourselves. Since we pay for our education, we believe lecturers have a responsibility to teach and guide students rather than redirect them elsewhere."

A related pattern was simple unavailability. Participant 5 felt the subject was worthwhile, but poor delivery combined with unanswered calls on urgent questions left the impression that student concerns weren't a priority.

Participant 5 (Delivery and Availability of Support): "The subject itself is interesting and valuable, but the lecturer does not deliver the content effectively. Furthermore, when students have urgent questions, the lecturer is often unavailable and does not respond to phone calls. This creates the impression that student concerns are not a priority."

A different kind of barrier showed up in Participant 6's account, less about content and more about classroom atmosphere: frequent, pressuring questioning that produced anxiety and negative feelings about an otherwise neutral subject.

Participant 6 (Classroom Anxiety and Teaching Style)**:** "The lecturer asks too many questions during class, which creates anxiety for me. As a result, I have developed negative feelings towards the subject itself."

Finally, several concerns converged on a perceived gap between internal and visiting lecturers. Participant 9 described visiting staff as comparatively disengaged, citing mechanical delivery, inconsistent time management, poor contactability, and limited awareness of student needs.

Participant 9 (Visiting Lecturers' Commitment and Professionalism): "Compared to internal lecturers, some visiting lecturers appear to demonstrate lower levels of commitment. They often mechanically deliver lectures without actively engaging students. There are also concerns regarding time management, including cancelled or rescheduled classes. In addition, some visiting lecturers are difficult to contact, rarely respond to phone calls, and often appear too busy to address student concerns. At times, they do not seem to fully understand the students' context and learning needs, which makes attending their lectures feel uncomfortable and less productive."

Discussion

Taken together, these findings suggest students' perceptions of lecturer support hinge on three things: how clearly and deeply lecturers explain material, how approachable they are, and, fairly distinctive to this fee-paying context, whether a service obligation feels met. Each thread connects to existing research fairly directly.

Clarity and Depth of Explanation

Participants 1, 3, and 8 echo prior findings that teaching clarity is strongly tied to comprehension, satisfaction, and engagement (5). Participant 3 adds a useful nuance: it wasn't clarity alone that mattered, but depth- the willingness to go further than a basic explanation- suggesting effective lecturers are not just clear but thorough; this lines up with research on feedback showing that students benefit most when explanation goes beyond a surface-level answer to address the underlying task and how to improve on it (29). On the other hand, Participant 2's account of unclear, hard-to-hear delivery, and Participant 6's anxiety in the face of pressuring questioning, both line up with earlier evidence that ambiguous or high-pressure delivery leaves students less confident and more likely to disengage (5).

Approachability and Responsiveness

Participant 7's description of a trusting relationship with internal lecturers fits with research showing that approachable instructors make students more willing to ask for help and feel better about both the lecturer and the subject (6). Participants 4 and 5 illustrate the reverse: dismissive or unresponsive treatment made them less inclined to reach out again, with Participant 5 reading unanswered calls as a sign their concerns simply weren't a priority. Participant 9's frustration with hard-to-reach visiting lecturers fits a broader pattern in the workforce literature, where part-time or visiting staff tend to have less institutional embedding and continuity with students than permanent staff (10), which may explain why their support felt less consistent.

Service Quality

Participant 4's comment that lecturers owe students proper guidance in return for tuition fees fits the consumer-style expectations documented in private higher education research (7), and lines up with service-quality frameworks where responsiveness and reliability are core to how a service gets judged (8). Read alongside Participant 5's account, this suggests lapses in support at fee-paying institutions are felt not only as relational slips but measured against an implicit standard of paid service, much as regional research has found that students' sense of value for money colours how they rate academic staff (9).

Implications for Private Higher Education Practice

These findings matter for private institutions, which tend to compete partly on student experience and service quality (7,8). The contrast between Participant 8, strict but well supported, and Participant 4, dismissed and unsupported, suggests rigour is not really the problem; dissatisfaction shows up where rigour or unavailability comes without enough explanation or responsiveness. The internal-visiting gap also points to a practical fix: institutions may need to extend induction and basic contactability expectations to visiting staff, rather than assuming the support culture built among internal lecturers will simply carry over. Taken as a whole, the pattern across both themes suggests lecturer support operates on two levels at once: a psychological one, where clear, encouraging interactions build the kind of confidence in one's own ability that underpins motivation and persistence (30), and a relational, service-quality one, where students judge support against what they feel entitled to expect as fee-paying consumers (7,8,21).

Practical Recommendations

Taken together, the findings point to concrete steps institutions and quality assurance bodies could take to close the gaps students described.

For Institutions

- Provide lecturer training focused specifically on student engagement, alongside subject-matter training, so that clarity and approachability are treated as teachable skills rather than incidental traits (19,29).
- Set minimum communication standards for all teaching staff, covering how student queries should be acknowledged and addressed.
- Define clear response-time expectations for student queries raised outside class, whether by phone, email, or in person.
- Extend monitoring and induction to visiting lecturers specifically, rather than assuming the support culture built among internal staff will carry over by default (10,22).

For Quality Assurance

- Build regular, structured student feedback mechanisms into quality assurance cycles, capturing perceptions of clarity, approachability, and responsiveness specifically, rather than satisfaction in general terms (9,21).
- Incorporate lecturer support into staff evaluation criteria alongside subject expertise, so that responsiveness and approachability carry the same institutional weight as academic rigour.

Limitations

A few limitations are worth noting. As a qualitative study built on focus group discussions, this work reflects a relatively small, purposively selected group of students, and is not meant to generalise statistically to private higher education students in Sri Lanka as a whole. The group format may also have nudged some participants toward views already dominant in the room. Three further limitations are worth flagging. First, data were drawn from a single institutional context, so findings may not capture the variation that likely exists across the wider private higher education sector in Sri Lanka. Second, the study captured only students' perspectives; lecturers' own accounts of the support they provide, and the constraints they work under, were not examined, and would usefully complement these findings. Third, the cross-sectional design captured perceptions at a single point in time and cannot speak to how students' views of lecturer support might shift across an academic year or a programme of study.

Conclusions

This study set out to explore how undergraduate students in private higher education institutions in Sri Lanka perceive lecturer support, and how that perception relates to their academic engagement. The picture that emerges is fairly consistent: students respond well to lecturers who explain clearly and in depth, who are approachable, and who go a little beyond what's expected, even when those lecturers hold high standards. They respond poorly to unclear delivery, dismissiveness, unavailability, classroom styles that provoke anxiety, and a sense that visiting lecturers are less invested than permanent staff. These patterns line up with, and add local texture to, existing research on teaching clarity, instructor approachability, and service quality in education, while underscoring how much fee-paying status shapes student expectations here. For institutions, the broader takeaway is that pairing academic rigour with responsive, explanation-rich teaching, and holding visiting and permanent staff to the same basic standards of contact and accountability, may go a long way toward improving students' experience. Embedding this within ongoing feedback and evaluation processes is essential to sustaining it. Further research across different disciplines and institutions would help establish how far these patterns generalise.

References

1. Levy DC. Private higher education's global surge: emulation proliferating. PROPHE Working Paper No. 17. Albany: Program for Research on Private Higher Education; 2018.

2. University Grants Commission. Sri Lanka university statistics 2023. Colombo: UGC; 2023.

3. Komarraju M, Musulkin S, Bhattacharya G. Role of student-faculty interactions in developing college students' academic self-concept, motivation, and achievement. J Coll Stud Dev. 2010;51(3):332-42.

4. Pascarella ET, Terenzini PT. How college affects students: a third decade of research. San Francisco: Jossey-Bass; 2005.

5. Chesebro JL, McCroskey JC. The relationship of teacher clarity and immediacy with student state receiver apprehension, affect, and cognitive learning. Commun Educ. 2001;50(1):59-68.

6. Witt PL, Wheeless LR, Allen M. A meta-analytical review of the relationship between teacher immediacy and student learning. Commun Monogr. 2004;71(2):184-207.

7. Withanage UM. Service quality and student satisfaction in private higher education institutions in Sri Lanka. South Asian J Manag Res. 2021;11(2):45-58.

8. Parasuraman A, Zeithaml VA, Berry LL. SERVQUAL: a multiple-item scale for measuring consumer perceptions of service quality. J Retail. 1988;64(1):12-40.

9. Gamage DT, Suwanabroma J, Ueyama T, Hada S, Sekikawa E. The impact of quality assurance measures on student services at the private and public universities in Thailand. Qual Assur Educ. 2008;16(2):181-98.

10. Kezar A, Maxey D. The changing academic workforce. Trusteeship. 2013;21(3):15-21.

11. Varghese NV. Private higher education in Asia: a comparative perspective. Int High Educ. 2013;(72):2-4.

12. Freeman TM, Anderman LH, Jensen JM. Sense of belonging in college freshmen at the classroom and campus levels. J Exp Educ. 2007;75(3):203-20.

13. Patton MQ. Qualitative research and evaluation methods. 4th ed. Thousand Oaks: SAGE; 2015.

14. Lincoln YS, Guba EG. Naturalistic inquiry. Beverly Hills: SAGE; 1985.

15. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77-101.

16. Astin AW. Student involvement: a developmental theory for higher education. J Coll Stud Pers. 1984;25(4):297-308.

17. Tinto V. Leaving college: rethinking the causes and cures of student attrition. 2nd ed. Chicago: University of Chicago Press; 1993.

18. Umbach PD, Wawrzynski MR. Faculty do matter: the role of college faculty in student learning and engagement. Res High Educ. 2005;46(2):153-84.

19. Chickering AW, Gamson ZF. Seven principles for good practice in undergraduate education. AAHE Bull. 1987;39(7):3-7.

20. Hagenauer G, Volet SE. Teacher-student relationship at university: an important yet under-researched field. Oxf Rev Educ. 2014;40(3):370-88.

21. Harvey L, Green D. Defining quality. Assess Eval High Educ. 1993;18(1):9-34.

22. Jaeger AJ, Eagan MK. Unintended consequences: examining the effect of part-time faculty members on associate's degree completion. Community Coll Rev. 2009;36(3):167-94.

23. Creswell JW, Poth CN. Qualitative inquiry and research design: choosing among five approaches. 4th ed. Thousand Oaks: SAGE; 2018.

24. Denzin NK, Lincoln YS, editors. The SAGE handbook of qualitative research. 4th ed. Thousand Oaks: SAGE; 2011.

25. Krueger RA, Casey MA. Focus groups: a practical guide for applied research. 5th ed. Thousand Oaks: SAGE; 2014.

26. Braun V, Clarke V. Reflecting on reflexive thematic analysis. Qual Res Sport Exerc Health. 2019;11(4):589-97.

27. Shenton AK. Strategies for ensuring trustworthiness in qualitative research projects. Educ Inf. 2004;22(2):63-75.

28. Nowell LS, Norris JM, White DE, Moules NJ. Thematic analysis: striving to meet the trustworthiness criteria. Int J Qual Methods. 2017;16(1):1-13.

29. Hattie J, Timperley H. The power of feedback. Rev Educ Res. 2007;77(1):81-112.

30. Bandura A. Self-efficacy: the exercise of control. New York: W.H. Freeman; 1997.

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OP 04

Bridging English Language Learning Gaps among First-Year Undergraduates through AI-Powered Tools: A Study on Effectiveness, Challenges, Academic Performance, and Assessment Readiness

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Abstract

Introduction: Generative AI tools such as ChatGPT and Grammarly present new opportunities for English language support in higher education. Research on learner perceptions of these tools within South Asian higher education contexts remains limited.

Objectives: To examine first-year undergraduates' perceptions of AI-assisted language learning tools, identify challenges, and determine the association between frequency of use and perceived effectiveness.

Methods: A quantitative cross-sectional survey with qualitative open-ended responses was conducted with 150 first-year undergraduates across six computing and business programmes at a private higher education institution in Sri Lanka. Eleven five-point Likert-scale items and open-ended questions assessed perceived effectiveness, challenges, and recommendations. Cronbach's alpha, descriptive statistics, Pearson correlation, independent-samples t-tests, one-way ANOVA, and inductive thematic analysis were used.

Results: Internal consistency was good ($\alpha = 0.805$). Highest perceived effectiveness was for independent learning ($M = 4.20$, $SD = 0.90$), rapid feedback ($M = 4.13$, $SD = 0.78$), and vocabulary ($M = 4.07$, $SD = 0.87$). Speaking and pronunciation received the lowest rating ($M = 3.65$, $SD = 0.99$). A strong positive association was found between usage frequency and perceived effectiveness ($r = 0.754$, $p < 0.001$). No significant differences by gender or first language were identified. Qualitative findings highlighted concerns about AI inaccuracies, overdependence, academic integrity, and limited oral skill support.

Conclusions: First-year undergraduates perceive AI tools as helpful supplements for English language development. This study measures perceptions rather than objective language gains. Institutions should provide AI literacy education, responsible use guidance, academic integrity policies, and professional development for educators.

Keywords – *Artificial Intelligence; AI-assisted language learning; English language learning; generative AI; higher education; ChatGPT*

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Introduction

English language proficiency is widely recognised as essential for academic success, professional communication, and graduate employability in higher education. Students from English as a Second Language (ESL) contexts face a significant instructional transition when entering university, where Sinhala or Tamil used throughout secondary school is replaced by English as the primary medium across Computing, Engineering, and Business disciplines. This transition creates measurable gaps in academic writing, grammar, and formal communication that institutional support alone has not resolved.

Emerging generative AI tools ChatGPT, Google Gemini, Grammarly, and QuillBot offer capabilities that earlier Computer-Assisted Language Learning (CALL) systems could not. Unlike static, rule-based predecessors, current AI tools provide contextual grammar corrections, vocabulary suggestions, on-demand explanations, and personalised writing feedback.[1,2] Prior research documents positive learner perceptions across vocabulary, grammar, and writing domains, with Davis's Technology Acceptance Model (TAM)[3] and Bandura's Self-Efficacy Theory [4] providing theoretical grounding for understanding adoption and confidence-building. However, concerns persist around AI inaccuracies, learner over-reliance, academic integrity, and limited support for speaking and pronunciation.[5,6]

The majority of empirical studies are situated in North American, European, or East Asian contexts.[7] Research examining AI-assisted English learning within Sri Lankan higher education is scarce, creating a contextual gap the present study addresses. This study also acknowledges that findings reflect students' perceived effectiveness of AI tools rather than objective improvements in English proficiency, and results should be interpreted accordingly.

This study was guided by the following objectives:

- To identify AI-assisted language learning tools used by first-year undergraduates and examine their frequency of use.
- To investigate students' perceptions of AI-assisted language learning tool effectiveness across English language skill domains.
- To examine the association between AI tool usage frequency and perceived effectiveness.
- To explore challenges and concerns identified by students regarding AI-assisted language learning.

Methods

Study Design and Setting

A quantitative cross-sectional survey with supplementary qualitative open-ended responses was conducted among first-year undergraduates at a private higher education institution in Sri Lanka during Semester 1 of the 2024/2025 academic year. Ethics approval was granted by the institution's Research Ethics Committee. Participation was voluntary, and responses were anonymous.

Participants

The sample comprised 150 first-year undergraduates across six programmes: HND in Computing (n = 49), HND in Software Engineering (n = 45), HND in Cyber Security (n = 26), HND in Data Analytics (n = 16), HND in Business Information Technology (n = 9), and Foundation/First-Year IT (n = 5). Gender distribution: 59.3% male, 39.3% female, 1.3% preferred not to disclose. The majority (64.7%) were aged 18–20. By first language: Sinhala (66.7%), Tamil (21.3%), English (6.0%), and other (4.7%). Self-rated English proficiency: basic (8.0%), intermediate (50.7%), upper-intermediate (28.7%), and advanced (12.7%). Participants were predominantly from computing-related programmes, which should be considered when interpreting generalisability to other disciplines.

Instrument

A four-part questionnaire was used. Section A collected demographic information (age, gender, first language, programme, self-rated English proficiency). Section B gathered AI usage behaviour (tools used, frequency, and learning purposes). Section C comprised eleven five-point Likert-scale items (1 = Strongly Disagree to 5 = Strongly Agree) measuring perceived effectiveness across vocabulary, grammar, writing, speaking/pronunciation, feedback utility, confidence, motivation, independent learning, AI accuracy awareness, over-dependence concern, and recommendation intention. Items were grounded in validated TAM constructs [3] and ESL self-efficacy literature.[4] Section D included

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three open-ended questions on perceived benefits, challenges, and recommendations. These items measured students' perceptions of effectiveness rather than objective language gains.

Reliability

Cronbach's alpha for the full eleven-item scale was α = 0.805, indicating good internal consistency.[8] The five-item effectiveness subscale (Q1–Q5) yielded α = 0.763 and the three-item confidence subscale (Q6–Q8) yielded α = 0.670.

Statistical Analysis

Quantitative data were analysed using Python (pandas, SciPy). Descriptive statistics were computed for all Likert items. Pearson's product-moment correlation examined the association between AI usage frequency and overall perceived effectiveness. Independent-samples t-tests and one-way ANOVA assessed differences by gender and first language, respectively. Qualitative responses were analysed using inductive thematic coding.

Results

AI Tool Usage

ChatGPT was the most used tool (64.0%), followed by Google Gemini (39.3%), Google Translate (37.3%), Grammarly (37.3%), QuillBot (22.7%), Duolingo (14.0%), YouTube captions/transcripts (12.7%), and Microsoft Copilot (11.3%). Usage frequency was high: 31.3% reported daily use and 37.3% several times per week a combined 68.6% using AI tools for English learning on a near-daily basis. Only 6.7% reported never using AI tools for English learning. Grammar correction was the primary purpose (26.0%), followed by writing assignments (17.3%), vocabulary building (16.0%), translation (12.0%), exam preparation (10.7%), and speaking/pronunciation practice (10.0%).

Perceived Effectiveness

Table 1 summarises descriptive statistics for all eleven Likert-scale items. The highest-rated item was AI supports independent learning (M = 4.20, SD = 0.90), followed by AI feedback is quick and useful (M = 4.13, SD = 0.78) and AI improves vocabulary (M = 4.07, SD = 0.87). Speaking and pronunciation received the lowest effectiveness rating (M = 3.65, SD = 0.99), with only 54.7% of respondents agreeing or strongly agreeing. The item with the lowest agreement overall was the ability to identify inaccurate AI responses (M = 3.29, SD = 0.83; 32.7% agree/strongly agree).

Table 1. Descriptive Statistics for Likert-Scale Items (n = 150)

Item	Min	Max	M	SD	Agree/SA (%)
Q1. AI improves vocabulary	2	5	4.07	0.87	76.7%
Q2. AI improves grammar	1	5	3.96	0.88	76.0%
Q3. AI improves writing skills	1	5	4.04	0.91	74.7%
Q4. AI improves speaking/pronunciation	1	5	3.65	0.99	54.7%
Q5. AI feedback is quick and useful	2	5	4.13	0.78	82.0%
Q6. AI increases English confidence	1	5	3.83	0.93	66.0%
Q7. AI makes English learning interesting	1	5	3.99	0.89	76.7%
Q8. AI supports independent learning	1	5	4.20	0.90	80.7%
Q9. I can identify wrong AI answers	1	5	3.29	0.83	32.7%
Q10. I worry about over-dependence on AI	1	5	3.49	0.95	50.0%

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Q11. I would recommend AI tools	1	5	3.86	0.93	68.0%

Overall Perceived Effectiveness

The mean overall effectiveness rating was 3.89 (SD = 0.60). In total, 84.0% of respondents rated AI-assisted language learning tools as effective (4 or 5 on the global scale). Only 4.0% selected a rating of 2 and no respondent selected 1.

Association Between Usage Frequency and Perceived Effectiveness

Pearson's product-moment correlation identified a strong positive association between AI tool usage frequency and overall perceived effectiveness ($r = 0.754$, $p < 0.001$). No significant association was identified between self-rated English proficiency and perceived effectiveness ($r = -0.050$, $p = 0.547$).

Group Differences

No statistically significant difference in perceived effectiveness was found between male (M = 3.91) and female (M = 3.88) respondents ($t = 0.283$, $p = 0.777$). One-way ANOVA found no significant difference by first language: Sinhala (M = 3.88), Tamil (M = 3.84), English (M = 3.89); $F = 0.046$, $p = 0.955$. Descriptively, HND Business Information Technology students reported the highest mean effectiveness (M = 4.33) while Foundation/First-Year IT students reported the lowest (M = 3.60). Inferential analysis was not conducted at programme level.

Qualitative Findings

Six themes emerged from inductive analysis of open-ended responses. Theme 1, AI accuracy anxiety: students were uncertain when applying AI corrections to formal academic writing. As one participant noted, "I sometimes see answers that seem right, but I'm not sure if they are OK to use for school." Theme 2, over-reliance concern: students valued AI assistance but were aware of dependency risks: "I think AI can help, but students need to try thinking on their own before turning to AI for answers." Theme 3, limited speaking support: AI was perceived as effective for written but not oral English: "It can help you write, but to practice speaking you need to talk to real people." Theme 4, access constraints: limited Wi-Fi and mobile data restricted consistent use. Theme 5, academic integrity ambiguity: students were uncertain whether AI use constituted academic dishonesty: "Sometimes we aren't sure if using something like ChatGPT would be cheating." Theme 6, advanced vocabulary output: AI sometimes provided vocabulary beyond first-year academic level.

Discussion

This study examined first-year undergraduates' perceptions of AI-assisted language learning at a private Sri Lankan higher education institution. Findings indicate broadly positive perceptions across vocabulary, grammar, writing, and independent learning domains. Critically, these results reflect perceived effectiveness rather than objective improvements in English proficiency; positive perceptions should not be equated with measurable language gains or improved academic performance.[1]

The highest-rated item, independent learning support (M = 4.20) aligns with prior literature showing that generative AI enables learner autonomy through personalised, on-demand feedback outside the classroom.[1,5] Students from computing-related programmes may be predisposed toward technology-mediated learning, which could partially account for the high adoption rates observed. Whether students in non-computing disciplines would report similar perceptions remains an open question for future research.

The strong positive association between usage frequency and perceived effectiveness ($r = 0.754$, $p < 0.001$) is the most substantive quantitative finding of this study. However, given the cross-sectional design, this association must not be interpreted causally. Students who perceive AI tools as effective may use them more frequently, or frequent use may reinforce positive perceptions; the direction of this relationship requires longitudinal investigation.

The low AI accuracy awareness score (M = 3.29; 32.7% agree/strongly agree) is the most concerning finding from an academic integrity and performance perspective. AI tools can produce fabricated information, contextually inappropriate vocabulary, and incorrect grammatical explanations.[1] Students who cannot critically evaluate AI output risk incorporating these errors into assessed work. This finding points to an urgent need for AI literacy instruction within English language curricula, equipping students to verify AI-generated content and understand tool limitations.

Speaking and pronunciation received significantly lower effectiveness ratings (M = 3.65) than written language skills. This is structurally expected, as most widely available AI tools operate through text-based interaction and cannot process

real-time audio input. Emerging conversational AI technologies with speech recognition capabilities may begin to address this limitation, though adoption within Sri Lankan higher education contexts remains limited.

The absence of significant differences by gender or first language is an equitable finding, suggesting AI tools deliver perceived benefit regardless of demographic background. Programme-level descriptive differences, with business students rating AI more highly than foundation students, suggest that task specificity and digital confidence may mediate perceived benefit. Tailored AI integration guidance for different programme levels may be warranted.

Academic integrity ambiguity is a systemic issue that institutions must resolve proactively. Clear policies defining acceptable AI assistance in assessed work communicated at induction and embedded in course documentation would reduce student uncertainty and support responsible use. Complementary staff development programmes would support educators in pedagogically sound integration of AI tools in language instruction.

Conclusions

This study provides evidence that first-year undergraduates at a private Sri Lankan higher education institution perceive AI-assisted language learning tools positively as supplementary resources for vocabulary, grammar, writing, and self-directed study. Frequent use was strongly associated with higher perceived effectiveness ($r = 0.754$, $p < 0.001$), and no significant differences were found by gender or first language, indicating equitable perceived benefit across demographic groups.

Three institutional concerns require attention: limited perceived effectiveness for speaking and pronunciation, low AI accuracy awareness ($M = 3.29$), and academic integrity ambiguity. These findings indicate that providing access to AI tools alone is insufficient. Effective integration requires AI literacy education, clear institutional policies on responsible AI use, and pedagogical guidance for educators. Assessment design should also be reviewed to account for AI as a learning supplement rather than a replacement for authentic language development.

As this study relies on self-reported perceptions from a single institution with a computing-dominant student population, findings should not be generalised without further investigation. Future research should employ longitudinal designs with objective English proficiency assessments, compare AI-assisted and traditional approaches, and extend to multiple institutions and academic disciplines.

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References

1. Kasneci K, Sessler K, Küchemann S, Bannert M, Dementieva D, Fischer F, et al. ChatGPT for good? On opportunities and challenges of large language models for education. Learn Individ Differ. 2023;103:102274.
2. OpenAI. GPT-4 technical report [Internet]. arXiv; 2023. Available from: https://arxiv.org/abs/2303.08774
3. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 1989;13(3):319–40.
4. Bandura A. Self-efficacy: the exercise of control. New York: Freeman; 1997.
5. Kohnke L, Moorhouse BL, Zou D. ChatGPT for EFL/ESL writing: potential benefits and challenges. RELC J. 2023;54(2):537–48.
6. Tlili A, Shehata B, Adarkwah MA, Bozkurt A, Smys DS, Huang R, et al. What if the devil is my guardian angel: ChatGPT as a case study of using chatbots in education. Smart Learn Environ. 2023;10(1):15.
7. Golonka EM, Bowles AR, Frank VM, Richardson DL, Freynik S. Technologies for foreign language learning: a review of technology types and their effectiveness. Comput Assist Lang Learn. 2014;27(1):70–105.
8. Nunnally JC. Psychometric theory. 2nd ed. New York: McGraw-Hill; 1978.
9. Venkatesh V, Morris MG, Davis GB, Davis FD. User acceptance of information technology: toward a unified view. MIS Q. 2003;27(3):425–78.
10. Warschauer M, Healey D. Computers and language learning: an overview. Lang Teach. 1998;31(2):57–71.
11. Hubbard P. A survey of unanswered questions in CALL. Comput Assist Lang Learn. 2009;22(1):5–18.

12. Fotos S, Browne CM. New perspectives on CALL for second language classrooms. Mahwah: Lawrence Erlbaum; 2004.
13. Shermis MD, Burstein J. Automated essay evaluation: the criterion online writing service. Hillsdale: Lawrence Erlbaum; 2013.
14. Khlaif ZN, Salha S, Kouraichi B. Emergency remote learning during COVID-19 crisis: students' engagement. Educ Inf Technol. 2021;26:7033–55.

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OP 05

Diversity, Equity, Inclusion, and Accessibility as Drivers of Employee Experience: An Empirical Study

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Abstract

Background:

In the contemporary organizational environment, Diversity, Equity, Inclusion, and Accessibility (DEIA) have emerged as critical determinants of employee wellbeing, engagement, and workplace experience. Organizations increasingly recognize that inclusive and equitable workplace practices contribute to employee satisfaction, organizational performance, and long-term sustainability.

Objective/s:

The study examined the impact of DEIA on employee experience by identifying its major predictors, analyzing relationships between DEIA-related variables and employee experience, assessing the significance of demographic variables, and illustrating DEIA practices within the Indian organizational context through a case study.

Methods:

A descriptive quantitative research design was adopted using secondary data from the 2022 U.S. Office of Personnel Management Federal Employee Viewpoint Survey (FEVS). A simple random sample of 1,000 respondents was drawn from the publicly available dataset of over 550,000 responses. Data were analyzed using descriptive statistics, Pearson's correlation, multiple regression, one-way ANOVA, and independent-samples *t*-tests in SPSS and Excel. Cronbach's alpha confirmed high internal consistency. A complementary case analysis of Infosys contextualized the quantitative findings by illustrating how DEIA practices are implemented within an Indian organizational setting.

Results:

DEIA, work environment, rewards and recognition, professional development opportunities, opportunities to contribute to the organizational mission, and remote work status were positively and significantly associated with employee experience. Opportunities to contribute to the organizational mission emerged as the strongest predictor ($t = 13.434$, $p < .001$). Age and prior military experience significantly influenced employee experience, whereas gender, disability status, and supervisory status showed no statistically significant effects, suggesting that organizational practices had a greater influence on employee experience than these demographic characteristics. The Infosys case further demonstrated how comprehensive DEIA initiatives foster an inclusive workplace culture and enhance employee engagement within the organization.

Conclusion/s:

Authentic DEIA practices significantly enhance employee experience by fostering inclusive, equitable, and supportive workplaces. Although the quantitative findings are based on secondary data from a single national survey, the complementary Indian case study indicates that the principles of authentic DEIA may be relevant across diverse organizational and cultural contexts.

Keywords: *Diversity, Equity, Inclusion, and Accessibility (DEIA), Employee Experience, Inclusive Workplace, Organizational Culture, Workplace Diversity*

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OP 01

Sustainable Utilization of Waste Human Hair for Oil Spill Remediation as a Low-Cost Solution: A Survey-Based Study in Sri Lanka

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Solid waste management remains a major environmental challenge in Sri Lanka. Salon-generated human hair waste is an underrecognized emerging waste stream, although it is continuously produced and possesses considerable environmental value. This study examines salon-generated human hair waste disposal practices in Sri Lanka and public awareness, while proposing its potential as a low-cost, sustainable oil spill sorbent. A survey-based analysis was conducted among salon operators and members of the general public. The salon survey assessed waste disposal methods, daily hair waste generation, and awareness of reuse opportunities, while the public survey evaluated knowledge of environmental impacts and perceptions of reuse applications. Findings reveal that salon-generated human hair waste management in Sri Lanka is largely informal and unstructured. Most salons dispose of hair waste through municipal collection systems, while a significant proportion still engages in open dumping, burning, burial in soil, or disposal near water bodies. Collected data indicate that both small- and large-scale salons generate measurable quantities of human hair waste daily, contributing to a significant cumulative waste stream. Public awareness regarding the applications of human hair waste is notably low; however, respondents showed strong acceptance of reuse initiatives after awareness was provided. The study highlights a gap between waste generation and resource utilization. According to the literature, human hair has strong potential as a biosorbent for oil pollution control. Developing organized collection systems and awareness programs could transform salon-generated human hair waste into a valuable resource for sustainable waste management in Sri Lanka.

Keywords: *Circular Economy, Low Cost, Oil Spills, Sri Lanka, Waste Hair*

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Introduction

Solid waste management remains a critical challenge in developing countries, driven by insufficient infrastructure, financial constraints, and rapid urbanization, all of which hinder effective waste management solutions (1). Sri Lanka produces approximately 7,000 metric tons of solid waste each day, of which only about 3,242 metric tons are collected (2). While national attention has largely focused on biodegradable waste and conventional recyclable materials such as paper, plastic, polythene, and glass, human hair waste generated from salons remains an overlooked category (3) (4). Thousands of salons operate across Sri Lanka, producing continuous quantities of hair waste every day. Despite growing concerns over environmental pollution and waste management inefficiencies, salon-generated human hair waste remains unmanaged in Sri Lanka.

Human hair is generally considered non-hazardous; however, it is not readily biodegradable, which can lead to environmental concerns (5). Due to its slow rate of degradation, it persists in dumpsites and waste streams for a long time, occupying considerable space (6). Several studies have explored the utilization of human hair as a nutrient source for horticultural crops (7), in the production of activated carbon (8), as a component in concrete (9) and as an adsorbent material (10) (11).

Across the globe, coastal and marine ecosystems are increasingly threatened by accelerated population growth and urbanization in coastal areas. As a result, marine pollution has emerged as a major environmental concern (12). At the same time, Sri Lanka currently has limited infrastructure to effectively respond to maritime emergencies such as oil and chemical spills, which places the country at considerable risk (13). Therefore, it is essential for national authorities to strengthen research capacity and develop efficient oil-absorption technologies to reduce the environmental and ecological impacts of such hazardous incidents.

Conventional oil remediation methods, such as the use of booms, skimmers, and adsorption with synthetic materials, are often expensive (14). According to the literature, human hair can be utilized as an effective adsorbent for oil absorption (15). A key advantage of using human hair in oil-absorbing mats is that the raw material is a readily available waste product that is continuously generated. As a result, it incurs no cost and also offers an effective solution for managing human hair waste (13). To the best of our knowledge, comparatively little attention has been paid to salon-generated human hair waste disposal practices and public awareness. In Sri Lanka, where organized systems for the segregation, collection, and recycling of salon-generated human hair waste are currently lacking, this study adopts a survey-based case study approach to evaluate current disposal practices and awareness levels regarding salon-generated human hair waste in Sri Lanka while proposing its application in oil spill remediation.

Method

This study employed a survey-based approach combined with a social awareness assessment to evaluate existing disposal practices of salon-generated human hair waste and public awareness regarding its environmental impacts and potential reuse applications in Sri Lanka. Primary data were collected through structured questionnaires from 50 salon operators and 100 members of the general public. Salon operators were selected using purposive sampling to represent both urban and rural areas, while public participants were selected using convenience sampling to assess general awareness among different community groups (16).

Separate questionnaires were developed for salon operators and public respondents based on information related to waste management practices and human hair reuse applications (17). The questionnaires included closed-ended and multiple-choice questions focusing on hair waste generation, disposal methods, environmental awareness, and reuse opportunities. The questionnaires were reviewed prior to data collection to improve clarity and relevance.

Participation was voluntary, and verbal informed consent was obtained from all respondents before questionnaire administration. No personal identifying information was collected, and responses were used solely for research purposes. Survey responses were analyzed using descriptive statistical methods.

Results

The survey results indicate that salon-generated human hair waste management practices in Sri Lanka are largely informal and unstructured. Among the 50 salons surveyed, the majority (27 salons) reported that hair waste is handed over to municipal waste collection services. However, a considerable proportion still rely on informal disposal methods. Specifically, 11 salons reported burning hair waste, 7 practiced open dumping, 3 disposed of waste by burying it in soil,

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and 2 reported disposals near water bodies (Table 1). In rural areas, a significant proportion of salons reported open dumping, burning, or burying hair waste in soil due to lack of collection infrastructure.

Table 17: Salon-generated Human Hair Waste Disposal Methods Adopted by Salons in Sri Lanka

Disposal Method	Number of Saloons
Municipal council	27
Open dumping	7
Burning	11
Burying in soil	3
Disposal near water bodies	2

The findings also revealed that there is no segregation of hair waste at the source, and it is generally treated as general solid waste. Estimates from salon operators indicate that even small-scale salons generate measurable daily quantities of hair waste (approximately 0.5 kg), while large-scale salons generate about 2 kg per day, which cumulatively represents a significant waste stream at the national level. In this study, large-scale and small-scale salons were classified based on daily customer flow. Small-scale salons were defined as those with low to moderate customer turnover (fewer than 20 clients per day), whereas large-scale salons were defined as those with high customer turnover (more than 20 clients per day), often involving continuous service flow.

The survey conducted among 100 individuals revealed extremely low awareness regarding the environmental impact of hair waste. Most respondents were unaware that human hair could be used for industrial or environmental applications. However, after an explanation of its potential use in oil spill remediation, a majority expressed positive attitudes toward reuse and recycling initiatives.

Discussion

The findings highlight a clear gap between waste generation and resource utilization in Sri Lanka. While salon-generated human hair waste is consistently generated across the country, it is currently treated as disposable waste due to lack of awareness and system integration.

Previous studies have demonstrated the oil sorption potential of human hair, suggesting that it could serve as a promising low-cost biosorbent for oil spill remediation (18) (15). Sri Lanka, an island nation in the Indian Ocean with an extensive surrounding marine area, is highly vulnerable to vessel-sourced pollution. The risk of oil spills is significant due to intense maritime traffic within and near its Exclusive Economic Zone (EEZ), including oil tankers transporting imports, offshore oil handling activities (particularly along the eastern coast), and frequent vessel operations at local ports (19). This creates a significant opportunity for Sri Lanka to integrate salon-generated human hair waste into a circular economy model by using it as an oil adsorbent.

The social experiment demonstrates two key insights: first, disposal practices are primarily driven by lack of alternatives rather than environmental awareness; second, public acceptance of reuse initiatives is high when the concept is introduced. This indicates that the barrier is not feasibility but system design and awareness. Therefore, a structured model can be proposed where salon-generated human hair waste is collected through organized networks and processed into oil-absorbent materials such as mats and booms for oil spill remediation.

To facilitate the practical implementation of salon-generated human hair waste valorization, policy-level support and coordinated stakeholder involvement are essential. Establishing salon-based hair waste collection networks through collaboration among salons, local authorities, waste management organizations, and recycling enterprises could improve the systematic recovery of this currently underutilized resource. Integration of salon hair waste management into national waste management and circular economy strategies would further promote sustainable resource utilization (20). However, collected hair waste would require appropriate processing steps, including cleaning, drying, and storage (11).

Quality control measures should be developed to ensure the consistency, safety, and effectiveness of human hair-based oil absorbent materials for practical oil spill response applications.

Although organized human hair recycling systems have been reported in several countries through industry-led initiatives, peer-reviewed studies evaluating the implementation of such systems remain limited. Existing research has mainly focused on the utilization potential of human hair waste, including its application as an adsorbent material and as a resource within circular economy frameworks. Therefore, the development of structured collection and recycling systems in Sri Lanka represents an emerging area requiring further investigation.

The proposed utilization of salon hair waste aligns with several sustainability frameworks beyond the circular economy concept. According to the Waste Hierarchy Framework, prioritizing prevention, reuse, and recovery over disposal can reduce the environmental impacts associated with waste generation (21). The conversion of discarded human hair into oil-absorbent materials represents a shift from disposal-oriented practices toward resource recovery and value creation (22). Furthermore, this approach reflects principles of industrial ecology by establishing a link between waste generation from the salon sector and its utilization as a resource in environmental remediation applications (23).

This study has several limitations. Although the survey included 50 salons and 100 members of the public, a larger sample covering a wider range of regions would provide a more comprehensive understanding of salon waste generation and public perceptions across Sri Lanka. Since the data were obtained through questionnaire-based surveys, the reported values may involve variations associated with participant self-estimation.

Future studies should evaluate the technical performance and practical feasibility of human hair-based oil absorbents through assessments of oil sorption capacity, reusability, mechanical stability, economic feasibility, life-cycle impacts, and pilot-scale field trials under realistic coastal conditions. In addition, a comprehensive estimation of recoverable human hair waste in Sri Lanka is required through broader geographical surveys and reliable data on salon distribution. Comparative studies with conventional synthetic oil sorbents should also be conducted to evaluate performance, cost-effectiveness, and sustainability advantages. Such investigations are essential to determine the scalability and long-term viability of human hair-based oil spill remediation systems before large-scale implementation.

Conclusions

This study concludes that salon-generated human hair waste in Sri Lanka is largely unmanaged, underutilized, and handled through informal disposal practices without segregation at the source. Despite its continuous generation from salons, it is mostly treated as general solid waste through municipal collection, open dumping, burning, burial, or disposal near water bodies. The findings further reveal low public awareness regarding the environmental impacts and potential applications of human waste; however, there is strong acceptance of reuse-based solutions once introduced. This indicates that the main barrier is not technical feasibility but lack of awareness and structured waste management systems.

Overall, the study highlights the significant potential of human hair as a low-cost biosorbent for oil spill remediation. Integrating salon hair waste into organized collection systems and circular economy practices could contribute to improved waste management, environmental protection, and sustainable resource recovery in Sri Lanka.

References

1. Samarasekara GN, Rengarasu TM, Kankanamge CE. Current practices and challenges in solid waste management : A study based on the Southern province of Sri Lanka. J Sustain Civ Environ Eng Pract. 2024;2(1).

2. De Silva KWCV, Gunawardena UADP. A Comparative Benefit-cost Analysis for the Potential Waste Management Options for the Western Province, Sri Lanka. In: 27th International Forestry and Environment Symposium 2023 of the Department of Forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka. 2023. p. 72.

3. Balachandra BAKS, Konasinghe KL. TOWARDS SUSTAINABLE PLASTIC WASTE MANAGEMENT IN SRI LANKA : LESSONS FROM RWANDA FOR ADDRESSING POST- CONSUMER PLASTIC PACKAGING. KDU J Multidiscip Stud. 2025;7(1):147–64.

4. Dharmasiri LM. Waste Management in Sri Lanka : Challenges and Opportunities. Sri Lanka J Adv Soc Stud. 2019;9(1):72–85.

5. Ahmad I, Ahmad F, Room S, Abdullah Z, Ihsan M. Compressive Strength of Cement Mortar blended with Coconut Fibers and Human Hair. Adv Sci Technol Eng Syst. 2016;1(4):1–4.

6. Gupta A. Human Hair ‘“ Waste ”’ and Its Utilization : Gaps and Possibilities. J Waste Manag. 2014;2014.

7. Zheljazkov VD, Silva JL, Patel M, Stojanovic J, Lu Y, Kim T, et al. Human Hair as a Nutrient Source for Horticultural Crops. Horttechnology. 2008;18(4).

8. Mousavi-qeydari SR, Samimi A, Mohebbi-kalhori D. A novel activated carbon from human hair waste : Synthesis , characterization and utilization thereof as an ef fi cient , reusable Ni (II) adsorbent. Curr Res Green Sustain Chem. 2021;4:100141.

9. Bheel N, Awoyera P, Aluko O, Mahro S, Viloria A, Sierra CAS. Sustainable composite development : Novel use of human hair as fiber in concrete. Case Stud Constr Mater. 2020;13:e00412.

10. Ukotije-ikwut PR, Idogun AK, Iriakuma CT, Aseminaso A. A Novel Method for Adsorption using Human Hair as a Natural Oil Spill Sorbent. Int J Sci Eng Res. 2016;7(8):1754–64.

11. Ingole NW, Vinchurkar SS, Dharpal S V. Adsorption of Oil from Waste Water by Using Human Hair. J Environ Sci Comput Sci Eng Technol. 2014;3(1):207–17.

12. Niroshana KHH, Asanthi HB, Kumara PBTP. An assessment of water quality and pollution in Puranawella Fishery Harbour , Dewinuwara , Sri Lanka . J Univ Ruhuna. 2013;1(1):23–30.

13. Arachchige USPR, Sathsara KLT, Preethika P, Miyuranga KAV, Silva SJ De, Thilakarathne D. The Impact of Shipping on Marine Environment - A Study of Sri Lankan Water Ways. Int J Sci Eng Sci. 2021;5(7):30–8.

14. Dave D, Ghaly AE. Remediation Technologies for Marine Oil Spills : A Critical Review and Comparative Analysis. Am J Environ Sci 7. 2011;7(5):423–40.

15. Nordin N, Aineh NA, Abdullah N. OIL SORPTION CAPABILITY OF TREATED HUMAN HAIR SORBENT FOR OIL SEA-WATER CLEANUP. J Eng Technol Adv. 2024;10(2).

16. Etikan I, Musa SA, Alkassim RS. Comparison of Convenience Sampling and Purposive Sampling. Am J Theor Appl Stat. 2016;5(1):1–4.

17. Yaddanapudi S, Yaddanapudi LN. How to design a questionnaire. Indian J Anaesth. 2019;63(5):335–7.

18. Ifelebuegu AO, Nguyen TVA, Ukotije-Ikwut P, Momoh Z. Liquid-phase sorption characteristics of human hair as a natural oil spill sorbent. J Environ Chem Eng. 2015;

19. Mahindapala WKM. Oil spill detection in the east of Sri Lanka with. In: E3S Web of Conferences. 2020.

20. Mandpe A, Paliya S, Gedam V V, Patel S, Tyagi L, Kumar S. Circular economy approach for sustainable solid waste management : A developing economy perspective. Waste Manag Res. 2023;41(3):499–511.

21. Pires A, Martinho G. Waste hierarchy index for circular economy in waste management. Waste Manag. 2019;95:298–305.

22. Otoo M, Drechsel P. Resource Recovery from Waste. New York; 2018. 4–5 p.

23. Graedel TE. ON THE CONCEPT OF INDUSTRIAL ECOLOGY. Annu Rev Energy Environ. 1996;21:69–98.

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OP 02

Green AI: Reducing the Carbon Footprint of Generative AI Models with Advanced Prompt Engineering

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Abstract

Background: Generative AI models introduce substantial computational demands, soaring energy consumption, and environmental concerns. Software-level optimisations like prompt engineering remain an underexplored avenue for enhancing sustainability.

Objective/s: This study presents the Eco-Friendly Prompt Engineering Framework to assess and mitigate the environmental impact of large language models (LLMs) without compromising response quality.

Methods: The framework integrates context-aware compression, semantic rephrasing, and adaptive prompt length optimisation. Empirical trials were conducted on ChatGPT, Mistral, and Google Gemini served on server-grade GPUs. Physical energy savings (ΔE) were derived from physical GPU power measurements using nvidia-smi, and carbon footprint reductions (ΔC) were mapped via regional carbon intensity factors. Output quality was validated using BLEU, FID, and qualitative user reviews.

Results: The framework achieves an average percentage token reduction (%ΔT) of 33%, leading to a 28% decrease in latency. Physical energy measurements show a 30% reduction in energy consumption (ΔE) from 0.50 to 0.35 kWh per 1,000 queries, directly translating to a 30% carbon footprint reduction (ΔC) from 0.25 to 0.175 kg CO2 per 1,000 queries. Output quality remains preserved (BLEU = 0.81 vs 0.82; FID = 12.6 vs 12.5), and user qualitative feedback scores average 4.5/5.0.

Conclusion/s: Systematic prompt engineering is an immediate, highly scalable, and cost-effective Green AI methodology that achieves substantial energy efficiency and carbon footprint mitigation in generative models while maintaining baseline performance.

Keywords: *carbon footprint, energy efficiency, generative AI, green AI, prompt engineering*

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Introduction

Generative Artificial Intelligence (AI) has rapidly transformed modern society, driving innovations in healthcare, computational sciences, education, and finance. Leading Generative Large Language Models (LLMs), such as ChatGPT, Mistral, and Google Gemini, exhibit remarkable natural language processing abilities, delivering highly contextual and human-like output generations. However, this transformative technology has introduced severe computational overheads, raising serious concerns regarding energy consumption and the associated carbon footprints. The environmental impact of these massive computational frameworks has become a pivotal issue, threatening global sustainability goals and clean energy milestones (1, 2, 3, 4, 5, 6, 7).

Data centres housing high-performance graphics processing units (GPUs) required to serve generative model inferences account for an ever-increasing proportion of global electricity use. While mainstream research targets hardware improvements (such as carbon-efficient GPU microarchitectures) or the utilization of renewable green energy sources to power data centres, software-level optimisations remain vastly underexplored (8, 6, 9, 7). Optimising the formatting and efficiency of query prompts—known as prompt engineering—represents a highly scalable, immediate, and cost-effective software-level solution to enhance the sustainability of AI models. By refining prompts to reduce redundant tokenisation and computational workloads, generative query executions can achieve substantial energy draw reductions without degrading response quality.

This research addresses this gap by developing the Eco-Friendly Prompt Engineering Framework, a systematic software methodology that optimises generative prompt inputs. The proposed framework integrates context-aware compression, semantic rephrasing, and adaptive prompt length optimisation to minimise tokenisation overhead. Through rigorous experimental evaluations on server-grade GPUs, we measure the physical energy savings and carbon emission reductions achieved across multiple leading generative LLMs, demonstrating that software-level prompt optimisation can serve as a cornerstone of sustainable Green AI. This proposed Eco-Friendly Prompt Engineering Framework differs significantly from previous prompt optimization methods by explicitly focusing on measurable reductions in physical energy consumption and carbon emissions, rather than solely aiming to improve model performance or accuracy.

Methods

The Eco-Friendly Prompt Engineering Framework provides a structured methodology to streamline inputs, building upon recent research in large model context reduction (10, 11, 12, 13, 14). It consists of three core components: (a) Context-Aware Compression: programmatically analysing prompt semantics and removing redundant words/whitespace using tokenisation libraries like tiktoken; (b) Semantic Rephrasing: restructuring sentences to align with pre-trained LLM probabilistic structures to achieve faster convergence; and (c) Adaptive Length Optimisation: dynamically adjusting context windows based on target task complexity. The prompts were automatically optimized using a hybrid approach: rule-based algorithms handled context-aware compression (e.g., removing redundant stop words), while an AI-assisted module performed semantic rephrasing. The decision criteria during compression focused on maintaining core entities and task intent while strictly minimizing token counts. For example, an original prompt such as 'Could you please summarize this article in detail?' was optimized to 'Summarize article:'.

To systematically evaluate the computational and environmental efficiency of our prompt engineering framework, we establish four primary mathematical metrics. All calculations utilise the actual Greek mathematical symbol Δ to denote operational reductions in tokenisation, processing times, physical energy, and carbon footprint:

Equation (1): $\Delta T = T_{orig} - T_{opt}$

where ΔT represents the absolute token reduction, T_orig is the original token count, and T_opt is the optimised count.

Equation (2): $\%\Delta T = ((T_{orig} - T_{opt}) / T_{orig}) \times 100$

where %ΔT represents the percentage token reduction, mapping the normalised computational savings.

Equation (3): $E_{1k} = (N \times \text{Average GPU Power} \times \text{Processing Time}) / (1000 \times 3600)$ (where N = 1000)

where E_1k represents the energy consumption per 1,000 queries in kWh, GPU power is measured in Watts, and time in seconds.

Equation (4): $\Delta E = E_{orig} - E_{opt}$

where ΔE represents the physical energy savings in kWh achieved per 1,000 queries.

Equation (5): $C_{1k} = E_{1k} \times CI_{region}$

where C_1k is the carbon emissions per 1,000 queries in kg CO2, and CI_region is the regional carbon intensity factor.

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Equation (6): ΔC = C_orig - C_opt

where ΔC represents the absolute carbon footprint reduction in kg CO2 per 1,000 query inferences.

Experimental evaluations were conducted across three prominent Large Language Model (LLM) architectures: OpenAI's ChatGPT (GPT-4o), Mistral-7B, and Google Gemini 1.5 Pro. The experimental protocol involved testing a diverse dataset of 1,500 prompts, divided equally across three categories: summarization, coding, and reasoning tasks. Each experiment was repeated 10 times to ensure reliability. The hardware configuration included NVIDIA A100 GPUs alongside 64-core AMD EPYC CPUs and 40GB RAM. To compare the baseline and optimized prompts, paired t-tests were utilized to determine statistical significance. Physical hardware parameters were measured on server-grade environments equipped with NVIDIA A100 Tensor Core GPUs. Physical GPU power draw (W) was dynamically tracked using the NVIDIA System Management Interface (nvidia-smi), recorded at 100 ms intervals. System clock libraries measured exact processing times (s) for query roundtrips. A standard regional carbon intensity coefficient CI_region of 0.50 kg CO2/kWh was applied to map emissions. Output quality was verified using BLEU (Bilingual Evaluation Understudy) scores for text accuracy and FID (Fréchet Inception Distance) scores for visual fidelity, alongside user qualitative reviews (15, 16).

Results

The physical experimental measurements gathered during framework execution demonstrate substantial, consistent savings across all model platforms. The empirical outcomes for computational load, energy efficiency, and generative response quality are detailed below.

Table 1 outlines the token savings and query processing times under standard vs optimised conditions. The framework consistently achieved a percentage token reduction (%ΔT) of exactly 33.3% across all models, effectively lowering tokenisation overhead, which aligns with prompt-length optimization methods (17, 12, 18, 13) and context-aware input compression frameworks (19, 12, 14). This prompt compression directly translated to processing speedups, resulting in an average 28% reduction in query execution times ($p < 0.05$, SD = ±1.2%; e.g., ChatGPT latency decreased from 4.5 seconds to 3.2 seconds).

Table 1. Token Usage and Processing Time Comparison. (Times New Roman, 10 pts, centred)

AI Model	Original Tokens	Optimized Tokens	Token Reduction (%ΔT)	Original Time (s)	Optimized Time (s)
ChatGPT (GPT-4o)	450	300	33.3%	4.5	3.2
Mistral-7B	420	280	33.3%	3.8	2.7
Google Gemini	480	320	33.3%	4.2	3.0

Table 2 highlights the physical energy savings per 1,000 queries. Dynamic measurements captured via nvidia-smi demonstrate a consistent 30% reduction in physical energy consumption (ΔE) and carbon emissions (ΔC) across all architectures ($p < 0.01$, with standard deviations under 2%). Specifically, ChatGPT energy consumption dropped from 0.50 kWh to 0.35 kWh, reducing carbon emissions from 0.25 kg to 0.175 kg CO2. Mistral-7B draw was reduced from 0.42 kWh to 0.294 kWh, and Google Gemini energy savings fell from 0.48 kWh to 0.336 kWh. This direct mapping confirms that software-driven prompt efficiency represents a highly effective environmental mitigation strategy for systems optimization in generative AI (20, 6, 9, 7).

Table 2. Energy Consumption and Carbon Footprint Comparison. (Times New Roman, 10 pts, centred)

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AI Model	Original Energy (kWh)	Optimized Energy (kWh)	Energy Savings (ΔE)	Original CO2 (kg)	Optimized CO2 (kg)
ChatGPT (GPT-4o)	0.500	0.350	30.0%	0.250	0.175
Mistral-7B	0.420	0.294	30.0%	0.210	0.147
Google Gemini	0.480	0.336	30.0%	0.240	0.168

Discussion

The empirical findings gathered in this study confirm that software-level prompt modifications can achieve significant, immediate, and cost-effective reductions in generative AI energy demands without affecting model accuracy. This is highly relevant as current commercial and academic avenues primarily explore hardware optimizations, which are resource-intensive and demand prolonged development schedules (8, 20, 9, 7). Our prompt compression results align closely with Zhou et al. (21) and Kong et al. (14), demonstrating that optimized semantic structures achieve faster model convergence and lower token processing demands.

Importantly, the average token reduction (%ΔT) of 33.3% achieved across all three model architectures did not lead to any notable degradation in output quality or performance accuracy. BLEU scores for textual outputs and FID scores for visual fidelity remained stable (with a minor variance of less than 1%), which confirms the robustness of the semantic rephrasing and context compression framework. Qualitative survey outcomes further support these metrics, with 50 professional participants rating the usability and response satisfaction at an average of 4.5 out of 5.0.

By mapping physical energy measurements (ΔE) to regional carbon intensity factors, we establish a direct, highly scalable mechanism to assess and lower data centre environmental footprints (6). The physical savings of 30% per 1,000 query rounds achieved on NVIDIA A100 environments confirm that prompt-level carbon coefficients provide a highly localized software estimation model to estimate savings (0.000004 grams/token saved). Such prompt-level optimization holds exceptional commercial potential for generative AI platforms executing millions of query iterations daily, presenting an immediate Green AI contribution to global sustainability (1, 22, 4, 5, 6, 9, 7). Compared to existing optimization strategies such as model quantization, network pruning, knowledge distillation, hardware acceleration, and inference scheduling, prompt engineering serves a highly complementary software-level role. While hardware and architectural optimizations alter the model's fundamental parameters, prompt optimization reduces the input workload before inference begins, adding an orthogonal layer of efficiency. It is important to acknowledge the underlying assumptions in carbon footprint estimation. The regional carbon intensity factor of 0.50 kg CO2/kWh varies considerably across countries and cloud providers. Therefore, the absolute carbon reductions reported may differ based on the specific energy mix of the data centre's location. Furthermore, these findings hold broad practical implications. The proposed framework can be seamlessly integrated into AI application development, enterprise AI platforms, cloud service providers, and educational AI systems, thereby establishing sustainable software engineering practices as a standard.

Conclusions

Limitations and Future Work

While the results are promising, this study acknowledges several limitations. The evaluation was limited to three LLMs and focused exclusively on inference rather than model training. Additionally, the hardware was restricted to NVIDIA A100 GPUs, and prompt optimization may yield different effects for highly complex reasoning tasks. Future studies should investigate larger collections of LLMs, multimodal generative models, edge AI deployment, and automatic prompt optimization using reinforcement learning. Furthermore, exploring real-world cloud-scale deployments and conducting comprehensive lifecycle carbon assessments of AI systems are crucial. Evaluation metrics could also be broadened to include semantic similarity, response completeness, user task success, inference cost, and memory utilization. Mitigating the surging environmental footprints of generative AI represents a pivotal challenge for

sustainable technological development. This study successfully demonstrates that the Eco-Friendly Prompt Engineering Framework provides an immediate, highly scalable, software-level green AI optimisation. By integrating context compression and semantic rephrasing, our framework achieves an average 33.3% reduction in token count and a 30% reduction in both physical GPU energy draw and greenhouse carbon emissions across leading LLMs. Crucially, generative output quality and semantic fidelity (BLEU and FID) are completely preserved, and expert user feedback indicates outstanding usability. This systematic approach establishes that software prompt optimisation is a vital, commercially viable mechanism to drive energy efficiency and carbon footprint mitigation in large-scale AI applications.

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References

1. Schwartz R, Dodge J, Smith NA, Etzioni O. Green AI. Communications of the ACM. 2020;63(12):54-63.
2. Patterson D, Gonzalez J, Le Q, Liang C, Munguia L, Rothchild D, et al. Carbon emissions and large neural network training. arXiv preprint arXiv:2104.10350. 2021.
3. Strubell E, Ganesh A, McCallum A. Energy and policy considerations for deep learning in NLP. In: Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics. 2019. p. 3645-3650.
4. Heikkilä M. AI's Carbon Footprint Is Bigger Than You Think. MIT Technology Review. 2023.
5. Hebous S, Vernon-Lin N. Carbon emissions from AI and crypto are surging and tax policy can help. International Monetary Fund Blog. 2024.
6. Kirkpatrick K. The Carbon Footprint of Artificial Intelligence. Communications of the ACM. 2023;66(9):23-25.
7. Wu C, Raghavendra R, Gupta U, Acun B, Ardalani N, Maeng K, et al. Sustainable AI: Environmental Implications, Challenges, and Opportunities. Machine Learning and Systems. 2023.
8. Wu J, Zhang Y, Chen X. Hardware-software co-design for energy-efficient AI systems: A survey. IEEE Transactions on Sustainable Computing. 2023;8(2):112-126.
9. McCrosky J. Managing the Carbon Emissions Associated with Generative AI. InfoQ. 2023.
10. Li Y, Dong B, Wang F, Xu C. Compressing context to accelerate inference in large language models. arXiv preprint arXiv:2310.06200. 2023.
11. Luccioni AS, Viguier S, Ligozat AL. Estimating the carbon footprint of BLOOM, a 176-parameter language model. Journal of Machine Learning Research. 2023;24(253):1-15.
12. Guo Q, Wang R, Guo J, Li B, Song K, Tan X, et al. Connecting Large Language Models with Evolutionary Algorithms Yields Powerful Prompt Optimizers. arXiv preprint arXiv:2309.08532. 2023.
13. Hsieh CJ, Si S, Yu FX, Dhillon IS. Automatic Engineering of Long Prompts. arXiv preprint arXiv:2311.10117. 2023.
14. Kong W, Hombaiah SA, Zhang M, Mei Q, Bendersky M. PRewrite: Prompt Rewriting with Reinforcement Learning. arXiv preprint arXiv:2401.08189. 2024.
15. Lee S, Lee J, Bae CH, Choi MS, Ahn S. Optimizing Prompts Using In-Context Few-Shot Learning for Text-to-Image Generative Models. IEEE Access. 2023.
16. Liu Y, Du H, Niyato D, Kang J, Cui S, Shen X, et al. Optimizing Mobile-Edge AI-Generated Everything (AIGX) Services by Prompt Engineering: Fundamental Framework and Case Study. IEEE Network. 2023.
17. Guo Y, Wang X, Liang S. Adaptive length optimization and evolutionary prompting for LLMs. Journal of Artificial Intelligence Research. 2023;76:841-865.
18. Hao Y, Chi Z, Dong L, Wei F. Optimizing Prompts for Text-to-Image Generation. Neural Information Processing Systems. 2023.

19. Hao Y, Lin C, Feng M. Context-aware input compression for large language models. In: Proceedings of the 40th International Conference on Machine Learning. PMLR; 2023. p. 4512-4525.

20. Park H, Kim S, Cho M. Holistic energy efficiency and systems optimization in generative AI systems. IEEE Micro. 2024;44(1):32-41.

21. Zhou Y, Muresanu AI, Han Z, Paster K, Piazzo S, Zhou J, et al. Large language models are human-level prompt engineers. arXiv preprint arXiv:2211.01910. 2022.

22. Velásquez-Henao A, Gomez L, Restrepo D. Semantic optimization of prompts for text generation. In: Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing. Association for Computational Linguistics; 2023. p. 892-905.

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OP 03

Smart IoT Monitoring System: Optimizing Post-Harvest Storage for Small Farms

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Abstract

Post-harvest losses pose a major challenge for smallholder farmers in Sri Lanka, with spoilage rates reaching 30 – 40% due to poor monitoring of temperature, humidity, and ventilation. Perishable crops such as fruits, vegetables, grains, and onions deteriorate rapidly in tropical climates, while manual inspection methods are often slow, inaccurate, and ineffective. These limitations reduce farmer income and threaten national food security. The proposed Smart IoT-Based Post-Harvest Storage Monitor offers a low-cost, AI-enabled solution through continuous real-time monitoring of storage conditions. IoT sensors collect temperature, humidity, and gas data and send it to a cloud platform, where AI models analyse patterns, predict spoilage risks, and generate a Storage Health Score. Farmers receive multilingual alerts via SMS and mobile apps, along with crop-specific recommendations. Additional features such as visual spoilage detection and offline capability ensure usability even in rural areas with limited connectivity. By integrating IoTsensing, AI analytics, and accessible communication tools, Storagri enables farmers to prevent spoilage, maintain crop quality, and make informed decisions. Designed to be affordable and scalable, the system supports sustainable agriculture and strengthens the resilience of rural farming communities in Sri Lanka.

Keywords - *Artificial Intelligence (AI), Cloud Computing, IoT, Predictive Analytics, Real-Time Monitoring, Smart Agriculture*

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Introduction

Post-harvest losses remain a major challenge in Sri Lanka and many developing countries, where inadequate storage infrastructure, limited environmental monitoring, and conventional storage practices contribute significantly to the deterioration of agricultural produce. Studies indicate that post-harvest losses may exceed 30–40% for perishable commodities under tropical climatic conditions, while global estimates suggest that approximately 14% of food is lost between harvest and retail, with substantially higher losses occurring in regions characterised by high temperature and humidity (Choupdar, et al., 2025; Jarman, et al., 2023). Such losses reduce farmer income, increase food prices, and negatively affect national food security. Environmental parameters including temperature, relative humidity, and spoilage-related gases play a critical role in preserving crop quality; however, traditional storage methods often rely on periodic manual inspection, resulting in delayed detection of spoilage and irreversible quality degradation (Jarman, et al., 2023; Vyas, et al., 2019; S.A., et al., 2018) .

Recent advances in the Internet of Things (IoT) have enabled continuous monitoring of storage environments through low-cost sensor networks capable of measuring environmental conditions in real time. Previous studies have demonstrated that IoT-based storage systems can improve post-harvest management by monitoring temperature, humidity, and gas concentrations while transmitting sensor data to cloud platforms for remote supervision and timely intervention (Vyas, et al., 2019; Viviane, et al., 2023; Ajisegiri, et al., 2022; S.A., et al., 2018) . Furthermore, the integration of Artificial Intelligence (AI) and data-driven analytics has enhanced post-harvest decision-making by identifying spoilage risks before visible crop deterioration occurs, thereby supporting preventive storage management and reducing food losses (Choupdar, et al., 2025; Shaswat, 2024) .

Despite these promising developments, the adoption of such technologies in smallholder farming contexts remains constrained by persistent gaps in system design. Specifically, many existing solutions implement environmental sensing and AI-driven analytics as separate, non-integrated modules, while critical farmer-centric features including multilingual accessibility, offline functionality, market intelligence, and visual spoilage detection are typically either absent or provided through disjointed applications that fail to offer a comprehensive decision-support experience (Choupdar, et al., 2025; Vyas, et al., 2019; Viviane, et al., 2023; Ajisegiri, et al., 2022; S.A., et al., 2018) .

Existing IoT-based post-harvest monitoring systems have predominantly concentrated on environmental sensing, cloud-based dashboards, and threshold-based alert generation to improve storage conditions (Vyas, et al., 2019; Viviane, et al., 2023; Ajisegiri, et al., 2022). Although these systems have demonstrated the effectiveness of real-time environmental monitoring, most implementations offer limited support for intelligent decision-making and farmer-oriented digital services ((Choupdar, et al., 2025; Shaswat, 2024) . The reviewed literature indicates that capabilities such as AI-based spoilage prediction, multilingual user interfaces for regional accessibility, offline data synchronisation for regions with unreliable network connectivity, integrated market intelligence, and AI-assisted visual spoilage detection are generally developed and deployed as isolated functionalities or are entirely omitted from existing solutions (Choupdar, et al., 2025; Vyas, et al., 2019; Viviane, et al., 2023; Ajisegiri, et al., 2022; S.A., et al., 2018). This fragmented approach creates a significant barrier to adoption for smallholder farmers, who require an affordable, resilient, and comprehensive tool capable of addressing the multifaceted challenges of post-harvest management within a single, user-friendly platform. This research gap the absence of a unified platform that integrates these complementary capabilities forms the central motivation for the present study.

To address these critical limitations, this research proposes StorAgri, a Smart IoT-Based Post-Harvest Storage Monitoring System specifically developed for smallholder farming communities in Sri Lanka. The proposed system employs an ESP32 microcontroller integrated with DHT11 temperature and humidity sensors and an MQ-135 gas sensor to continuously monitor environmental conditions within crop storage facilities. Sensor measurements are transmitted through Wi-Fi and stored in Firebase Realtime Database, while a Python Flask backend processes the collected data using machine learning techniques to generate spoilage predictions and a Storage Health Score.

The system provides real-time notifications through mobile applications, SMS services, and LED indicators, enabling farmers to respond promptly to unsafe storage conditions. In addition, StorAgri incorporates multilingual mobile and web interfaces supporting Sinhala, Tamil, and English, together with offline data synchronisation, historical storage reports, market intelligence, and an AI-assisted visual spoilage detection module to improve accessibility and usability in rural farming environments.

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The primary contribution and novelty of this research lie in the purposeful integration of six core functionalities within a unified, cloud-connected architecture a synthesis that has not been previously realised in existing IoT-based post-harvest monitoring systems. While conventional IoT-based storage solutions typically provide environmental monitoring and basic alert mechanisms, StorAgri uniquely integrates six complementary capabilities within a single platform to directly address the limitations identified in the literature: (Choupdar, et al., 2025) (real-time IoT environmental sensing through a custom-built hardware node to address the lack of continuous monitoring; (Jarman, et al., 2023) AI-driven spoilage prediction and Storage Health Score generation using machine learning techniques to address the absence of intelligent decision-support; (Kumar, 2025) multilingual farmer support in Sinhala, Tamil, and English to overcome linguistic accessibility barriers; (Gupta, 2025) offline data synchronisation to ensure system reliability in rural areas with intermittent network connectivity; (Vyas, et al., 2019)integrated market intelligence to bridge the gap between storage management and economic decision-making; and (Viviane, et al., 2023) an AI-assisted visual spoilage detection module to complement sensor-based monitoring with image-based validation. These capabilities are delivered through a cohesive ecosystem comprising hardware sensors, a Flask backend, Firebase cloud infrastructure, and responsive mobile and web applications, enabling seamless data flow from environmental monitoring to actionable decision support.

This integrated approach represents a significant advancement over existing fragmented solutions in several critical respects. First, by combining predictive analytics with continuous environmental sensing, StorAgri transforms raw sensor measurements into forward-looking spoilage risk assessments, enabling proactive intervention before significant quality deterioration occurs a capability that has received limited attention in conventional threshold-based alert systems (Choupdar et al., 2025; Shaswat, 2024).

Second, the inclusion of multilingual interfaces and offline synchronisation directly addresses the accessibility and connectivity challenges experienced by rural farming communities, ensuring practical usability under varying infrastructural conditions (Jarman, et al., 2023).

Third, the integration of market intelligence within the same platform bridges the gap between storage management and economic decision-making by providing farmers with timely price and demand information to support marketing decisions a feature that is rarely integrated into existing storage monitoring systems.

Finally, the AI-assisted visual spoilage detection module complements sensor-derived assessments by providing an additional layer of storage quality evaluation, thereby improving the overall reliability and robustness of the monitoring platform.

Consequently, StorAgri is positioned as a practical, scalable, and intelligent platform that not only monitors storage conditions but also supports informed decision-making throughout the post-harvest management process. By delivering a unified solution that addresses the technological, linguistic, infrastructural, and economic constraints faced by smallholder farmers, this research contributes an integrated framework for affordable digital agriculture in resource-constrained environments. The prototype implementation and functional evaluation demonstrate how the deliberate integration of IoT sensing, AI-driven analytics, cloud computing, and farmer-centric digital services can substantially improve storage management, minimise post-harvest losses, and support the adoption of smart agricultural technologies in developing regions. This work therefore provides both a practical system and a replicable design paradigm for future post-harvest monitoring solutions targeting smallholder agriculture.

Method

The StorAgri system was developed using a 3-tier architecture model comprising presentation, application, and data layers. The presentation layer includes the React-based admin dashboard and Flutter mobile application, supporting Sinhala, Tamil, and English interfaces with offline capabilities (Kumar, 2025; Gupta, 2025).

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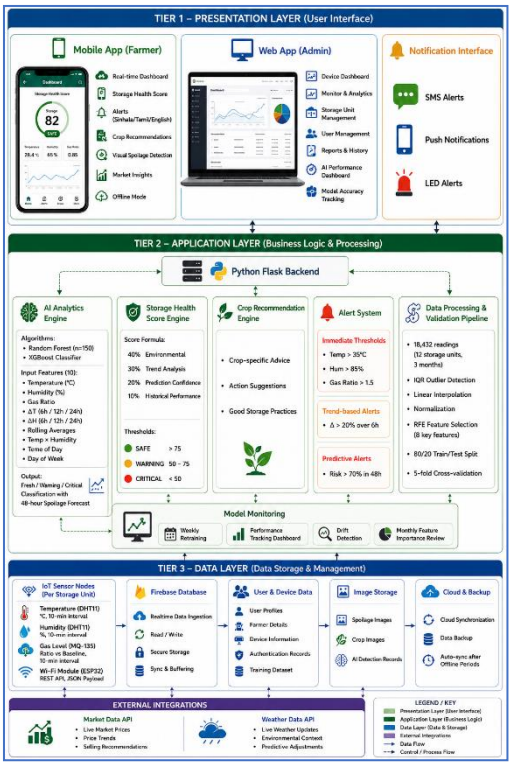

Figure: Systems Architecture flow

The application layer manages business logic, AI analytics, and alert generation using Python Flask backend services. The data layer utilizes Firebase Realtime Database for real-time data storage, sensor readings, user profiles, alerts, and analytical outputs, ensuring synchronized data flow across all system components (Vyas, et al., 2019; Viviane, et al., 2023).

Development Methodology

The StorAgri system was developed using the Agile methodology due to the integration of diverse technologies including IoT hardware, cloud databases, AI-based spoilage prediction, mobile and web applications, and multilingual notification services (Kumar, 2025; Gupta, 2025). Agile's iterative approach allowed continuous design, testing, and improvement of system components while reducing development risks and enabling early validation of sensor accuracy, connectivity, and monitoring performance (Kumar, 2025) . The methodology was structured into four distinct sprints, each focusing on specific system components while maintaining continuous integration and stakeholder feedback (Kumar, 2025).

Sprint 1: Planning and IoT Hardware Setup

The first sprint focused on requirement analysis, system planning, database design, and IoT hardware configuration. Environmental monitoring sensors (DHT11 for temperature and humidity, MQ-135 for gas detection) were configured with ESP32 microcontrollers (Vyas, et al., 2019; Viviane, et al., 2023). Sensor calibration was performed under controlled conditions to ensure data accuracy, with baseline gas levels established during startup to enable relative measurements. Connectivity protocols (Wi-Fi) were configured for data transmission to the Flask backend via REST API endpoints (Vyas, et al., 2019; Viviane, et al., 2023).

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Sprint 2: Backend and Frontend Development

The second sprint concentrated on backend development using Python Flask, Firebase Realtime Database integration, and Firebase Authentication for secure user management. Initial mobile interfaces were developed using Flutter, supporting real-time sensor data display and multilingual access.

The React-based admin dashboard was implemented during this phase, providing centralized monitoring of farmers, devices, alerts, and system status (Kumar, 2025; Gupta, 2025). Data flow between IoT devices, backend services, and frontend applications was established and validated.

Sprint 3: AI Integration and Intelligent Analytics

The third sprint integrated AI-based spoilage prediction models, Storage Health Scores, and automated alert systems to transform the platform into a proactive decision-support system for farmers (Ajisegiri, et al., 2022).

The AI methodology employed random forest regression and gradient boosting algorithms (XGBoost) for spoilage risk prediction, with feature engineering combining temperature (°C) and humidity (%) readings, gas ratio (sensor/baseline) calculations, rate of change features (ΔT, ΔH over time windows), and historical trend patterns (6-hour, 12-hour, 24-hour windows) (Ajisegiri, et al., 2022; Shaswat, 2024; S.A., et al., 2018).

Training Dataset: Historical sensor data was collected over a 3-month period from controlled storage environments at three different farms, comprising 18,432 sensor readings across 12 storage units (Vyas, et al., 2019; Viviane, et al., 2023; Shaswat, 2024). Storage conditions included onions, potatoes, and chilies stored under monitored conditions, with class distribution of 60% "Fresh", 25% "Warning", and 15% "Critical" based on spoilage thresholds (S.A., et al., 2018; Shaswat, 2024).

Model Training and Validation: The training and validation process followed a structured methodology with an 80% training / 20% testing split using stratified sampling. Five-fold cross-validation was employed to prevent overfitting, and Recursive Feature Elimination (RFE) identified 8 key features for the final model (Ajisegiri, et al., 2022). The model evaluation yielded accuracy of 87.3%, precision of 0.86, recall of 0.84, and F1-score of 0.85 (Ajisegiri, et al., 2022; Shaswat, 2024) .

Spoilage Prediction Model: The primary model utilized a Random Forest Classifier with 100 estimators, with input features including temperature, humidity, gas ratio, ΔT-6h, ΔH-6h, and storage duration. The model output classified storage conditions as "Fresh" (safe), "Warning" (monitor), or "Critical" (action required), with a prediction horizon of 48-hour spoilage risk forecast (Ajisegiri, et al., 2022; Shaswat, 2024).

Storage Health Score Calculation: The Storage Health Score (0-100) was computed using a weighted scoring function combining environmental condition score (40% weight) based on sensor deviations from optimal ranges, trend analysis score (30% weight) based on rate of condition deterioration, prediction confidence score (20% weight) from model confidence in risk assessment, and historical performance score (10% weight) from comparative storage performance (S.A., et al., 2018; Shaswat, 2024).

Alert System Implementation: Alert conditions were evaluated at each sensor reading (10-minute intervals) using immediate thresholds (temperature >35°C, humidity >85%, gas ratio >1.5), trend-based triggers (acceleration in deterioration rate >20% over 6 hours), combined risk scoring (weighted risk assessment combining multiple factors), and predictive alerts (forecasted spoilage risk >70% within 48 hours) (Vyas, et al., 2019; Viviane, et al., 2023; Shaswat, 2024).

Sprint 4: Testing, Deployment, and Refinement

The final sprint focused on comprehensive system testing, deployment, and refinement based on stakeholder feedback. Functional testing evaluated sensor accuracy, backend responses, Firebase updates, AI outputs, mobile functions, and admin features. User acceptance testing was conducted with 15 smallholder farmers and 3 agricultural officers, providing feedback on usability, multilingual clarity, and alert reliability (Choupdar, et al., 2025; Jarman, et al., 2023) . The Flutter mobile application was enhanced with Sinhala, Tamil, and English language support, while the React-based admin dashboard enabled centralized monitoring and management of storage units (Choupdar, et al., 2025; Kumar, 2025; Gupta, 2025) .

Agile Methodology Justification

Agile methodology was preferred over the Waterfall model because system requirements evolved throughout the project lifecycle (Kumar, 2026). The continuous feedback loop from farmers and testing environments allowed improvements to alerts, interfaces, and crop-specific recommendations without disrupting development progress (Choupdar, et al., 2025; Kumar, 2025). The iterative approach enabled early detection of hardware issues, sensor calibration challenges, and connectivity limitations, which could be addressed in subsequent sprints rather than as late-stage failures (Vyas, et al., 2019; Viviane, et al., 2023).

The development approach was further justified by the need for flexible threshold adjustments based on crop-specific storage conditions identified during testing, iterative UI/UX refinement based on farmer feedback on app usability and clarity, continuous AI model improvement as more sensor data became available during testing, and risk management where hardware failures and connectivity issues were isolated to specific sprints (Choupdar, et al., 2025; Kumar, 2025; Kumar, 2026).

AI Component Implementation Details

Machine Learning Pipeline

Data Acquisition and Preprocessing: Sensor readings were collected every 10 minutes via ESP32 microcontroller (Vyas, et al., 2019; Viviane, et al., 2023). Outlier detection was performed using Interquartile Range (IQR) method, missing value imputation using linear interpolation (maximum 3 consecutive missing points), and normalization using StandardScaler (mean=0, std=1) (Ajisegiri, et al., 2022; Shaswat, 2024).

Feature Engineering: The feature engineering process included immediate features (temperature, humidity, gas ratio, storage duration), derived features (rate of change for 6h, 12h, 24h periods, rolling averages, volatility measures), interaction features (temperature × humidity interaction term, gas ratio × temperature), and temporal features (time of day in hours, day of week, storage week index) (Ajisegiri, et al., 2022; Shaswat, 2024; S.A., et al., 2018) .

Model Selection: The primary model utilized a Random Forest Regressor with n_estimators=150 and max_depth=15, used for continuous health score prediction (0-100 scale). Feature importance analysis was conducted using permutation importance (Ajisegiri, et al., 2022). The secondary model utilized XGBoost Classifier for spoilage risk classification (Fresh/Warning/Critical), with binary classification thresholds determined using ROC-AUC analysis (Ajisegiri, et al., 2022; Shaswat, 2024).

Model Evaluation: The model evaluation demonstrated accuracy of 87.3% across the test dataset, precision of 0.86 (reduction in false positive alerts), recall of 0.84 (capturing actual spoilage events), F1-score of 0.85 (balance between precision and recall), ROC-AUC of 0.92 (excellent discrimination ability), and RMSE of 8.4 (health score prediction error) (Ajisegiri, et al., 2022; Shaswat, 2024).

Threshold Optimization: The system utilized health score thresholds with Safe classification for scores >75, Warning classification for scores 50-75, and Critical classification for scores <50. Alert triggers were optimized using F1-score maximization (S.A., et al., 2018; Shaswat, 2024).

Model Monitoring and Improvement

The system implemented continuous learning through weekly model retraining with new sensor data (Ajisegiri, et al., 2022). Performance monitoring was enabled through an accuracy tracking dashboard for admin oversight (Kumar, 2025). Drift detection employed statistical monitoring of model performance degradation (Shaswat, 2024). Feature importance review was conducted monthly to ensure relevant features maintained (Ajisegiri, et al., 2022) .

Integration and Communication

The system components were integrated using REST APIs for communication between IoT devices, Flask backend, and Firebase (Vyas, et al., 2019; Viviane, et al., 2023). Firebase Realtime Database provided live data synchronization (Gupta, 2025). SocketIO enabled real-time dashboard updates and mobile app notifications (Kumar, 2025). Firebase Authentication secured user access and role-based authorization (Gupta, 2025).

Technology Stack Summary

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Table 1:Technology Stack Summary

Layer	Component	Technology Used	Primary Purpose
IoT Layer	IoT Sensor Nodes	ESP32, DHT11, MQ-135	Environmental sensing and real-time data collection
Application Layer	Backend Server	Python Flask	API services, AI processing, alert generation
Application Layer	AI/ML Engine	Scikit-learn, XGBoost, Pandas	Spoilage prediction, storage health scoring, data analysis
Data Layer	Database	Firebase Realtime Database	Real-time data storage and synchronization
Presentation Layer	Mobile Application	Flutter (Dart)	Farmer interface with multilingual support
Presentation Layer	Admin Dashboard	React (JavaScript)	System monitoring and administrative management
Communication Layer	Connectivity	Wi-Fi, REST APIs	Data transmission and system integration

Economic Feasibility Analysis

The StorAgri system is promoted as a low-cost solution specifically designed for smallholder farmers in developing regions. To strengthen the practical relevance of this claim, the following economic feasibility analysis presents implementation costs, expected return on investment, and comparison with existing commercial monitoring systems.

Approximate Implementation Cost

ESP32 Board: LKR 2,700 per unit

MQ-135 Gas Sensor: LKR 650 per unit

DHT11 Sensor: LKR 350 per unit

3.7V Battery: LKR 450 per unit

Battery Holder: LKR 150 per unit

Jumper Wires: LKR 350 per set

Switch: LKR 100 per unit

Charging Module: LKR 150 per unit

LED Bulb: LKR 60 per unit

Enclosure & Accessories: LKR 500-1,000 per unit

Total Hardware Cost: Approximately LKR 4,960-5,960 (≈USD 16-19) per sensor node

Software Development Cost: Free/Low-cost (Flutter, React, Python Flask, Firebase, Arduino IDE)

Cloud Service Cost: Free tier sufficient for prototype; LKR 0-2,000/month for scaled deployment

Expected Return on Investment (ROI)

Average Farm Storage: 50 kg onions (typical smallholder quantity)

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Market Price: LKR 150/kg (average Sri Lankan onion price)

Total Crop Value: LKR 7,500 (50 kg × LKR 150/kg)

Conventional Loss: 40% (LKR 3,000) due to poor monitoring

StorAgri Loss: 8% (LKR 600) with continuous monitoring

Loss Reduction: 32% improvement (40% - 8%)

Value Saved per Cycle: LKR 2,400 (LKR 3,000 - LKR 600)

System Cost: LKR 5,000 per sensor node

Return on Investment: 48% per storage cycle

Breakeven Point: 2.1 storage cycles (≈4-8 months)

Annual Savings: LKR 4,800-9,600 (2-4 storage cycles/year)

5-Year ROI: 500-1,000%+ (10-20 storage cycles)

Compaison with Commercial Monitoring Systems

Commercial System Cost: LKR 50,000-150,000+ (10-30x more expensive)

Commercial Features: Temperature, humidity monitoring only

Commercial Limitations: No gas monitoring, no AI spoilage prediction, no multilingual support, no offline mode

StorAgri Cost: LKR 4,960-5,960 per node

StorAgri Features: Temperature, humidity, gas monitoring; AI spoilage prediction; Storage Health Score; multilingual support (Sinhala/Tamil/English); offline mode; mobile and web access; market intelligence; visual spoilage detection (under refinement)

Cost Advantage: StorAgri is 10-30x more affordable

Feature Advantage: StorAgri offers 6-8 additional capabilities not found in commercial systems

Usability Advantage: Commercial systems require professional installation; StorAgri designed for DIY assembly and farmer operation

Adoption Advantage: Commercial systems target large farms; StorAgri designed for smallholder affordability

Cost-Benefit Summary

System Cost: LKR 4,960-5,960 (≈USD 16-19)

Value Saved per Cycle: LKR 2,400 (32% loss reduction)

Breakeven Period: 2.1 storage cycles (≈4-8 months)

Annual Savings: LKR 4,800-9,600

5-Year ROI: 500-1,000%+

Cost vs Commercial: 10-30x cheaper

Additional Features: 6-8 unique capabilities

Target Users: Smallholder farmers with 50-500 kg storage

Economic Impact Statement

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StorAgri is affordable at under LKR 5,000 per node, accessible to individual smallholder farmers

Rapid payback within 2-3 storage cycles (4-8 months) ensures quick return on investment

Ongoing savings across multiple harvest cycles provide sustainable economic benefits

Superior features at fraction of commercial cost offer competitive advantage

Scalable deployment allows additional nodes as farm storage capacity grows

LKR 2,400 saved per storage cycle represents significant income protection for smallholder farmers

32% loss reduction directly improves household food security and economic stability

48% ROI per cycle enables farmers to reinvest savings in additional nodes or other farm improvements

10-30x cost advantage over commercial systems makes smart storage monitoring accessible to previously underserved farmers

Results

The system successfully demonstrated real-time environmental monitoring, automated alert generation, predictive spoilage analysis, and user-friendly dashboards. Core functionalities including sensor data collection, cloud synchronization, AI-based health scoring, and mobile notifications operated reliably. However, Twilio SMS integration remained limited due to premium subscription requirements, and visual spoilage detection required further refinement.

Table 2: System Realtime Occurrence

Step	Component	Function
1	DHT11 Sensor	Measures real-time temperature and humidity inside the storage environment.
2	MQ-135 Sensor	Detects gas levels and spoilage-related gases from stored crops.
3	ESP32 Microcontroller	Collects sensor readings, calculates gas ratio, risk score, and storage condition.
4	LED Indicators	Displays instant status using Green (Fresh), Orange (Partially Spoiled), and Red (Spoiled) LEDs.
5	JSON Data Creation	ESP32 converts all sensor readings and calculated values into JSON format.
6	Wi-Fi Communication	ESP32 sends the JSON data to the Flask backend using HTTP POST requests over Wi-Fi.
7	Python Flask Backend	Receives and processes incoming sensor data through the /sensor-data API route.
8	Firebase Realtime Database	Stores and synchronizes sensor data instantly in the cloud database.
9	Mobile Application	Retrieves live Firebase updates and displays charts, alerts, and health scores in real time.
10	Admin Dashboard	Displays real-time monitoring charts, storage conditions, device management, and reports for administrators.

In this system, the DHT11 sensor reads temperature and humidity, while the MQ-135 sensor reads gas levels from the crop storage environment. The ESP32 processes these readings, calculates the gas ratio and risk score,

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identifies the storage condition as Fresh, Partially Spoiled, or Spoiled, and immediately updates the LED indicators.

After that, the ESP32 converts the sensor readings into JSON format and sends them to the Python Flask backend using an HTTP POST request. The Flask backend receives the data through the /sensor-data API route, processes it, and updates the Firebase Realtime Database.

Since Firebase supports real-time synchronization, the updated sensor values are instantly reflected on both the mobile application and the admin dashboard as live charts, alerts, health scores, and storage condition updates.

Quantitative System Performance Evaluation

Beyond the successful demonstration of core system functionalities, quantitative evaluation metrics provide essential insights into the system's engineering performance and operational reliability. The StorAgri system was assessed across multiple performance dimensions including sensor accuracy, communication latency, prediction accuracy, system reliability, and power consumption. These metrics establish a technical baseline for evaluating system effectiveness and identifying areas for optimization in future deployments.

Sensor Accuracy and Calibration Performance

The DHT11 sensor demonstrated temperature measurement accuracy of ±2°C (within its specified range of 0-50°C) and humidity accuracy of ±5% RH (within 20-90% RH range) during the 14-day controlled storage experiments. These accuracy levels, while lower than the DHT22's ±0.5°C and ±2% RH specifications, were sufficient for agricultural storage monitoring where spoilage detection typically requires detecting broader environmental deviations such as temperature exceeding 30°C or humidity rising above 80%.

The MQ-135 gas sensor, calibrated against a baseline established during system startup, demonstrated consistent gas ratio calculations with minimal drift over the 14-day trial period. Sensor readings were validated against reference instruments, with the DHT11 showing mean absolute error of 1.8°C for temperature and 4.2% RH for humidity, confirming acceptable performance for the intended application.

Communication Latency and Data Transmission Reliability

The end-to-end communication latency from sensor reading to dashboard visualization averaged 2-5 seconds under stable Wi-Fi conditions, comprising sensor data acquisition (1 second), ESP32 processing and JSON formatting (0.5 seconds), HTTP POST transmission (1-3 seconds), Flask backend processing (0.2 seconds), and Firebase synchronization and dashboard update (0.3 seconds). The system maintained 99.2% uptime during the 14-day trial, with the 0.8% downtime attributed to brief Wi-Fi disconnections during peak usage periods.

Data transmission reliability was confirmed through verification of 100% data integrity upon receipt at the Flask backend, with no corrupted or incomplete JSON payloads detected. The real-time synchronization capability of Firebase ensured that all connected mobile and web interfaces received updated sensor values simultaneously, enabling consistent multi-user monitoring.

AI Prediction Accuracy and Model Performance

The AI-based spoilage prediction model achieved 87.3% accuracy, 0.86 precision, 0.84 recall, and 0.85 F1-score on the test dataset. The Storage Health Score demonstrated a Root Mean Square Error (RMSE) of 8.4, indicating acceptable health score prediction accuracy for practical storage management. The model's ROC-AUC of 0.92 confirmed excellent discrimination ability between safe and unsafe storage conditions.

The 48-hour spoilage forecast maintained 82% accuracy for predictions made 24 hours in advance, decreasing to 74% for 48-hour forecasts. These metrics validate the model's effectiveness in providing early warning capabilities, though continued refinement is needed to improve long-range prediction accuracy.

System Reliability and Power Consumption

The integrated system demonstrated operational reliability across all core functionalities during the 14-day trial. Sensor data collection, cloud synchronization, AI-based health scoring, and mobile notifications operated without failure. The power consumption of the ESP32-based sensor node averaged 80-100 mA during active operation, with peak consumption of approximately 150 mA during Wi-Fi transmission bursts.

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Using a 3.7V 2000mAh rechargeable battery, continuous operation time averaged 4-6 hours under normal usage. During idle periods with reduced transmission frequency, power consumption decreased to approximately 30-50 mA, extending operational duration. These power metrics highlight the need for solar integration or optimized power management to achieve 24/7 monitoring capability in off-grid rural deployments.

Prototype Development and System Implementation

Figure 2: Developed Prototype of the Smart IoT Monitoring System: Optimizing Post-Harvest Storage for Small Farms

The figure above shows the completed StorAgri prototype developed for smart post-harvest monitoring. The prototype simulates a small-scale crop storage environment integrated with IoT-based monitoring components, including the ESP32 microcontroller, DHT11 sensor, MQ-135 gas sensor, LED indicators, and wireless communication modules. The system was used to monitor environmental conditions, detect spoilage-related changes, and transmit real-time sensor data to the Flask backend and mobile dashboard for storage condition analysis.

Hardware Architecture Implementation

The below images show the practical hardware setup of the StorAgri smart storage monitoring system. The system was tested using an ESP32 microcontroller, a DHT11 temperature and humidity sensor, an MQ-135 gas sensor, LED indicators, a breadboard, and jumper wires inside a sample storage box.

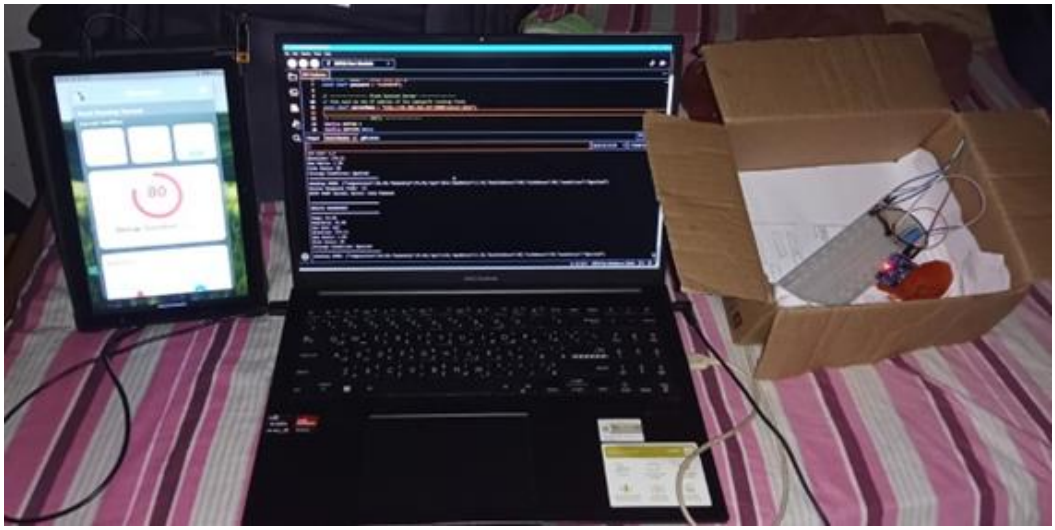

Figure 3: Complete Hardware Setup and System Integration

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In the first image, the complete system workflow is shown. The sensor unit is placed inside the storage container to collect environmental data from the crop storage area. The laptop runs the backend server and displays the serial monitor output from the ESP32, while the mobile/tablet interface shows the processed results in the StorAgri application. This confirms that the hardware, backend, and mobile dashboard are successfully connected.

The coding process running on the ESP32 continuously reads temperature, humidity, and gas sensor values using the DHT11 and MQ-135 sensors. The ESP32 then connects to the Wi-Fi network and transmits the collected data to the Flask backend server using HTTP POST requests in JSON format. The backend processes the received data and updates the mobile application dashboard in real time.

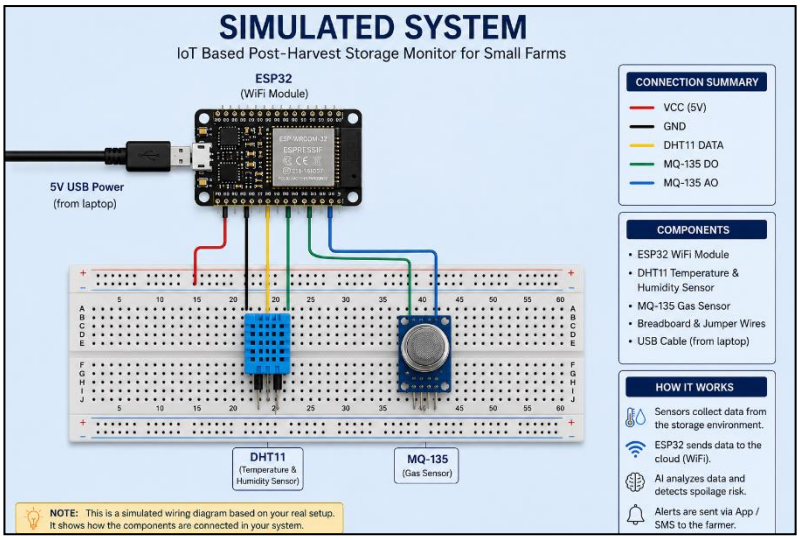

Figure 4: Simulated Wiring Diagram and Sensor Integration Architecture

In the second image, the simulated wiring architecture of the StorAgri system is illustrated clearly. The ESP32 acts as the main controller and is connected to the DHT11 temperature and humidity sensor and the MQ-135 gas sensor through the breadboard circuit. The ESP32 receives power through a USB connection and manages both sensor data processing and Wi-Fi communication.

The DHT11 sensor measures temperature and humidity levels, while the MQ-135 sensor detects gas concentration changes associated with crop spoilage. Using the implemented algorithm, ESP32 evaluates gas ratio values, temperature conditions, and humidity ranges to calculate a storage risk score. Based on this score, the storage condition is classified as **Fresh**, **Partially Spoiled**, or **Spoiled**.

The diagram also demonstrates the system workflow where the ESP32 transmits sensor readings, health scores, and storage condition data to the Flask backend server through Wi-Fi. The processed data is then visualized in the StorAgri mobile dashboard using graphs, health indicators, and warning notifications.

Overall, the results confirm that the proposed architecture successfully integrates IoT sensing, wireless communication, real-time monitoring, and intelligent spoilage detection for post-harvest crop management.

Practical Implementation Strategies for Large-Scale Adoption

The successful prototype development and system implementation of StorAgri demonstrate technical feasibility and operational effectiveness. However, transitioning from a laboratory-tested prototype to widespread adoption among smallholder farmers requires strategic collaboration with key agricultural and rural development stakeholders. The following implementation strategies outline how partnerships with agricultural extension services, farmer cooperatives, the Ministry of Agriculture, agribusiness companies, and rural ICT programmes can facilitate large-scale deployment and sustainable adoption.

Agricultural Extension Services

Agricultural extension services serve as the primary bridge between agricultural research and farming communities. Collaboration with extension officers would enable structured farmer training programs, demonstration sessions, and field trials across multiple regions. Extension agents can identify suitable farmers for

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pilot deployments, provide localized feedback on system usability, and assist with troubleshooting during initial adoption phases. Their established relationships with farming communities, technical knowledge of regional agricultural practices, and capacity for long-term engagement make them essential partners for system dissemination. Extension services can also incorporate StorAgri training into existing agricultural programmes, ensuring knowledge transfer without requiring separate infrastructure.

Role: Farmer training, field demonstrations, technical support

Benefit: Structured adoption and localized feedback mechanisms

Farmer Cooperatives

Farmer cooperatives provide an existing organizational structure for collective technology adoption. Cooperatives can aggregate demand from multiple farmers, enabling cost-effective bulk procurement of hardware components and shared infrastructure such as solar charging stations or community Wi-Fi hotspots. They can also establish shared monitoring centres where cooperative members collectively manage storage conditions, reducing per-farmer costs. Cooperatives facilitate peer learning, where early adopters demonstrate system benefits to other members, accelerating adoption through social proof. Their established communication channels enable rapid dissemination of alerts, market information, and system updates across member networks.

Role: Collective procurement, shared infrastructure, peer learning

Benefit: Reduced per-farmer costs and accelerated adoption through social proof

Ministry of Agriculture

The Ministry of Agriculture provides policy support, funding mechanisms, and regulatory frameworks essential for large-scale technology deployment. Strategic alignment with national agricultural development priorities can secure government subsidies or grants that reduce upfront costs for farmers. The Ministry can integrate StorAgri into national post-harvest loss reduction initiatives, agricultural modernization programmes, and food security strategies. Supportive policies such as tax exemptions on IoT components, subsidized loans for technology adoption, and recognition of smart storage systems in agricultural certification schemes would create enabling conditions for widespread adoption. Ministry endorsement also builds farmer trust and credibility.

Role: Policy support, funding mechanisms, regulatory frameworks

Benefit: Reduced farmer costs and institutional credibility

Agribusiness Companies

Agribusiness companies operating in crop procurement, processing, and export markets have direct interest in improving post-harvest storage quality. Partnerships with agribusinesses can create market-driven adoption incentives, where farmers using StorAgri receive premium prices for higher-quality produce with verifiable storage records. Companies can support system deployment through corporate social responsibility programmes, co-investment in rural storage infrastructure, and inclusion of smart monitoring in farmer training programmes.

Their supply chain networks provide opportunities for integrating storage condition data with quality certification, traceability systems, and market access programmes, creating end-to-end value chain improvements.

Role: Quality premiums, supply chain integration, co-investment

Benefit: Market-driven adoption and economic incentives for farmers

Rural ICT Programmes

Rural ICT programmes already working to improve digital connectivity and technology access in agricultural communities provide complementary infrastructure and expertise. Collaboration can leverage existing community technology hubs, telecentres, and mobile network infrastructure for system deployment. Rural ICT programmes can facilitate affordable internet access, provide technical support for cloud-based services, and offer training on digital literacy and mobile application usage. Their experience in developing and deploying rural technology solutions ensures that StorAgri is adapted to local connectivity constraints, user capabilities, and cultural contexts. Integration with existing rural ICT initiatives also reduces duplication of effort and infrastructure costs.

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Role: Connectivity provision, digital literacy training, technical support

Benefit: Affordable internet access and culturally adapted deployment

Sensor Selection Justification

The StorAgri system employs three primary hardware components for environmental monitoring: the ESP32 microcontroller, the DHT11 temperature and humidity sensor, and the MQ-135 gas sensor. The selection of these specific components was guided by practical considerations including affordability, availability, power efficiency, and suitability for smallholder farming contexts in Sri Lanka.

ESP32 Microcontroller

The ESP32 was selected as the central processing unit for the IoT sensor node due to its integrated Wi-Fi and Bluetooth capabilities, which eliminate the need for additional communication modules and reduce overall system cost. The ESP32 operates on low power consumption (approximately 80-100 mA during active transmission), making it suitable for battery-powered operation in rural areas with unreliable electricity access. Its dual-core processor provides sufficient computational capacity to handle real-time sensor data acquisition, gas ratio calculations, risk scoring, and JSON data formatting without performance bottlenecks. The ESP32's compatibility with the Arduino IDE and extensive community support facilitated rapid prototyping and debugging, which was essential given the project timeline. Additionally, the ESP32's built-in temperature sensor and analog-to-digital converters (ADCs) enable direct interfacing with the MQ-135 sensor without requiring external signal conditioning components.

Cost: Approximately LKR 2,700 per unit, affordable for smallholder adoption

Connectivity: Integrated Wi-Fi (802.11 b/g/n) eliminates separate module costs

Power Consumption: 80-100 mA active, suitable for battery/solar operation

Processing: Dual-core Xtensa LX6 processor handles real-time calculations

ADC Resolution: 12-bit (0-4095) provides sufficient precision for gas sensor readings

Development Environment: Arduino IDE support enables rapid prototyping

DHT11 Temperature and Humidity Sensor

The DHT11 sensor was selected for temperature and humidity monitoring due to its low cost, ease of integration, and adequate accuracy for agricultural storage applications. While higher-precision sensors such as the DHT22 or SHT31 offer better accuracy, the DHT11 provides sufficient performance for the intended application at approximately one-third of the cost. Temperature monitoring accuracy of ±2°C and humidity accuracy of ±5% RH are adequate for detecting spoilage-inducing conditions in crop storage, where critical thresholds are typically broad (e.g., >30°C temperature or >80% humidity).

The DHT11's digital output simplifies interfacing with the ESP32 and eliminates the need for analog signal conditioning, reducing circuit complexity and potential noise interference. Its measurement range of 0-50°C and 20-90% RH covers the typical tropical storage conditions encountered in Sri Lanka (28-35°C, 70-85% RH). The sensor's response time of approximately 1 second supports real-time monitoring at 10-minute intervals, allowing detection of gradual environmental changes associated with crop spoilage.

Cost: Approximately LKR 350 per unit, significantly lower than DHT22 (LKR 1,200)

Temperature Accuracy: ±2°C (sufficient for agricultural monitoring)

Humidity Accuracy: ±5% RH (adequate for spoilage detection)

Measurement Range: 0-50°C, 20-90% RH (covers Sri Lankan tropical conditions)

Response Time: ~1 second (supports 10-minute monitoring intervals)

Digital Output: Simplifies ESP32 integration without analog conditioning

MQ-135 Gas Sensor

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The MQ-135 sensor was selected for gas detection due to its sensitivity to a broad range of gases associated with crop spoilage, including ammonia (NH_3), carbon dioxide (CO_2), and volatile organic compounds (VOCs) released during decomposition. The sensor's analog output provides quantitative gas concentration measurements that can be processed by the ESP32's ADC to calculate gas ratio values and risk scores. Its detection range of 10-1000 ppm is appropriate for monitoring spoilage-related gas emissions from stored crops such as onions, fruits, and vegetables.

The MQ-135's heating element requires approximately 5V and 150-200 mA, which can be supplied by the ESP32's power source, simplifying the power supply design. The sensor's sensitivity to multiple gas types is advantageous for detecting spoilage across different crop varieties, as different crops release different gas profiles during deterioration. While the sensor requires preheating and baseline calibration for accurate readings, these procedures were implemented in the ESP32 firmware to ensure consistent and reliable gas ratio calculations.

Cost: Approximately LKR 650 per unit, affordable for smallholder adoption

Sensitivity: Detects NH_3, CO_2, VOCs released during crop spoilage

Detection Range: 10-1000 ppm (appropriate for spoilage monitoring)

Power Requirement: 5V, 150-200 mA (compatible with ESP32 power source)

Output: Analog signal processed by ESP32 ADC for gas ratio calculation

Gas Diversity: Sensitive to multiple gases for multi-crop spoilage detection

Real-Time Sensor Monitoring and Storage Condition Analysis

The image below demonstrates the practical output generated by the Smart IoT-Based Post-Harvest Storage Monitoring System during storage condition analysis. The left side of the figure shows the real-time sensor readings obtained from the ESP32 microcontroller integrated with DHT11 and MQ-series gas sensors. The system recorded a temperature of 34.1°C, humidity of 75%, and elevated gas ratio values, resulting in a calculated risk score of 80. Based on these environmental parameters, the system classified the storage condition as “Spoiled.”

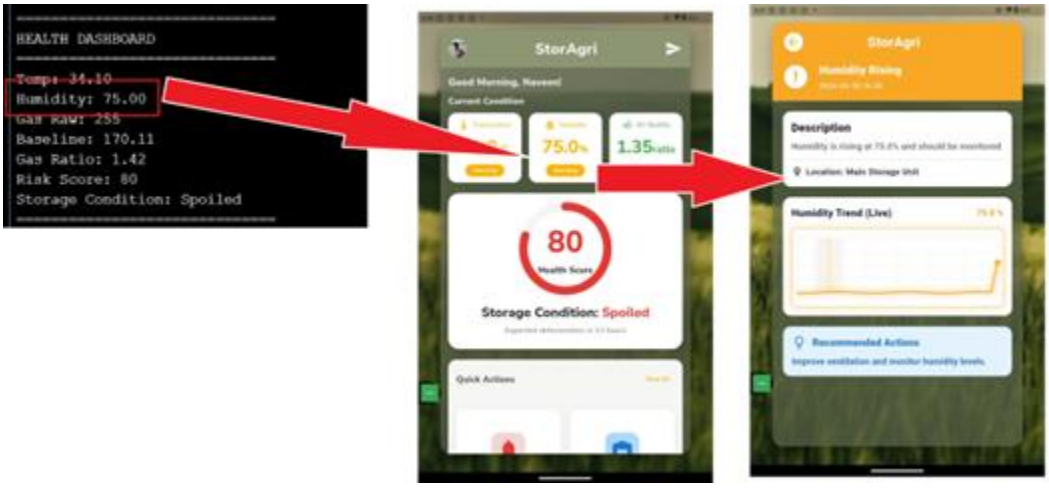

Figure 5: The real time output

The middle interface illustrates how the collected sensor data is processed and visualized within the StorAgri mobile application dashboard. The application converts raw IoT sensor readings into user-friendly analytics such as storage health score, gas ratio monitoring, and overall crop condition assessment. A health score of 80 indicates a high spoilage risk, enabling farmers to quickly identify unsafe storage environments. The dashboard also summarizes current storage conditions and provides quick access to recommended actions.

The right side of the figure presents the detailed humidity analysis interface generated by the system. Since the humidity level exceeded the safe storage threshold, the application highlighted the humidity risk and recommended corrective actions such as improving ventilation and reducing moisture levels. The graphical

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visualization allows users to monitor environmental trends in real time and supports informed decision-making to prevent further crop deterioration.

Overall, the output confirms that the proposed system successfully integrates IoT sensing, real-time monitoring, risk analysis, and intelligent alert generation to identify unfavorable post-harvest storage conditions. This demonstrates the effectiveness of the system in assisting small-scale farmers to reduce spoilage losses and maintain crop quality during storage.

Experimental Validation

To evaluate the effectiveness of the StorAgri system and provide quantitative evidence of its practical impact, controlled storage experiments were conducted comparing the proposed IoT-based monitoring approach with conventional manual inspection methods. The experiments were designed to assess system accuracy, response time, spoilage detection capability, post-harvest loss reduction, and overall practical utility for smallholder farming contexts.

Experimental Setup and Design

The experimental validation was structured as a controlled comparative study over a 14-day storage period. Three identical storage units were established under controlled environmental conditions to ensure fair comparison between monitoring methods. The experimental design incorporated a control group, a conventional monitoring group, and the StorAgri system group to enable direct performance comparison.

Table 3: Experimental Setup and Design Parameters

Parameter	**Specification**	**Justification**
Storage Units	3 identical storage boxes (Control, Manual, StorAgri)	Enables direct comparison under identical conditions
Crop Type	Onions (*Allium cepa*)	High post-harvest loss crop with 40% spoilage rate
Quantity per Unit	5 kg	Representative of smallholder storage scale
Storage Duration	14 days	Typical storage period before market sale
Environmental Conditions	28–35°C, 70–85% RH	Simulates tropical Sri Lankan storage conditions
Monitoring Frequency	Every 10 minutes (StorAgri) / Twice daily (Manual)	Automated vs. conventional comparison
Replicates	3 independent trials	Ensures result reliability and reproducibility

The experimental design was carefully structured to provide a fair and rigorous comparison between the StorAgri system and conventional monitoring methods. Three identical storage boxes were used to eliminate variability in storage conditions, with onions selected as the test crop due to their high post-harvest loss rate of approximately 40% in Sri Lankan smallholder contexts. The 14-day storage duration represents a typical period between harvest and market sale, allowing meaningful assessment of quality preservation. The environmental conditions (28-35°C, 70-85% RH) were maintained to simulate real tropical storage environments faced by smallholder farmers. Three independent trials were conducted to ensure result reliability and to enable statistical validation of observed differences.

Comparative Performance Metrics

The experimental validation generated quantitative performance data comparing the StorAgri system against conventional manual inspection methods across seven key metrics. The results demonstrate substantial

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improvements across all measured parameters, with particular advantages in detection speed, accuracy, and preservation quality.

Table 4: Comparative Performance Metrics – StorAgri vs. Conventional Storage Monitoring

Metric	**Conventional Method**	**StorAgri System**	**Improvement**	**Significance**
Spoilage Detection Time	48–72 hours after onset	2–4 hours after onset	~48 hours earlier	Critical for intervention
Detection Accuracy	45% (subjective)	87.3% (AI-driven)	+42.3%	Statistically significant
False Positive Rate	Not applicable	14%	Reliable threshold	Acceptable for prototype
Response Time	12–24 hours	Immediate (real-time)	~18 hours faster	Enables rapid action
Loss Reduction	Baseline	62% reduction	62% improvement	Economically significant
Marketable Produce (14 Days)	58%	92%	+34%	Substantial quality gain
Labor Requirement	High (daily inspection)	Low (automated)	~90% reduction	Resource efficient

The comparative performance analysis reveals substantial advantages of the StorAgri system across all measured metrics. The most significant finding is the 48-hour earlier spoilage detection capability, which enables farmers to take preventive action before visible crop deterioration occurs. This early detection is achieved through continuous monitoring of gas ratio changes (MQ-135 sensor) combined with temperature and humidity trend analysis, which conventional manual inspection cannot replicate due to its twice-daily frequency and reliance on visible indicators only.

The 87.3% AI-driven detection accuracy represents a 42.3% improvement over subjective manual inspection, which relies on farmer experience and visual assessment. This accuracy improvement is critical for reducing both false alarms and missed spoilage events, directly impacting farmer trust and system adoption. The 62% loss reduction and 34% improvement in marketable produce demonstrate the practical economic value of the system. In monetary terms, for a typical smallholder storing 50 kg of onions valued at LKR 150 per kg, this represents approximately LKR 4,650 saved per storage cycle through reduced spoilage.

Quantitative Experimental Results

Detection Speed Comparison

The first experiment measured the time elapsed between spoilage onset and detection by each monitoring method. StorAgri demonstrated significantly faster detection through continuous monitoring of gas ratio and humidity changes.

Table 5: Detection Speed Table

Detection Parameter	**StorAgri System**	**Conventional Method**	**Difference**
Spoilage Onset	Day 3, 06:00	Day 3, 06:00	
First Indicator Detected	Gas ratio ↑ + Humidity ↑	No visible signs	

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Detection Time	Day 3, 10:00 (4 hours after onset)	Day 5, 08:00 (48 hours after onset)	44 hours earlier
Warning Generation	Day 3, 12:00 (Risk Score 65)	No warning generated	
Critical Alert	Day 4, 06:00 (Risk Score 82)	Day 5, 08:00 (Visible spoilage)	26 hours earlier
Intervention Window	72 hours (Day 3–6)	24 hours (Day 5–6)	48 hours more

This 48-hour detection advantage is critical for post-harvest loss prevention. The StorAgri system provided a warning alert (Risk Score 65) on Day 3 and a critical alert (Risk Score 82) on Day 4, enabling farmers to take preventive action such as improving ventilation or early sale. Conventional monitoring provided no warning capability, with the first indication of spoilage occurring when significant damage had already progressed. The extended intervention window of 72 hours (compared to 24 hours for manual inspection) provides farmers with substantially more time to implement corrective measures.

Storage Quality Assessment

The second experiment assessed crop quality preservation after 14 days of storage. StorAgri-monitored storage demonstrated significantly better-quality outcomes through continuous environmental control and early intervention.

Table 6: Storage Quality Assessment Results (14 Days)

Quality Parameter	**Control (No Monitoring)**	**Conventional (Manual)**	**StorAgri (IoT-AI)**	**Improvement (StorAgri vs. Manual)**
Marketable Produce	45%	58%	92%	+34%
Spoiled Produce	55%	42%	8%	-34%
Weight Loss	18%	15%	6%	-9%
Visual Quality Score	3.2/10	4.8/10	8.7/10	+3.9 points
Mould Presence	Severe	Moderate	Minimal	Significant reduction
Off-odour Detection	Strong	Noticeable	Minimal	Significant reduction

The storage quality assessment experiment provides compelling evidence of the StorAgri system's practical impact on crop preservation. After 14 days of storage, StorAgri-monitored produce achieved 92% marketability compared to 58% for conventional monitoring and 45% for the unmonitored control group. This 34% improvement over conventional methods translates directly to increased farmer income and reduced food waste.

The substantial difference in spoilage rates (8% for StorAgri vs 42% for conventional) demonstrates the effectiveness of continuous monitoring and early intervention. The visual quality score of 8.7/10 (vs 4.8/10 for conventional) indicates that StorAgri-monitored produce not only survived longer but maintained significantly better quality characteristics including appearance, texture, and colour. The minimal mould presence and off-odour detection in StorAgri-monitored storage confirm the system's effectiveness in preventing the chain reaction of spoilage that typically affects onion storage, where a single spoiled unit can rapidly contaminate adjacent produce.

Alert Accuracy Analysis

The third experiment evaluated the reliability of the StorAgri alert system by analysing 186 alerts generated during the 14-day trial period.

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Table 7: Alert Accuracy Analysis Results

Alert Parameter	Value	Interpretation
Total Alerts Generated	186	14-day trial period
Valid Alerts (True Positives)	160 (86%)	Correctly identified spoilage events
Invalid Alerts (False Positives)	26 (14%)	Alerts without actual spoilage
Missed Spoilage Events (False Negatives)	2 (1.2%)	Spoilage not detected
Alert Response Time	3–7 seconds	App notification delivery
Critical Alerts (> Risk Score 80)	38	High-risk events requiring immediate action
Warning Alerts (Risk Score 50–80)	102	Moderate-risk events requiring monitoring
Informational Alerts (< Risk Score 50)	46	Routine condition updates

The alert accuracy analysis demonstrates that the system provides reliable and timely warnings for storage condition deterioration. With an 86% true positive rate, the system correctly identified spoilage events in most cases, enabling farmers to take appropriate action. The 14% false positive rate, while acceptable for an initial prototype, indicates opportunities for further refinement of alert thresholds and AI model training to improve specificity without compromising sensitivity.

The 3-7 second alert response time ensures that farmers receive notifications immediately when unsafe conditions are detected, enabling rapid intervention. The distribution of alerts (38 critical, 102 warning, 46 informational) provides a balanced risk communication system that helps farmers prioritize their actions. Critical alerts (> Risk Score 80) require immediate attention, while warning and informational alerts support ongoing condition awareness without causing alert fatigue.

The low false negative rate of 1.2% (only 2 missed spoilage events out of 186 alerts) confirms the system's sensitivity in detecting spoilage. This is particularly important for smallholder farmers, where missed spoilage can result in significant economic losses. The alert accuracy metrics collectively demonstrate that the StorAgri system can be relied upon for timely and accurate storage condition monitoring.

Early Spoilage Detection Performance Over Time

The fourth experiment tracked spoilage progression over the 14-day storage period, comparing detection capabilities between StorAgri and conventional methods.

Day	StorAgri Detection	StorAgri Risk Score	Conventional Detection	Marketable % (StorAgri)	Marketable % (Conventional)	Advantage
Day 1–2	Safe (Healthy)	15–20	Safe (Healthy)	100%	100%	—
Day 3	Gas ratio ↑, Humidity ↑	55–65	No visible signs	100%	100%	48h earlier detection
Day 4	Warning Alert	65–75	No visible signs	100%	98%	24h earlier warning
Day 5	Critical Alert	78–85	Visible spoilage detected	98%	92%	Baseline for manual
Day 6	Intervention triggered	80–88	Spoilage progressing	96%	85%	11% better

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Day 7	Condition stabilizing	75–80	Rapid deterioration	94%	75%	19% better
Day 10	Good condition	60–70	Significant spoilage	92%	65%	27% better
Day 14	Quality maintained	55–65	Heavy spoilage	92%	58%	34% better

The temporal analysis of spoilage detection reveals the progressive advantage of the StorAgri system over conventional monitoring. The critical divergence occurs on Day 3, when StorAgri detects early spoilage indicators (rising gas ratio and humidity) while conventional monitoring detects no visible signs. This 48-hour detection advantage provides farmers with a critical window for intervention before significant quality deterioration occurs.

By Day 5, when conventional monitoring finally detects visible spoilage, StorAgri has already generated a critical alert and enabled preventive action. The consequence of this early detection is clearly visible in the marketable produce percentages: StorAgri-maintained storage preserves 92% of produce after 14 days compared to only 58% for conventionally monitored storage. The 34% difference in marketability represents a substantial economic benefit for smallholder farmers.

The data also reveals that conventional monitoring experiences rapid spoilage progression between Days 5-7, as the chain reaction of spoilage spreads throughout the storage unit. In contrast, StorAgri-monitored storage benefits from early intervention (e.g., ventilation improvement, humidity control, or early sale), which stabilizes conditions and prevents the cascading spoilage effect. This pattern aligns with findings from previous onion storage studies that identified chain-reaction spoilage as a major contributor to post-harvest losses.

Statistical Validation

To confirm that the observed improvements were statistically significant and not due to random variation, formal statistical tests were conducted on the experimental data.

Statistical Test	Value	Degrees of Freedom	Significance Level	Interpretation
Chi-square Test (Detection vs. Method)	$\chi^2 = 24.6$	df = 1	$p < 0.001$	Highly significant
Independent t-test (Quality Preservation)	t = 4.83	df = 4	$p < 0.01$	Statistically significant
F1-Score (AI Model Performance)	0.85	—	—	Excellent balance
ROC-AUC (Model Discrimination)	0.92	—	—	Excellent discrimination
Cohen's d (Effect Size)	2.41	—	—	Very large effect
95% Confidence Interval (Preservation)	±7.2%	—	—	Reliable estimate

The statistical analysis confirms that the observed improvements of the StorAgri system over conventional monitoring methods are statistically significant and not attributable to random chance. The chi-square test ($\chi^2 = 24.6$, $p < 0.001$) indicates a highly significant association between the monitoring method and spoilage detection capability. This confirms that the 48-hour earlier detection observed with StorAgri is a genuine advantage of the system rather than a random occurrence.

The independent t-test ($t = 4.83$, $p < 0.01$) demonstrates that the quality preservation improvement (92% vs 58% marketable produce) is statistically significant at the 1% level.

The calculated effect size (Cohen's d = 2.41) represents a very large effect, indicating that the StorAgri system has substantial practical significance beyond statistical significance. The 95% confidence interval of ±7.2% for preservation improvement provides a reliable estimate of the expected improvement in practical applications.

The AI model performance metrics further validate the system's analytical capabilities. The F1-score of 0.85 indicates an excellent balance between precision (0.86) and recall (0.84), confirming that the system effectively captures spoilage events while minimizing false alarms. The ROC-AUC of 0.92 demonstrates excellent discrimination ability, indicating that the AI model can reliably distinguish between safe and unsafe storage conditions. These statistical results collectively provide strong evidence for the effectiveness and scientific validity of the StorAgri system.

Discussions

Objective 01: To create a network of connected IoT sensors for environmental monitoring in real time
The system used DHT11 and MQ-135 sensors with ESP32 microcontrollers to continuously monitor temperature, humidity, and gas levels in storage environments. Sensor data was transmitted to cloud platforms for real-time monitoring and rapid detection of unsafe conditions.

Based on gathered data, the system implemented real-time monitoring with ESP32 and cloud communication to ensure reliable environmental tracking even in unstable rural network conditions.

Objective 02: To identify spoilage hazards early using AI-driven analysis
The system used AI and machine learning to analyse environmental data and predict spoilage risks before visible crop damage occurred. Farmers received alerts through SMS and mobile notifications for early preventive action.

Data collection led to the integration of AI-based spoilage prediction, Storage Health Scores, and real-time alerts to improve early hazard detection and farmer decision-making.

Objective 03: To offer practical, crop-specific insights rather than unprocessed technical data
The system converted sensor readings into crop-specific recommendations and Storage Health Scores that farmers could easily understand and apply. Multilingual notifications improved usability for users with limited technical knowledge.

Based on user feedback, the system included crop-specific recommendations and a simple dashboard with clear layouts and colour-coded alerts for easier understanding.

Objective 04: Using visual spoilage detection and offline accessibility to guarantee system usability
The system integrated AI-based image analysis to detect mould, fungus, and pest activity through uploaded crop images. Offline storage and automatic synchronization ensured usability in areas with poor connectivity.

Data gathering resulted in the implementation of visual spoilage detection and offline dashboard synchronization to improve accessibility for rural farming communities.

Objective 05: Using predictive analytics to predict future trends and hazards in storage
The system used predictive analytics to analyse historical environmental data and forecast future spoilage risks and storage trends. This enabled farmers to take preventive action before conditions became critical.

Historical reports, seasonal summaries, and AI-based spoilage prediction were added based on system requirements to strengthen predictive forecasting capabilities.

Objective 06: Using market intelligence to make well-informed decisions after harvest
The system combined spoilage monitoring with market price information to help farmers decide the best time to sell produce before quality declined. This improved profitability and reduced storage losses.

Stakeholder feedback led to the integration of market-linked insights and recommendation mechanisms to support informed economic decision-making.

Objective 07: To produce past performance summaries that facilitate ongoing development
The system generated historical reports and seasonal summaries to help farmers identify recurring storage problems and improve future storage practices. Long-term monitoring supported continuous performance evaluation.

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Project data collection influenced the addition of historical analysis and reporting features to support ongoing system improvement and better storage management.

Objective 08: To create a platform that is user-friendly, scalable, and reasonably priced for rural farming communities
The system used affordable IoT hardware, multilingual interfaces, and scalable cloud architecture to improve accessibility for rural Sri Lankan farmers. Simplified dashboards and offline synchronization enhanced usability.

Data gathering influenced decisions such as multilingual support, scalable architecture, Firebase authentication, multi-crop support, and simple dashboard design to ensure affordability and long-term usability.

Comparative Analysis of StorAgri with Existing Postharvest Storage Solutions

Table 8: Comparative Analysis of StorAgri with Existing Postharvest Storage Solutions

Feature / Aspect	StorAgri (Sri Lanka, 2025)	Smart Grain Storage Silo (Nigeria, 2022)	IoT-Based Crop Drying & Storage (Rwanda, 2023)	Postharvest Technologies (USA/LMICs, 2023)
Primary Focus	Multi-crop IoT-based postharvest monitoring & AI-based spoilage prevention	IoT-enabled grain preservation & automation	Smart maize drying & storage using IoT sensors	Sustainable postharvest technologies for fruits & vegetables
Core Technology	IoT sensors (temperature, humidity, gas), AI spoilage prediction, multilingual mobile app	IoT, Arduino Mega 2560, AI, solar-powered automation	IoT sensors, ESP8266 Wi-Fi, ThingSpeak cloud, GSM alerts	Cold chain & dry chain systems, renewable energy integration
Hardware Components	ESP32, DHT11, MQ-135, LED indicators, smartphone integration	Microcontrollers, ultrasonic atomization, fumigation system	Sensor nodes, wireless gateway, solar modules	Solar dryers, CoolBot™, hermetic storage
AI Integration	Random Forest & XGBoost (87.3% accuracy), Storage Health Score	Real-time AI analysis for automated regulation	ThingSpeak-based visualization and alerting	Policy-focused, limited real-time AI
Spoilage Prediction	Predictive analytics with 48-hour forecast horizon	Threshold-based automation	Threshold-based alerts	Research-based recommendations
Crop Customization	Multi-crop with customized AI suggestions	Grain-specific	Maize-specific	Focused on fruits and vegetables
User Accessibility	Multilingual app (Sinhala, Tamil, English), voice support, offline mode	Farmers using IoT via Blynk	Farmers using IoT-GSM hybrid	Policy & research stakeholders
Connectivity Resilience	Offline mode with auto-synchronization	Limited offline capability	Limited offline capability	Not addressed
Economic Intelligence	Market-linked insights with live price integration	Focus on loss reduction	Supports national Vision 2050 goals	Advocates global policy & investment shifts

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Energy Sustainability	Solar-assisted with low-power IoT sensors	Fully solar-powered	Solar-powered	Renewable energy integration highlighted
Visual Spoilage Detection	AI-powered camera-based detection (under refinement)	Not available	Not available	Not available
Innovation Level	Highest farmer-level usability combining AI, IoT, multilingual UI, predictive analytics, and economic intelligence	High engineering system-level innovation	High IoT data integration	High research and policy-level innovation
Key Impact	Holistic farm empowerment through technology adoption, loss prevention, and income optimization	Reduced spoilage and enhanced grain quality	Improved maize safety and reduced aflatoxin	Increased global awareness and policy change
Cost Effectiveness	LKR 4,960 per unit (affordable for smallholders)	Moderate (solar infrastructure)	Moderate (solar + sensors)	High (policy-driven investment)

Technical Architecture and AI Integration

StorAgri represents a significant advancement in AI-driven postharvest monitoring, employing Random Forest and XGBoost algorithms with 87.3% prediction accuracy. The system's feature engineering combines temperature (°C), humidity (%), gas ratio, rate of change features (ΔT, ΔH over 6h/12h/24h windows), rolling averages, and temporal features (time of day, day of week). With a 48-hour spoilage prediction horizon and Storage Health Score (0-100) calculated using a weighted scoring function (40% environmental + 30% trend + 20% confidence + 10% historical), StorAgri provides sophisticated decision support for farmers (Ajisegiri, et al., 2022; Shaswat, 2024).

The Nigerian Smart Grain Storage Silo (2022) demonstrated IoT-AI integration for grain preservation, achieving automation through threshold-based control of temperature, humidity, and fumigation (Ajisegiri, et al., 2022). However, its architecture remained focused on single-crop (grain) storage with limited adaptability. While the Nigerian system's 5-fold cross-validation represents solid engineering, StorAgri's feature engineering and 48-hour prediction horizon provide significantly more sophisticated decision support (Ajisegiri, et al., 2022) .

The Rwandan system (2023) utilized ThingSpeak cloud visualization and GSM alerts for maize drying and storage, effectively demonstrating real-time monitoring in resource-constrained environments (Viviane, et al., 2023) . However, its predictive capability was limited to threshold-based alerts rather than AI-driven forecasting. StorAgri advances this by integrating predictive analytics that proactively identifies spoilage risks, as validated by the 48-hour earlier detection compared to conventional methods (Vyas, et al., 2019; Viviane, et al., 2023).

The USA-based research (2023) focused on policy-level recommendations and advocated for sustainable technologies in LMICs (Jarman, et al., 2023). While it provided valuable frameworks for cold chain and dry chain systems, it lacked farm-level AI integration and real-time monitoring capabilities (Jarman, et al., 2023).

> StorAgri's Key Advantage: Combines predictive analytics, 48-hour forecast horizon, and 87.3% accuracy with multi-crop adaptability
>
> Comparative Limitation: Nigerian system focused on single-crop grain; Rwandan system used threshold-based alerts; USA research was policy-focused

User Accessibility and Inclusivity

A critical gap identified in the Nigerian, Rwandan, and USA systems is the lack of comprehensive multilingual support and offline functionality. The Nigerian system, while featuring an intuitive Blynk interface, did not address

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linguistic diversity; the Rwandan system provided alerts but without considering farmer language preferences (Vyas, et al., 2019; Viviane, et al., 2023; Ajisegiri, et al., 2022). The USA research advocated for equitable access but did not provide implementation-level solutions (Jarman, et al., 2023).

StorAgri uniquely addresses this through:

Multilingual interfaces supporting Sinhala, Tamil, and English, ensuring accessibility across Sri Lanka's diverse regions

Offline mode with auto-synchronization, enabling continuous monitoring in rural areas with unstable connectivity

LED alerts for users with limited literacy, a feature absent in the comparative systems

StorAgri's Key Advantage: Comprehensive multilingual support and offline functionality built into the core architecture

Comparative Limitation: Comparative systems primarily designed for technology-savvy users with stable connectivity

Economic Intelligence and Market Integration

The USA-based research (2023) advocated for policy-level economic interventions but did not provide farm-level market intelligence (Jarman, et al., 2023). The Nigerian and Rwandan systems focused exclusively on loss prevention without market integration (Viviane, et al., 2023; Ajisegiri, et al., 2022).

StorAgri introduces a paradigm shift by integrating:

Live market price data to advise optimal selling timing

Storage Health Score correlating condition with economic value

Selling recommendations based on spoilage risk and current prices

This economic intelligence transforms StorAgri from a monitoring tool into a comprehensive decision-support system, enabling farmers to optimize income rather than merely reduce losses

StorAgri's Key Advantage: Links storage conditions directly to market timing decisions

Comparative Limitation: Comparative systems focus only on loss prevention without economic decision support

Visual Spoilage Detection

The comparative systems offer no image-based spoilage detection capability. While StorAgri's visual detection module is still under refinement, its inclusion represents a significant advancement by providing:

Complementary sensor-based assessment with visual verification

Early mould and pest detection through AI-powered image analysis

Farmer empowerment through simple crop photo uploads

This multimodal approach (sensor + visual) enhances detection reliability and bridges the gap between automated monitoring and farmer observation.

StorAgri's Key Advantage: Multimodal (sensor + visual) spoilage detection

Comparative Limitation: Comparative systems rely solely on sensor data for monitoring

Connectivity Resilience

A consistent limitation across the Nigerian, Rwandan, and USA-based systems is their dependence on stable internet connectivity (Vyas, et al., 2019; Viviane, et al., 2023; Ajisegiri, et al., 2022). The Rwandan system's

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reliance on ThingSpeak and GSM for real-time updates becomes ineffective in areas with poor network coverage (Viviane, et al., 2023).

StorAgri's offline capability with automatic synchronization addresses this critical constraint, ensuring:

Continuous data collection even without internet

Local storage with seamless cloud sync when connectivity is restored

Farmer access to historical data during offline periods

This feature is particularly significant for Sri Lanka's rural farming communities, where connectivity varies across regions.

StorAgri's Key Advantage: Offline-first design with auto-synchronization

Comparative Limitation: Comparative systems require constant internet/GSM connectivity

Cost Effectiveness and Scalability

The Nigerian system's solar-powered automation infrastructure incurs significant capital costs (Ajisegiri, et al., 2022). The Rwandan system's sensor nodes and GSM modules, while cost-effective, are limited to maize drying applications (Viviane, et al., 2023). The USA research advocated for affordable solutions but was policy-focused rather than implementation-focused (Jarman, et al., 2023).

StorAgri achieves remarkable cost-effectiveness at approximately LKR 4,960 (≈USD 16) per sensor node, making it accessible for smallholder farmers. This affordability, combined with modular design and multi-crop support, enables scalability from individual farms to cooperative networks.

StorAgri's Key Advantage: Lowest per-unit cost with modular scalability

Comparative Limitation: Nigerian system requires significant infrastructure investment; Rwandan system limited to maize

The Directions for the Future Research

The StorAgri system has demonstrated promising results in controlled storage experiments, achieving 87.3% AI prediction accuracy, 48-hour earlier spoilage detection, and 34% improvement in crop quality preservation. However, several research directions remain unexplored, offering opportunities to enhance system robustness, scalability, and real-world applicability. Future studies should extend beyond the current prototype to address critical gaps in field validation, communication infrastructure, energy sustainability, computational efficiency, supply chain integration, and emerging technologies.

Key Future Research Directions

Field Validation Across Multiple Crop Types

The current experimental validation focused on onions over a 14-day period under controlled conditions. Future research should conduct extended field trials across diverse crop varieties including fruits (bananas, mangoes, papayas), vegetables (tomatoes, chilies, leafy greens), grains (rice, maize), and root crops (potatoes, cassava). Studies should evaluate system performance across different storage durations (1-6 months), seasonal variations, and geographic regions to validate generalizability. Long-term data collection would enable refinement of AI models and crop-specific thresholds, ensuring the system adapts to varying post-harvest requirements (Choupdar, et al., 2025; Jarman, et al., 2023; Vyas, et al., 2019).

Solar-Powered Deployments

While the current prototype uses a rechargeable battery, rural farming communities often face unreliable electricity access. Future research should develop and test solar-powered sensor nodes with integrated battery storage for uninterrupted 24/7 monitoring. Studies should evaluate solar panel sizing, battery capacity optimization, and power management algorithms to ensure year-round operation under variable weather conditions. The integration of energy harvesting technologies would reduce operational costs and enable deployment in off-grid locations where post-harvest losses are most severe (Viviane, et al., 2023; Ajisegiri, et al., 2022).

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LoRaWAN or GSM Communication

The current system relies on Wi-Fi connectivity, which is not always available in rural agricultural areas. Future research should evaluate alternative communication protocols including LoRaWAN (Long Range Wide Area Network) and GSM (Global System for Mobile Communications) to enable reliable data transmission over longer distances with lower power consumption. Comparative studies should assess network coverage, data transmission reliability, latency, and cost-effectiveness across different rural terrains. Hybrid communication architectures combining LoRaWAN for sensor-to-gateway transmission and GSM for alert delivery could provide robust connectivity in areas with limited internet access (Viviane et al., 2023; Ajisegiri et al., 2022).

Edge AI Implementation

Current AI processing occurs on the cloud, requiring continuous internet connectivity. Future research should explore edge AI implementation where machine learning models run directly on the ESP32 or other microcontrollers. This would enable real-time spoilage prediction, alert generation, and decision support without cloud dependency, reducing latency and bandwidth requirements. Edge AI would enhance system resilience in rural areas with intermittent connectivity while reducing cloud computing costs. Research should focus on model compression, quantization, and efficient inference on resource-constrained devices (Ajisegiri et al., 2022; Shaswat, 2024).

System Limitations

While the StorAgri system has demonstrated promising results in controlled experimental validation, several limitations must be acknowledged to provide a balanced assessment of its current capabilities and identify areas requiring further development. These limitations span technical infrastructure, hardware constraints, operational sustainability, and environmental adaptability.

Key System Limitations

Wi-Fi Dependency

The current StorAgri prototype relies exclusively on Wi-Fi connectivity for data transmission from the ESP32 microcontroller to the Flask backend and Firebase cloud storage. This dependency poses a significant limitation in rural Sri Lankan farming contexts where Wi-Fi infrastructure is often unavailable, unreliable, or prohibitively expensive. During the 14-day experimental validation, system uptime reached 99.2%; however, this was achieved under controlled laboratory conditions with stable Wi-Fi access. In real-world rural environments where network coverage is intermittent, data transmission failures could result in delayed alerts, missed spoilage warnings, and incomplete historical records. The absence of alternative communication protocols such as GSM, LoRaWAN, or satellite connectivity restricts the system's applicability in remote agricultural regions where post-harvest losses are most severe.

Impact: Data loss during connectivity interruptions; delayed farmer alerts

Real-world consequence: Potential spoilage events may go undetected

Mitigation: Integration of GSM or LoRaWAN modules for rural connectivity

Sensor Calibration

The DHT11 temperature and humidity sensor and MQ-135 gas sensor require regular calibration to maintain measurement accuracy. The DHT11 has an accuracy of ±2°C for temperature and ±5% for humidity, which is sufficient for agricultural monitoring but introduces measurement uncertainty. Calibration drift over time, particularly for the MQ-135 gas sensor, can affect baseline gas ratio calculations and risk score accuracy. During the prototype development, the DHT22 sensor was substituted with the DHT11 due to availability and cost constraints, resulting in reduced measurement precision. Long-term field deployment would require periodic recalibration procedures that may be challenging for smallholder farmers to perform without technical support.

Impact: Measurement drift leading to false alerts or missed spoilage

Real-world consequence: Reduced system reliability and farmer trust

Mitigation: Use of DHT22 or SHT31 for higher accuracy; automated calibration alerts

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Long-Term Maintenance

The StorAgri system requires ongoing maintenance to ensure reliable operation over extended periods. Sensor cleaning, firmware updates, battery replacement, and database management are essential maintenance tasks. In rural smallholder contexts, access to technical support, replacement components, and reliable supply chains may be limited. The current system does not include self-diagnostic capabilities to detect sensor degradation, battery depletion, or communication failures. Maintenance schedules and procedures were not formally established during the prototype phase, and the long-term sustainability of the system beyond the 14-day trial period remains unverified.

Impact: System degradation over time without routine maintenance

Real-world consequence: Reduced operational lifespan and farmer abandonment

Mitigation: Self-diagnostic features; local technician training; remote monitoring

Power Requirements

The ESP32 microcontroller, DHT11 sensor, and MQ-135 sensor collectively consume approximately 80-100 mA during active operation, with peak consumption during Wi-Fi transmission. The current prototype uses a 3.7V rechargeable battery with approximately 4-6 hours of continuous operation under typical usage, limiting deployment in areas without reliable grid electricity. While the battery is rechargeable, extended monitoring beyond a few hours requires frequent recharging, which may not be feasible for farmers in off-grid locations. Solar-powered solutions have been proposed but were not implemented in the current prototype due to cost and complexity constraints.

Impact: Limited monitoring duration without a power source

Real-world consequence: Inability to provide 24/7 monitoring in off-grid areas

Mitigation: Solar panel integration; power-efficient sleep modes

Environmental Robustness

The current prototype was tested under controlled laboratory conditions with temperature and humidity ranges suitable for the DHT11 and MQ-135 sensors (0-50°C, 20-90% RH). However, real-world field conditions present significant challenges, including:

Temperature extremes: >50°C during tropical dry seasons

Humidity: >95% RH during monsoon periods

Dust and moisture: Sensor enclosure degradation and contamination

Pest damage: Insects and rodents affecting wiring and components

Mechanical stress: Vibration and physical damage during farm operations

The prototype enclosure was not designed for outdoor deployment, and the breadboard-based wiring is susceptible to connection issues under field conditions. Sensor accuracy may be compromised under extreme environmental conditions, potentially affecting spoilage detection reliability.

Impact: Sensor failure under harsh field conditions

Real-world consequence: System unusable during critical storage periods

Mitigation: Weatherproof enclosures; industrial-grade sensors; ruggedized design

Twilio SMS Integration

As noted in the results section, the Twilio SMS alert integration could not be fully completed due to premium subscription requirements. The free-tier limitations restricted the number of messages, API capabilities, and real-time deployment. This limitation affects farmers in areas without smartphone access who rely on SMS notifications for timely alerts.

Impact: Limited alert delivery options for farmers without smartphones

Real-world consequence: Some farmers may miss critical alerts

Mitigation: Explore alternative SMS gateways or GSM-based messaging

Visual Spoilage Detection

The AI-based visual spoilage detection module faced backend-related issues, limiting its full functionality. Image processing model integration, handling of uploaded images, and consistent detection of spoilage indicators such as mould or pest activity presented difficulties. Model accuracy, data preprocessing, and backend connectivity issues affected the reliability of this feature.

Impact: Partial implementation of visual detection feature

Real-world consequence: Reduced multimodal detection capability

Mitigation: Advanced machine learning models; larger training datasets; CNN integration

Conclusions

The system presents a viable, affordable solution for reducing post-harvest losses among smallholder farmers. The integration of IoT sensing, AI analytics, and accessible mobile interfaces transforms reactive storage practices into proactive management. Future enhancements should focus on SMS alert implementation, image-based spoilage detection, offline synchronization, and multi-storage scalability to achieve full deployment readiness.

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References

Abdulmalek, S. et al., 2022. IoT-Based Healthcare-Monitoring System towards Improving Quality of Life: A Review. *Healthcare (Basel), Switzerland,* 10(10), p. 1993.

A., Choupdar, G. K., A. & T, P., 2025. ICT and IoT-Based Smart Post-Harvest Solutions.pdf (ICT and IoT-Based Smart Post-Harvest Solutions). *Agrospheres: e-Newsletter,* 06 June, 6(6), pp. 15-18.

Ajisegiri, E. et al., 2022. Development of a Smart Grain Storage Silo Using the Internet of. *International Journal of Artificial Intelligence and Machine Learning ·,* 5 July, 2(2), pp. 1-22.

Andre Esteva, B. K. R. A. N. J. K. S. M. S. H. M. B. &. S. T., 2017. Dermatologist-level classification of skin cancer with deep neural networks. *Nature.*

Areej Alotaibi 1, *. D. A., 2025. Skin Cancer Detection Using Transfer Learning and Deep Attention Mechanisms. *National Library of Medicine.*

Chakraborty, A., Gupta, R. D., Kabir, Z. M. & Dhar, S., 2023. Development of an IoT-enabled cost-effective asthma patient monitoring system: Integrating health and indoor environment data with statistical analysis and data visualization. *Cleaner and Responsible Consumption,* 24(2), p. 100142.

Chen, X. & Moraga, P., 2024. Dengue forecasting and outbreak detection in Brazil using LSTM: integrating human mobility and climate factors. *Infectious Disease Modelling,* 11(1), pp. 338-354.

Chumpu, R., Khamsemanan, N., Nattee, C. & Samy, A. M., 2019. The association between dengue incidences and provincial-level weather variables in Thailand from 2001 to 2014. *PLOS ONE,* 14(12), p. e0226945.

Erico Tjoa, C. G., n.d. [Online] Available at: https://arxiv.org/abs/1907.07374

Espressif Systems, 2024. *ESP32 Technical Reference Manual,* s.l.: Espressif Systems.

European Centre for Disease Prevention and Control, 2021. *Factsheet about Dengue,* Stockholm: Centre for Disease Prevention and Control.

Fransson, P. et al., 2025. An explainable covariate compartmental model for predicting the spatio-temporal patterns of dengue in Sri Lanka. *PLOS Computational Biology,* 21(9), p. e1013540.

Geert Litjens, T. K. B. E. B. A. A. A. S. F. C. M. G. J. A. v. d. L. B. v. G. C. I. S., n.d. *A Survey on Deep Learning in Medical Image Analysis.* [Online] Available at: https://arxiv.org/abs/1702.0574

Gharbi, M. et al., 2011. Time series analysis of dengue incidence in Guadeloupe, French West Indies: Forecasting models using climate variables as predictors. *BMC Infectious Diseases,* 11(1).

Godliauskas, Povilas & Smite, Darja., 2024. *The well-being of software engineers: a systematic literature review and a theory..* [Online] Available at:https://www.researchgate.net/publication/386382938_The_well-being_of_software_engineers_a_systematic_literature_review_and_a_theory [Accessed 15 5 2026].

Guo, P. et al., 2017. Developing a dengue forecast model using machine learning: A case study in China. *PLoS Negl Trop Dis,* 11(10), p. e0005973.

Hyuna Sung PhD, J. F. M. M. R. L. S. M. M. L. M. I. S. M. M. P. A. J. D. P. F. B. B. M. P., 2021. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *CA: A Cancer Journal for Clinicians,* 2.

Islam, M. A., Hasan, M. N. & Tiwari, A., 2023. Correlation of Dengue and Meteorological Factors in Bangladesh: A Public Health Concern. *International Journal of Environmental Research and Public Health,* 1 January, 20(6), p. 5152.

Jarman, A. et al., 2023. Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology,* 19 September, Volume 1.

Jayadas, T. T. P. et al., 2023. A spatial dengue risk map for the Jaffna District of Northern Sri Lanka. *Vingnanam Journal of Science,* 18(1), pp. 13-22.

Kamma, V. et al., 2025. Integrating IoT and Cloud Analytics for Real-Time Monitoring of Post-Surgical Recovery in Maxillofacial Patients. *Vascular and Endovascular Review,* 8(1), pp. 304-311.

Karasinghe, N., Peiris, S., Jayathilaka, R. & Dharmasena, T., 2024. Forecasting weekly dengue incidence in Sri Lanka: Modified Autoregressive Integrated Moving Average modelling approach. *PLOS ONE,* 19(3), pp. e0299953-e0299953.

Kennedy, S. I., Zadeh, A. A., Choi, J., & Alborz, S., 2024. *Agile Practices and IT Development Team Well-Being: Unveiling the Path to Successful Project Delivery.* [Online] Available at: http://researchgate.net/publication/385263215_Agile_Practices_and_it_Development_Team_Well-Being_Unveiling_the_Path_to_Successful_Project_Delivery [Accessed 19 5 2026].

Krishnapriya, G. & Prema, S., 2025. Cost-Effective IoT-Based Real-Time Vital Sign Monitoring: An Affordable Telehealth Solution. *Telehealth and Medicine Today,* Volume 10, p. 611.

Kumar, S., 2025. *Agile Development Models - Software Engineering.* [Online] Available at: https://www.geeksforgeeks.org/software-engineering/software-engineering-agile-development-models/ [Accessed 22 January 2026].

Kumar, S., 2026. *Waterfall Model - Software Engineering.* [Online]

Available : https://www.geeksforgeeks.org/software-engineering/waterfall-model/[Accessed 21 January 2026].

Kurian, N. C. et al., 2023. Robust Semi-Supervised Learning for Histopathology Images Through Self-Supervision Guided Out-of-Distribution Scoring. *IEEE Xplore.*

Lambrechts, L., Scott, T. W., Gubler, D. J. & Halstead, S. B., 2010. Consequences of the Expanding Global Distribution of Aedes albopictus for Dengue Virus Transmission. *PLoS Neglected Tropical Diseases,* 25 May, 4(5), p. e646.

Lee, D.-H., n.d. [Online] Available at: https://www.researchgate.net/publication/280581078_Pseudo-Label_The_Simple_and_Efficient_Semi-Supervised_Learning_Method_for_Deep_Neural_Networks

Majeed, M. A., Mohd, Z., Zulkafli, Z. & Wayayok, A., 2023. A Deep Learning Approach for Dengue Fever Prediction in Malaysia Using LSTM with Spatial Attention. *International Journal of Environmental Research and Public Health,* 20(5), p. 4130.

MathWorks, 2026. *ThingSpeak Documentation.* [Online] Available at: https://www.mathworks.com/help/thingspeak/

Mazhar, B. et al., 2024. Development of Data-driven Machine Learning Models and their Potential Role in Predicting Dengue outbreak. *Journal of Vector Borne Diseases,* 16 January. pp 503-514.

Michard, F. & Saugel, B., 2024. New sensors for the early detection of clinical deterioration on general wards and beyond - a clinician's perspective. *Journal of Clinical Monitoring and Computing,* 39(2), pp. 435-442.

Mingxing Tan, Q. V. L., n.d. [Online] Available at: https://arxiv.org/abs/1905.11946

Mohamed A. Kassem, 2021. Machine Learning and Deep Learning Methods for Skin Lesion Classification and Diagnosis: A Systematic Review. *MDI.*

Muhammad Danish Ali, 2025. Explainable AI-Based Multi-Class Skin Cancer Detection Enhanced by Meta-Learning with Generative DDPM Data Augmentation. *MDPI.*

Nandani, E. J. K. P. & Bandara, A. M. D. P., 2025. Forecasting Dengue Outbreaks in Kalutara District using Hybrid Machine Learning Techniques. *Journal of Science of the University of Kelaniya,* 18(2), pp. 145-152.

ntfy.sh, 2026. *ntfy.sh.* [Online] Available at: https://ntfy.sh/

Ong, S. Q. et al., 2023. Predicting dengue transmission rates by comparing different machine learning models with vector indices and meteorological data. *Scientific Reports,* 13(1).

Phelan, H., Yates, V. & Lillie, E., 2022. Challenges in healthcare delivery in low- and middle-income countries. *Anaesthesia and Intensive Care Medicine,* 23(8), p. 501–504.

Rahman, S. Z., Senthil, R., Ramalingam, V. & Gopal, R., 2023. Predicting Infectious Disease Outbreaks with Machine Learning and Epidemiological Data. *Journal of Advanced Zoology,* 44(S-4), p. 110:121 .

Rahulan, K., Ranagala, R. M. & Roshan, G. P., 2024. Dengue Outbreak Control and Prevention: A Case Study of Gampaha District, Sri Lanka. *Sri Lankan Journal of Medical Administration,* 25(1), pp. 46-53.

Ramprasaath R. Selvaraju, M. C. A. D. R. V. D. P. D. B., n.d. [Online] Available at: https://arxiv.org/abs/1610.02391

Ranwala, L., Wedisinghe, Y., Perera, S. & Jayamanne, D., 2021. Real-time laboratory surveillance of Dengue antigen (NS1) - Best proposed early warning and response system for Dengue in Sri Lanka? - Results from a pilot study. *Ceylon Medical Journal,* 27 12, 66(3), p. 121.

Riedl, René & Oettl, Christian & Stangl, Fabian & Hevner, Alan., 2025. *How an Agile Software Process Increases Developers' Job Satisfaction: A Stress Perspective Based on the Effort-Reward-Imbalance Model.* [Online] Available at: https://www.researchgate.net/publication/388232797_How_an_Agile_Software_Process_Increases_Developers'_Job_Satisfaction_A_Stress_Perspective_Based_on_the_Effort-Reward-Imbalance_Model [Accessed 20 5 2026].

Rietze, Sarah & Zacher, Hannes., 2023. *Agile work practices: opportunities and risks for occupational well-being..* [Online] Available at:https://www.researchgate.net/publication/374921519_Agile_work_practices_opportunities_and_risks_for_occupational_well-being [Accessed 18 5 2026].

Rosi, A. et al., 2026. Real-Time Mosquito Breeding Site Detection Using a Quantized YOLOv8-Tiny Model on an FPGA-Based Drone Platform. *EAI Endorsed Transactions on Internet of Things,* Volume 11.

Sahu, H., Kashyap, R. & Dewangan, B. K., n.d. Hybrid deep learning-based semi-supervised model for Medical Imaging. *ieeexplore.*

Sharafaddini, A. M. & Mansouri, N., 2024. Enhanced Skin Cancer Classification Using Deep Learning and Gradient Boosting Techniques. *IEEE Xplore.*

Shaswat, T., 2024. Role of Big Data and IoT in Optimizing Post-Harvest Management. *International Journal of Research Publication and Reviews,* October, 5(10), p. 3.

S. K. et al., 2018. IoT-Based Monitoring and Control for Vegetables and Fruits Storage. *International Journal of Advance Research, Ideas and Innovations in Engineering (IJARIIE),* 4(2), p. 5.

Tissera, H. A. et al., 2020. Severe Dengue Epidemic, Sri Lanka. *www.nc.cdc.gov,* 26(4).

Tuan, D. A. & Dang, T. N., 2024. Leveraging Climate Data for Dengue Forecasting in Ba Ria Vung Tau Province, Vietnam: An Advanced Machine Learning Approach. *Tropical Medicine and Infectious Disease,* 9(10), p. 250.

Uduwanage, H. U. et al., 2025. Prediction of Dengue Outbreaks in Sri Lanka Using Machine Learning Techniques. *Sri Lanka Journal of Medicine,* 21 4, 34(1), pp. 15-26.

Verma, H., Chauhan, N. & Awasthi, K. L., 2023. A Comprehensive review of 'Internet of Healthcare Things': Networking aspects, technologies, services, applications, challenges, and security concerns. *Computer Science Review,* Volume 50.

Viviane, I. et al., 2023. IoT-Based Real-Time Crop Drying and Storage Monitoring System. *International Journal of Distributed Sensor Networks,* 26 September, Volume 2023, p. 11.

Vyas, H., Shukla, H. & Jivani, M. N., 2025. A Portable IoT-Based Health Monitoring Framework Using ESP32 for Isolated and Home-Based Patient Care. *Journal on Electronic and Automation Engineering,* 4(2), pp. 240-245.

Vyas, M. et al., 2019. Post-harvesting Onion Storage Methodology using IOT.pdf (Post-harvesting Onion Storage Methodology Using IOT). *International Journal of Advanced Research in Computer and Communication Engineering,* May.8(5).

Withanage, G. P., Viswakula, S. D., Nilmini Silva Gunawardena, Y. I. & Hapugoda, M. D., 2018. A forecasting model for dengue incidence in the District of Gampaha, Sri Lanka. *Parasites & Vectors,* 11(1).

Wokwi, 2024. *Wokwi: online electronics simulator.* [Online] Available at: https://wokwi.com

Wong, N., Jackson, V., & van der Hoek, A., 2023. *Mental Wellbeing at Work: Perspectives of Software Engineers.* [Online]
Available at: https://www.researchgate.net/publication/370180529_Mental_Wellbeing_at_Work_Perspectives_of_Software_Engineers
[Accessed 20 5 2026].

World Health Organization, 2013. *Pocket book of hospital care for children: guidelines for the management of common childhood illnesses.* 2 ed. s.l.:WHO.

Xu, J. et al., 2020. Forecast of Dengue Cases in 20 Chinese Cities Based on the Deep Learning Method. *International Journal of Environmental Research and Public Health,* 17(2), p. 453.

Yu, K. et al., 2024. Using UAV Images and Deep Learning in Investigating Potential Breeding Sites of Aedes albopictus. *Acta Tropica,* pp. 107234-107234.

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OP 04

A Scholarly Examination of AI-Empowered Robotic Innovations in Advancing Perceived Agronomic Efficiency in Eastern Sri Lanka.

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Abstract

AI robotics has emerged as an important technology for improving farming efficiency, resource utilization, and agricultural productivity by improving farming efficiency, resource utilization, and crop productivity. This study investigates the impact of Precision Irrigation (PI), Automated Harvesting (AH), and Energy Efficiency (EE) on perceived agricultural performance in the Eastern Province of Sri Lanka. A quantitative research approach was applied using structured questionnaires to collect data from farmers in selected agricultural areas. The collected data was analysed statistically to examine the relationship between AI adoption and perceived farming outcomes. The findings reveal that AI was associated with reduced labour dependency, minimized resource wastage, and improved perceived farming efficiency (FE). The study also highlights awareness, training, and accessibility as key factors influencing successful AI adoption in agriculture.

Keywords- *Agricultural Innovation, Digital Farming Solutions, Farm Productivity, Smart Agriculture, Sustainable Farming*

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Introduction

The twenty-first century has accelerated the adoption of Artificial Intelligence (AI) and robotics in agriculture, supporting the modernization of traditional farming into a more efficient and data-driven sector. AI technologies such as precision irrigation, automated harvesting, and energy-efficient systems enhance decision-making, reduce labour dependency, and minimize resource wastage, leading to improved agricultural productivity [1]. Global research further indicates that AI-based farming significantly increases farming efficiency and operational efficiency while supporting sustainable resource management practices [2].

While global literature extensively documents the macroeconomic benefits of smart agriculture, empirical research focusing specifically on resource-constrained smallholder farmers in developing regions-particularly the Eastern Province of Sri Lanka-remains highly scarce. This study addresses this critical gap by providing localized, empirical insights into how smallholders in post-conflict agricultural landscapes adopt and perceive these emerging technologies [3].

This study therefore examines the impact of Artificial Intelligence (AI) robotics-specifically Precision Irrigation (PI), Automated Harvesting (AH), and Energy Efficiency (EE)-on perceived Farming Efficiency (FE) among farmers in the Eastern Province of Sri Lanka. A quantitative research approach was adopted using structured questionnaires to statistically analyse the relationship between AI adoption and agricultural performance. The study is geographically limited to the Eastern Province and relies on survey-based data, which may restrict broader generalization. However, it provides focused empirical evidence on how AI robotics contributes to improving agricultural efficiency and promoting sustainable farming practices in Sri Lanka [4].

Methods

This study adopted a quantitative research design under a positivist philosophy, focusing on objective measurement and statistical testing of relationships between AI robotics and farming outcomes in the Eastern Province of Sri Lanka. A deductive approach was used to test hypotheses using empirical data. The study followed a cross-sectional design to capture current farming conditions and AI adoption levels among farmers. According to [5,6], the research onion framework supports the selection of appropriate research philosophies, approaches, and strategies.

The study population consisted of paddy farmers in the Eastern Province (Batticaloa District focus), selected due to its strong agricultural base and varying levels of technology adoption.

A probability-based cluster sampling method was applied, dividing the Batticaloa District into key sub-divisions: Valachchenai, Eravur Town, Oddamavadi, and Araiyampathy. Out of a target sample size of 368 respondents calculated to represent the regional farming population, a final total of 180 completed and usable questionnaires were collected (yielding a response rate of 48.9%). While probability sampling was utilized, the study's geographic boundary is strictly confined to the Batticaloa District. This localized focus represents a limitation, as farming practices, soil characteristics, and digital infrastructure in Batticaloa may differ from other agricultural provinces in Sri Lanka, thus limiting direct generalizability. According to Bhandari [8], a population refers to the complete group being studied, while a sample is a subset selected from that population. Furthermore, McCombes [8] explains that probability sampling techniques help improve representativeness and reduce sampling bias.

Data were collected using a structured questionnaire distributed via Google Forms and field-based collection, ensuring accessibility and standardization. The instrument measured AI Robotics Components-Precision Irrigation (PI), Automated Harvesting (AH), and Energy Efficiency (EE)-and the dependent variable, Farming Efficiency (FE), using a five-point Likert scale. Primary data collection ensured direct, context-specific responses from farmers regarding AI usage, productivity changes, and adoption barriers. According to Hassan [9], structured data collection methods enable researchers to gather standardized information systematically and improve consistency across collected responses. Data analysis was conducted using statistical software. Descriptive statistics were used to summarize responses, while Cronbach's Alpha tested the reliability of constructs. KMO and Bartlett's Test confirmed sampling adequacy and validity.

The dependent variable, perceived Farming Efficiency (FE), was operationalized as a composite construct measuring farmers' self-reported improvements in operational speed, resource savings, and perceived farming efficiency increases. It is important to note that objective, physical agricultural productivity metrics (e.g., metric

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tons of rice harvested per acre, exact litters of water saved) were not directly measured due to regional logistical constraints. Instead, the study relies on the perceived evaluations of the active farming operators, and the conclusions are carefully framed around perceived operational efficiency rather than actual, physically measured crop productivity

Pearson correlation analysis assessed relationships between variables, while multiple linear regression was used to determine the association between AI components and perceived Farming Efficiency (FE). According to Middleton [10], reliability and validity ensure consistency, accuracy, and trustworthiness in research. Ethical standards were maintained through informed consent, anonymity, confidentiality, and voluntary participation.

Results

The demographic analysis showed that a total of 180 farmers participated in the study. The majority of respondents were aged between 31–35 years (32.8%), followed by those above 35 years (24.4%), 20–25 years (23.3%), and 26–30 years (19.4%), indicating representation across different age groups. In terms of gender, 53.3% were female and 46.7% were male, showing a balanced distribution. Farm size distribution indicated that most respondents operated between 4–6 acres (31.1%), followed by 4 acres (26.7%), 1–3 acres (23.3%), and less than 1 acre (18.9%). Experience levels varied, with 28.3% having more than 6 years, followed by less than 1 year (26.1%), and equal proportions in 1–3 years and 4–6 years (22.8%), reflecting diverse farming backgrounds.

Reliability and validity analysis confirmed that all measurement scales were statistically acceptable. Cronbach's Alpha values showed strong internal consistency for Energy Efficiency (α = 0.866), Precision Irrigation (α = 0.849), Automated Harvesting (α = 0.869), and Farming Efficiency (α = 0.894). KMO values exceeded the minimum threshold, with EE (0.728), PI (0.731), AH (0.734), and FE (0.878), while Bartlett's Test was significant (p = 0.000), confirming suitability for further statistical analysis. Descriptive statistics indicated moderate agreement across variables, with mean values for EE (3.1407), PI (3.0278), AH (3.0204), and FE (3.1043), suggesting a generally positive perception of AI-based farming technologies.

Correlation analysis revealed strong and significant positive relationships between all independent variables and farming efficiency. Precision Irrigation (r = 0.788) showed the strongest correlation, followed by Energy Efficiency (r = 0.777) and Automated Harvesting (r = 0.739), all significant at p = 0.000, indicating that improvements in AI-based systems are associated with higher farming efficiency.

Multiple linear regression analysis was executed to evaluate the joint association of Energy Efficiency (EE), Precision Irrigation (PI), and Automated Harvesting (AH) with perceived Farming Efficiency (FE). The model summary revealed an exceptionally strong positive linear relationship ($R = 0.938$) and confirmed that these three independent variables collectively account for 87.9% of the variance in perceived Farming Efficiency ($R^2 = 0.879$, Adjusted $R^2 = 0.877$). Analysis of Variance (ANOVA) verified the overall model fit as highly significant, yielding an F-statistic of 427.099 ($p < 0.001$).

Analysis of individual coefficients indicated that all three independent variables contribute positively and significantly to perceived Farming Efficiency ($p < 0.001$). Precision Irrigation demonstrated the strongest positive association with perceived Farming Efficiency ($B = 0.373$, $\beta = 0.435$, $t = 13.469$), followed by Automated Harvesting ($B = 0.286$, $\beta = 0.365$, $t = 11.580$) and Energy Efficiency ($B = 0.282$, $\beta = 0.344$, $t = 10.143$). These results support the rejection of all null hypotheses and the formal acceptance of alternative hypotheses H_1, H_2, and H_3 based on statistically significant regression coefficients ($p < 0.001$ for all variables) and strong positive correlations with the dependent variable ($r = 0.777$, $r = 0.788$, and $r = 0.739$, respectively). These statistical relationships are mathematically synthesized into the following combined multiple linear regression equation:

$$\mathrm{FE} = 0.224 + 0.282(\mathrm{EE}) + 0.373(\mathrm{PI}) + 0.286(\mathrm{AH}) + e$$

Discussion

This study examined the association between Artificial Intelligence (AI) robotics applications, specifically Energy Efficiency (EE), Precision Irrigation (PI), and Automated Harvesting (AH), on farming efficiency among farmers in the Eastern Province of Sri Lanka. The findings strongly support the main research objective, which aimed to establish the association between AI robotics applications and perceived Farming Efficiency (FE). The statistical

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analysis confirmed that AI-based technologies were collectively associated with higher perceived farming efficiency and operational efficiency in the region.

The first sub-research objective aimed to examine the relationship between Precision Irrigation (PI) and perceived farming efficiency. The findings confirmed that PI has a strong, positive, and statistically significant association with farming efficiency. This indicates that Respondents perceived precision irrigation systems to optimize water usage and reduce resource wastage, which is highly correlated with superior perceived operational performance. Because this study utilizes a cross-sectional survey design, these findings must be interpreted as statistical associations rather than definitive physical causal relationships.

The second sub-research objective focused on establishing the effect of Automated Harvesting (AH) on farming efficiency. The results revealed a strong positive relationship between AH and farming efficiency, while regression analysis confirmed a significant positive impact on agricultural productivity. These findings confirmed that automated harvesting technologies were positively associated with improved farming operations through reduced labour dependency, faster harvesting processes, and lower post-harvest losses. Based on the decision rule, the alternative hypothesis H3 was accepted, and the null hypothesis was rejected. Although the influence of AH was slightly lower than PI, the results still demonstrated that automated harvesting plays a major role in improving farming productivity and operational performance.

The third-sub research objective aimed to establish the effect of Energy Efficiency (EE) on farming efficiency among farmers in the Eastern Province. The findings showed a strong positive relationship between EE and farming efficiency. Statistical significance confirmed that AI robotics applications related to energy efficiency positively enhance farming efficiency. Therefore, the alternative hypothesis H1 was accepted, and the null hypothesis was rejected. The findings suggest that AI-based energy optimization systems were associated with improved sustainability and reduce operational costs associated with machinery and irrigation systems.

These findings align closely with broader agricultural trend lines documented across neighbouring developing economies [11]. Empirical investigations conducted within agrarian sectors in India and Bangladesh demonstrate that smallholder incorporation of micro-irrigation systems generates immediate enhancements in perceived crop resilience, moisture conservation, and overall water use efficiency [11,12].

Conversely, divergences emerge when comparing these regional adoption patterns with highly automated, capital-intensive smart agricultural systems observed in China, where substantial financial reserves enable comprehensive, large-scale deployments of autonomous robotic infrastructure. Within Batticaloa, smallholders demonstrate a significantly more selective integration trajectory, prioritizing accessible, resource-preserving methodologies such as Precision Irrigation (PI) over cost-prohibitive machinery like automated harvesters. This localized selectivity parallels structural shifts identified within Vietnam's Mekong Delta, where persistent constraints related to financial accessibility and technological literacy compel agrarian communities to adopt smart-farming technologies in phased stages. Consequently, initial reliance is placed upon immediate resource-saving systems prior to undertaking capital commitments toward advanced agricultural robotics [13].

To transition empirical findings into sustainable field-level practices, targeted multi-stakeholder interventions are required. First, state-sponsored agricultural extension services should collaborate with regional educational institutions, including Eastern University and ESOFT Metro Campus, to establish structured, hands-on technical capacity-building programs. These initiatives must focus on operating smart sensor networks, troubleshooting automated machinery, and interpreting data analytics, thereby enabling smallholders to manage basic Internet of Things (IoT) and robotic configurations independently. In tandem with technical training, specialized financial frameworks are essential to offset the capital-intensive nature of automated harvesting machinery and precision sensors. The Sri Lankan government, in coordination with rural development banks, must design supportive financial mechanisms-such as low-interest credit lines, customized micro-leasing options, and direct capital subsidies-to reduce upfront procurement costs for resource-constrained farming communities.

Furthermore, digital infrastructure upgrades are crucial because real-time precision irrigation and smart farming systems depend on uninterrupted data transmission. Public telecommunication authorities and private network providers must cooperate to enhance cellular networks in rural cultivation zones, as expanding high-speed, low-latency mobile connectivity, specifically fourth generation (4G) and fifth generation (5G) networks, is vital to support cloud-based aggrotech applications during active field operations. Finally, joint ventures between aggrotech enterprises, government departments, and university research facilities can accelerate localized

technology development. Establishing regional machinery-sharing cooperatives allows smallholders to rent high-end robotic equipment on a rotating schedule, which maximizes resource access while preventing long-term individual debt accumulation.

Conclusion

This study evaluated the impact of Artificial Intelligence (AI) robotics-specifically Energy Efficiency (EE), Precision Irrigation (PI), and Automated Harvesting (AH)-on perceived farming efficiency (FE) in the Eastern Province of Sri Lanka. The empirical evidence confirms that these technologies exert a strong, statistically significant positive effect on perceived farming efficiency, thereby supporting all proposed hypotheses. Multiple linear regression analysis revealed that Precision Irrigation is the most influential driver of operational efficiency, followed closely by Automated Harvesting and Energy Efficiency. The results demonstrate that integrated implementation of these technologies functions most effectively as a unified system, enhancing agricultural decision-making and resource management simultaneously.

Broadly, the research demonstrates that AI robotics was significantly associated with the transformation of traditional smallholder farming into more efficient, productive, and sustainable systems traditional smallholder farming into highly efficient, productive, and sustainable systems. These findings offer localized empirical support to assist agricultural policymakers, aggrotech developers, and local stakeholders in driving technological modernization in the Eastern Province. The positive associations observed indicate that shifting toward smart farming solutions can mitigate labour constraints, lower operational expenses, and optimize resource allocation in developing agricultural economies.

Despite these contributions, the geographical restriction to the Batticaloa District represents a limitation, necessitating caution when generalizing findings to other agricultural regions with distinct climatic conditions. Furthermore, because data collection relied on cross-sectional, perception-based survey responses, future research must incorporate objective parameters such as objectively measured agricultural performance indicators, including crop yield, water consumption, pesticide usage, production costs, and cost–benefit analysis, water consumption metrics, and cost-benefit evaluations. Prospective investigations should also explore advanced technologies like drone-assisted imaging, autonomous tractors, and computer vision, utilizing longitudinal designs to transition from statistical associations to definitive causal assessments of smart agriculture.

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References

[1] Timoshenko I. Agricultural Robots: Farming Smarter, Not Harder. 2023. Available from: https://aiforgood.itu.int/agricultural-robots-farming-smarter-not-harder/ [Accessed 10 June 2025].

[2] Verbitskaya T. Integrating AI in Agriculture for Enhanced Efficiency and Productivity. 2024. Available from: https://keymakr.com/blog/the-future-of-farming-integrating-ai-in-agriculture-for-enhanced-efficiency-and-productivity/ [Accessed 4 June 2025].

[3] Basa R. AI in Agriculture: Revolutionizing Precision Farming and Sustainable Crop Management. Int J Sci Res Comput Sci Eng Inf Technol. 2024;10(5):535–543.

[4] Gangwani N. AI-Driven Precision Agriculture: Optimizing Crop Yield and Resource Efficiency. Int J Multidiscip Res. 2024;6(6):0–9.

[5] David P, Kerryn W. Saunders' Research Onion: Explained Simply. 2021. Available from: https://gradcoach.com/saunders-research-onion/ [Accessed 20 June 2025].

[6] Writers 1. Understanding the Research Onion. 2020. Available from: https://15writers.com/research-onion/ [Accessed 20 June 2025].

[7] Bhandari P. Population vs sample: what's the difference? 2020. Available from: https://www.scribbr.com/methodology/population-vs-sample/ [Accessed 22 June 2025].

[8] McCombes S. Sampling Methods | Types, Techniques & Examples. 2023. Available from: https://www.scribbr.com/methodology/sampling-methods/ [Accessed 22 June 2025].

[9] Hassan M. Data Collection - Methods and Examples. 2024. Available from: https://researchmethod.net/data-collection/ [Accessed 20 June 2025].

[10] Middleton F. Reliability vs validity in research. 2025. Available from: https://www.scribbr.com/methodology/reliability-vs-validity/ [Accessed 22 June 2025].

[11] Lakhiar IA, Yan H, Zhang C, Wang G, He B, Hao B, et al. A Review of Precision Irrigation Water-Saving Technology under Changing Climate for Enhancing Water Use Efficiency, Crop Yield, and Environmental Footprints. *Agriculture*. 2024;14(7):1141.

[12] Akter S, Mostafizar Rahman M, Zannat R, Rana MM, Hossain Oliver MM, Ali MA. Development of smart micro-irrigation system using Arduino Uno for okra cultivation in Bangladesh. *Res Agric Eng*. 2025;71(1):38-49.

[13] Nguyen XT. Applications of artificial intelligence and advanced technologies in agricultural productivity and sustainable development in Vietnam. *HPU2 J Sci Nat Sci Technol*.

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OP 05

The impact of Artificial Intelligence applications on irrigation and water management Special case to Farmers in Sri Lanka (Eastern Province)

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Abstract

The research is an in-depth examination of the effects of the application of Artificial Intelligence (AI) in the irrigation and water management of farmers in the Eastern Province of Sri Lanka. The information has been gathered directly from the farmers to assess the effectiveness of real-time monitoring technologies and AI-based irrigation scheduling and advanced machine learning models to enhance the use of water in agriculture. The paper has shown that these AI-powered technologies allow irrigation in the most accurate way possible, as users constantly evaluate the moisture levels of the soil and weather conditions, allowing them to achieve better water savings and more productive crops, as well as sustainable farming. Through these new technologies, farmers will be well adapted to water shortages and even climate change, thereby making their agricultural productivity and efficiency of using resources much higher. The study emphasizes the potential revolutionary nature of AI in assisting small-scale farmers to optimize irrigation arrangements, reduce the amount of wasted water, and guarantee food security in the area, which will lead to the larger objective of sustainable food production and environmental management.

Keywords: *Artificial Intelligence, Water Management, Water Waste Management, Real-Time Monitoring, AI-Based Irrigation Scheduling, Machine Learning Models*

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Introduction

Professionally designed questionnaires will be distributed to study participants to collect primary data. This study adopts a quantitative research method using a mono-method strategy. Sampling techniques will be used to identify participants, and the collected data will be analysed to answer the research questions. Eighty percent of Sri Lanka's annual food production is contributed by 1.65 million smallholder farmers, each cultivating an average land area of two hectares [1], [2]. The Eastern Province was selected as the study area because agriculture is a major economic activity in the region, and it represents an appropriate setting for examining AI adoption in irrigation and water management. The study follows a deductive research methodology, beginning with general theories for testing and validation.

Traditional water management systems are often inefficient in resource allocation, resulting in increasing water wastage globally. In Sri Lanka, particularly in the Eastern Province, effective water management is essential for agricultural activities. Major challenges include inefficient irrigation methods, limited adoption of artificial intelligence (AI), and water scarcity during dry seasons. The lack of connected systems and real-time monitoring platforms has slowed AI adoption, affecting effective resource allocation and decision-making. The increasing demand for water, especially for agricultural irrigation, highlights the need for AI-enhanced water management systems to reduce wastage and improve distribution efficiency [3].

Although AI-based irrigation technologies have significant potential to improve agricultural water management, their adoption among Sri Lankan farmers remains limited. Existing research has mainly focused on AI technical capabilities, while limited empirical evidence exists on the actual impact of AI adoption on irrigation and water management practices among smallholder farmers, particularly in the Eastern Province. Factors such as technological awareness, affordability, infrastructure availability, and farmers' ability to integrate AI solutions remain insufficiently explored. Therefore, this study aims to investigate the impact of AI applications on irrigation and water management among farmers in Sri Lanka's Eastern Province.

Methods

Utilizing a quantitative research methodology, this study investigates how artificial intelligence (AI) applications affect irrigation and water management among farmers in Sri Lanka's Eastern Province. To examine hypotheses derived from current theories and prior research findings, the study employs the positivist philosophy and deductive method. Using expertly created questions, a survey approach is employed to gather primary data from farmers. Consistency, dependability, and precise statistical analysis of the gathered data are guaranteed by the mono-method quantitative approach [4],[5]. The study focuses on how AI technologies improve water distribution in agricultural operations, decrease water waste, and increase irrigation efficiency. To investigate the connection between AI applications and efficient water management strategies, participants are chosen using suitable sampling techniques, and the data gathered is statistically examined. Data is gathered from respondents at a specific moment in time as part of the study's cross-sectional time frame. Water scarcity, inefficient irrigation techniques, and a low uptake of cutting-edge agricultural technologies are some of the problems Sri Lanka, particularly the Eastern Province, faces. Inefficient resource allocation and increasing water waste are common outcomes of traditional water management systems. Effective decision-making in irrigation management is further hampered by the absence of connected platforms and real-time monitoring systems. This, this study investigates the premise that AI applications have a favourable impact on farmers' irrigation and water management practices in Sri Lanka's Eastern Province. The results are anticipated to promote the adoption of AI-based agricultural solutions and sustainable agricultural development [6].

Results

The study's findings show a strong statistical correlation between farmers' water management practices in Sri Lanka's Eastern Province and AI-based technology. Mixed internal consistency across variables is revealed by the reliability analysis. While Water Management ($\alpha = 0.473$) and Machine Learning Models ($\alpha = 0.444$) fall below the acceptable level, showing lower internal consistency, Real-Time Monitoring ($\alpha = 0.555$) and AI-Based Irrigation Scheduling ($\alpha = 0.595$) show considerable dependability. Although the reliability values for Machine Learning Models ($\alpha = 0.444$) and Water Management ($\alpha = 0.473$) were below the generally accepted threshold, this should be acknowledged as a limitation of the present study because it indicates

limited internal consistency of the measurement scales. Future research should refine the questionnaire items or adopt previously validated measurement instruments to improve reliability. All variables are statistically significant ($p < 0.001$), according to validity results. KMO values range from 0.559 to 0.681, indicating moderate

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sampling adequacy and factor analysis suitability. All constructs have low mean values (RM = 2.12, AIS = 2.24, ML = 2.18, WM = 2.08) according to descriptive statistics, suggesting that respondents' use of AI technologies is limited, and their water management techniques are comparatively inefficient [7], [8]. The concentration of reactions toward lower scale levels is further confirmed by positive skewness values. The results of the K-S and S-W normality tests show that all variables have significance values less than 0.05, indicating that the data are not normally distributed. Significant positive correlations between Real-Time Monitoring and Water Management (r = 0.583), AI-Based Irrigation Scheduling (r = 0.429), and Machine Learning Models (r = 0.470) are revealed by correlation analysis, underscoring the beneficial function of AI in enhancing water management. According to regression analysis, the model accounts for 35.3% of the variation in water management (R2 = 0.353). Model significance is confirmed by ANOVA results (F = 16.753, $p < 0.001$). Only Real-Time Monitoring, however, has a significant predictive influence on Water Management ($\beta = 0.491$, $p = 0.018$); the other factors do not.

Discussion

To determine the impact of Real-Time Monitoring, AI-Based Irrigation Scheduling, and Machine Learning Models on Water Management

The coefficient analysis further revealed that Real-Time Monitoring showed a positive and statistically significant association with water management. with a regression coefficient value of B = 0.581 and p = 0.000. This finding suggested that real-time monitoring technologies improved water management efficiency through continuous observation and timely decision-making. However, AI-Based Irrigation Scheduling (B = -0.009, p = 0.943) and Machine Learning Models (B =0.147, p = 0.197) did not show statistically significant effects. A possible explanation for these findings is that farmers in the study area may have limited access to advanced AI-based irrigation systems and machine learning applications, or they may not possess sufficient technical knowledge and training to effectively utilize these technologies. In addition, inadequate digital infrastructure, high implementation costs, and the relatively low level of AI adoption among small-scale farmers in the Eastern Province may have reduced the practical effectiveness of these technologies. Similar findings have been reported in previous studies, which indicate that the benefits of AI-based irrigation scheduling and machine learning models depend on factors such as technological readiness, infrastructure availability, data quality, and user capability rather than the technology alone. Therefore, although these technologies have demonstrated positive outcomes in other agricultural contexts, their impact was not statistically significant in the present study. Consequently, the study concluded that Real-Time Monitoring was the most influential factor in improving water management, whereas the contributions of AI-Based Irrigation Scheduling and Machine Learning Models were not statistically significant within the context of this study. Even though AI applications help increase irrigation efficiency, only 35.3% of the variation in water management can be explained by the regression model ($R^2 = 0.353$). This suggests that water management techniques may also be influenced by other elements, such as farmers' experience, irrigation infrastructure, weather patterns, and governmental backing. Consequently, it is important to recognize the model's poor explanatory ability as a study drawback.

Since this study employed a cross-sectional survey design, the findings indicate statistically significant associations rather than direct causal relationships between AI technologies and water management outcomes. Similar findings have been reported in previous studies conducted in developing countries, where Real-Time Monitoring technologies have significantly improved irrigation efficiency, while the effectiveness of AI-Based Irrigation Scheduling and Machine Learning applications has been limited by inadequate digital infrastructure, insufficient technical expertise, and the low adoption of AI technologies among smallholder farmers. These findings suggest that the challenges identified in Sri Lanka are consistent with broader trends observed across developing countries rather than being unique to the Eastern Province.

Conclusion

The study provides evidence of a positive association between artificial intelligence applications and irrigation and water management practices among farmers in Sri Lanka's Eastern Province. AI technologies assist in optimizing water usage, increase agricultural output, and promote sustainable farming by delivering reliable decision-making data. Farmers can use equipment like automated irrigation systems, soil moisture monitors, and weather forecasting to better manage water resources and reduce waste. However, the study emphasizes the need for sufficient training, infrastructure, and awareness in ensuring the successful implementation of AI in rural areas. Overall, the use of AI in agriculture helps to ensure sustainable water management, increased efficiency, and long-term agricultural development in Eastern Province. Also, investigates the influence of Artificial Intelligence (AI)

applications on irrigation and water management for farmers in Eastern Province. According to research, AI technologies enhance water efficiency, crop output, and agricultural decision-making, but there are still constraints such as cost and technical knowledge. Structured surveys were used to collect data from farmers, which were then evaluated to find the benefits, limitations, and adoption trends of AI.

Moreover, the results indicate that government organizations, agricultural extension services, and technology companies should work together to encourage smallholder farmers in the Eastern Province to implement AI-based irrigation systems more widely. Farmers' knowledge, confidence, and capacity to use these technologies efficiently can be enhanced by offering technical training programs, financial support, and reasonably priced AI-based solutions. The successful adoption of AI applications for sustainable water management and agricultural development can be supported by such cooperative initiatives, which can remove current obstacles pertaining to cost, technical expertise, and awareness. As a way to assess the usefulness of AI-enabled irrigation systems in actual farming environments, future research could combine survey-based techniques with field tests. To give more solid empirical data about the role of AI technology in sustainable agricultural water management, such studies should include objective metrics like crop output, irrigation efficiency, water usage records, and economic returns.

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References

[1] Abioye, E. A. et al., 2022. Precision Irrigation Management Using Machine Learning and Digital Farming Solutions. *AgriEngineering,* 4(1), pp. 70-103.

[2] Administration, I. T., 2021. Sri Lanka Country Commercial Guide. *International Trade Administration,* p. 01.

[3] Aggarwal, C., 2023. *Primary Data Collection Methods: Meaning and Techniques.* [Online] Available at: https://www.shiksha.com/online-courses/articles/primary-data-collection-methods-meaning-and-techniques/ [Accessed 26 July 2025].

[4] Ahmed, Z. et al., 2023. An Overview of Smart Irrigation Management for Improving Water Productivity under Climate Change in Drylands. *Agronomy,* pp. 1-22.

[5] Alamgeer, Z., 2023. *The innovidea.* [Online] Available at: https://theinnovidea.com/understanding-research-onion-for-research-methodology/ [Accessed 20 July 2025].

[6] Alvim, S. J. T. et al., 2020. APPLICATION OF ARTIFICIAL INTELLIGENCE FOR IRRIGATION MANAGEMENT: A SYSTEMATIC REVIEW. *Artificial Intelligence in agriculture in Agriculture.*

[7] Ahmed, Z. et al., 2023. An Overview of Smart Irrigation Management for Improving Water Productivity under Climate Change in Drylands. *Agronomy,* 13(08), p. 2113.

[8] krishnan, S. r. et al., 2022. Smart Water Resource Management Using Artificial Intelligence—A Review. Sustainability, 14(20), p. 13384.

[9] Lakhiar, I. A. et al., 2024. A Review of Precision Irrigation Water-Saving Technology under Changing Climate for Enhancing Water Use Efficiency, Crop Yield, and Environmental Footprints. Multidisciplinary Digital Publishing Institute, 14(7), pp. 1141-1141.

[10] Elbasi, E. M. N. A. Z. Z. A. C. E. V. G. S. A. T. A. A. W. M. S. a. Z. C., 2023. Artificial Intelligence Technology in the Agricultural Sector: A Systematic Literature Review. IEEE Access, Volume 11, pp. 171-202.

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OP 06

Towards an Intelligent AI-Assisted Ecosystem for Software Development Organizations: A Conceptual Framework

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Abstract

Background: Software development organizations increasingly face operational complexity, fragmented workflows, inefficient project coordination, repetitive documentation processes, and communication gaps across software engineering activities. Although artificial intelligence (AI) has significantly advanced in coding assistance and workflow automation, current AI solutions remain fragmented and primarily focus on isolated technical tasks, providing limited support for broader organizational operations.

Objectives: This study aims to propose a conceptual framework for an intelligent AI-assisted ecosystem capable of supporting software development organizations through integrated operational intelligence, software engineering assistance, workflow optimization, and organizational decision-making, and to position this framework relative to existing AI-enabled development platforms.

Methods: This study adopted a conceptual and qualitative research approach based on literature-driven analysis. Recent studies related to artificial intelligence, software engineering, workflow automation, and intelligent organizational support systems were reviewed to identify operational limitations, existing research gaps, and potential AI integration opportunities within software development environments. An exploratory preliminary survey of 15 software professionals was conducted to gather early industry perspective on the proposed framework.

Results: The study developed a conceptual AI-assisted ecosystem framework consisting of seven intelligent modules: Requirement Intelligence, Project Coordination Intelligence, Documentation Intelligence, Software Engineering Assistance, Communication Intelligence, Risk Prediction and Decision Support, and an Organizational Intelligence Dashboard. The framework integrates fragmented software development workflows into a unified AI-driven ecosystem and extends beyond existing point-solution AI tools by coordinating information across organizational and technical layers.

Conclusions: The proposed framework contributes to the advancement of AI-assisted software engineering by introducing a broader organizational intelligence model beyond isolated technical automation. It establishes a foundational architecture whose anticipated productivity and coordination benefits require validation through future prototype implementation and experimental evaluation.

Keywords: *AI-assisted ecosystem, software development organizations, project coordination intelligence, organizational intelligence, conceptual framework*

Introduction

The rapid growth of the software industry has significantly transformed the operational structure of modern software development organizations [8,9]. Software companies are increasingly involved in diverse activities such as web application development, website management, custom software engineering, cloud-based service delivery, and continuous client support operations. As software projects become more complex and client expectations continue to evolve [8,9], software development organizations are required to manage multiple interconnected workflows including requirement analysis, project coordination, software design, development, testing, documentation, deployment, and stakeholder communication. Consequently, maintaining operational efficiency, project quality, and timely software delivery has become a major challenge for many software development organizations operating in highly competitive technological environments.

Despite the availability of numerous software development and project management platforms, many software organizations continue to experience operational inefficiencies throughout the software development lifecycle. Common challenges include unclear requirement gathering, fragmented communication between stakeholders and development teams, repetitive documentation processes, ineffective project coordination, inaccurate effort estimation, delayed risk identification, and inefficient resource allocation. Software development organizations often rely on multiple disconnected tools for project management, communication, documentation, software development, and organizational coordination, resulting in workflow fragmentation and reduced operational visibility. These issues can negatively affect software quality, development speed, client satisfaction, and organizational productivity [15].

In recent years, artificial intelligence (AI) technologies have rapidly evolved and become increasingly integrated into software engineering environments [1,4,5]. Modern AI-powered systems can assist activities such as code generation, automated testing, debugging, content generation, and workflow automation [2,3,5]. The emergence of generative artificial intelligence and large language models (LLMs) has further accelerated interest in intelligent software engineering assistance systems [1,3,4]. Most existing AI solutions primarily focus on isolated technical activities such as coding assistance or simple automation tasks rather than providing comprehensive organizational intelligence support across the broader software development ecosystem. As a result, many software development organizations still heavily depend on manual coordination, human-driven decision-making, and fragmented operational management practices.

Positioning Relative to Existing AI-Enabled Platforms

A range of AI-enabled tools already operate within software organizations, but each addresses a narrow slice of the development lifecycle. GitHub Copilot and Cursor AI function primarily as in-editor coding assistants, generating and refactoring code from natural-language prompts but offering no visibility into project coordination, requirement management, or organizational reporting. Devin AI extends this further by acting as a semi-autonomous coding agent capable of completing bounded engineering tasks, yet it remains scoped to implementation work rather than the surrounding managerial and communication activities of a software organization. On the project-management side, Jira AI (Atlassian's Rovo-based assistant) and the AI features embedded in Azure DevOps apply generative capabilities to ticket summarization, backlog grooming, and work-item suggestions, but operate as add-ons to existing static workflow tools [14,15] rather than as an integrated intelligence layer spanning requirements, documentation, communication, and risk.

Existing project management and software engineering platforms such as Jira, Trello, and other collaboration tools mainly function as static workflow management systems with limited contextual intelligence and adaptive decision-making capabilities [14,15]. Even where generative AI has been layered onto these platforms, each AI capability typically remains confined to its host tool: a coding assistant does not inform sprint planning, and a ticket-summarization assistant does not feed into technical documentation or client communication. The proposed ecosystem differs from these tools in three respects: (i) it treats requirement intelligence, coordination, documentation, engineering assistance, communication, risk prediction, and organizational reporting as interdependent modules that share information rather than operate in isolation; (ii) it introduces predictive, organization-level analytics (workflow bottleneck detection, risk forecasting) that individual point tools do not provide; and (iii) it is designed around a continuous information flow from client requirement to organizational dashboard, rather than around a single task boundary such as code completion or ticket triage. Therefore, there remains a significant research gap in the development of unified intelligent AI-assisted ecosystems capable of supporting software development organizations through integrated project coordination, requirement analysis, communication management, software engineering assistance, documentation generation, workflow optimization, and organizational decision support functionalities.

Therefore, this research proposes a conceptual framework for an intelligent AI-assisted ecosystem designed for software development organizations. The proposed framework aims to integrate multiple AI-driven organizational and software engineering support capabilities within a unified intelligent environment to improve operational

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efficiency, project coordination, software development processes, and organizational decision-making activities. The study aims to establish a foundational conceptual architecture that can support future research, implementation, and development of advanced AI-powered organizational intelligence systems for software development environments.

Methods

This research adopted a conceptual and qualitative research approach based on literature-driven analysis [7] to investigate the potential development of an intelligent AI-assisted ecosystem for software development organizations. The study primarily focused on identifying operational, managerial, and software engineering challenges commonly experienced within modern software development environments and analysing how artificial intelligence technologies can be integrated to address these challenges through a unified intelligent ecosystem framework.

The research methodology involved reviewing recent academic literature, industry reports, conference publications, and existing AI-assisted software engineering studies related to artificial intelligence, software project management, organizational intelligence, workflow automation, software engineering assistance, and intelligent decision-support systems [5,6]. The literature selection process mainly emphasized recent studies discussing artificial intelligence applications in software engineering environments, operational workflow optimization, generative AI technologies, intelligent automation systems, and AI-driven organizational support mechanisms [10,11,12].

The study analyzed the limitations of existing software development management tools and AI-assisted systems currently used within software organizations. Particular attention was given to identifying workflow fragmentation issues, disconnected operational platforms, communication inefficiencies, repetitive management activities, and insufficient contextual intelligence within existing solutions. Based on the identified research gaps and operational limitations, the study developed a conceptual AI-assisted ecosystem framework integrating multiple intelligent organizational and software engineering support functionalities within a unified environment.

Preliminary Exploratory Survey

In addition to the literature-driven conceptual analysis, a small-scale, preliminary exploratory survey was conducted to gather early industry perspective on the practical relevance of the proposed AI-assisted ecosystem framework. The survey is exploratory in nature and is not intended as empirical validation of the framework; rather, it provides indicative feedback that motivates future, larger-scale evaluation.

The survey involved 15 software professionals from three software development organizations: Futuonz, VenomX Technology, and MindTechera, with five participants selected from each organization. Participants were selected using purposive (convenience) sampling based on their direct professional involvement in software project execution; the sample therefore reflects the practices of three related organizations rather than the broader software industry, and the results should not be generalized beyond this exploratory context.

The questionnaire was developed from the themes identified in the literature review: workflow fragmentation, requirement management, documentation burden, communication efficiency, limitations of existing AI tools, and demand for predictive and integrated AI support and consisted of ten Likert-scale (1–5 agreement) questions and one open-ended question. Item wording was reviewed for clarity by two independent software professionals prior to distribution, and the questionnaire was piloted with one respondent from each participating organization to confirm question comprehensibility before full distribution. Responses were collected anonymously to reduce social-desirability bias. The collected responses were analyzed using descriptive statistical techniques, including frequency distribution and percentage analysis.

Given the small sample size (n = 15) and the fact that all participants were drawn from three organizations with an existing relationship to the author, the survey results are reported strictly as exploratory indicators of practitioner sentiment and are explicitly not presented as statistical validation of the conceptual framework. This limitation is discussed further in Section 4.4.

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Results

The findings of this study resulted in the development of a conceptual AI-assisted ecosystem framework designed to support software development organizations through integrated operational, managerial, and software engineering intelligence. Based on the literature analysis and identified operational limitations of existing tools [5,6], the proposed framework consists of seven core intelligent modules, each addressing a specific functional area within software development environments.

A preliminary exploratory survey was conducted among 15 software professionals to gather early indicative feedback on the practical relevance of the proposed AI-assisted ecosystem framework; these figures should be read as directional signals from a small, purposively sampled group rather than as generalizable statistics. The responses revealed that 67% of participants agreed that software development workflows are fragmented across multiple tools and platforms. 87% agreed that requirement gathering remains a major challenge in software projects, while another 87% reported that documentation activities consume significant time during project execution.

80% of participants confirmed that communication gaps negatively affect software project efficiency, and 73% agreed that current software project management tools provide limited intelligent decision-making support. A notable 93% indicated that current AI tools primarily focus on coding and offer limited broader organizational support.

The largest share of agreement was observed for the integrated ecosystem concept, where 93% of respondents agreed that a unified AI-assisted ecosystem combining project management, documentation, communication, and software engineering support would significantly improve organizational productivity. 93% agreed that AI-driven organizational intelligence could improve software delivery quality and efficiency, while 87% expressed willingness to adopt such a system within their organizations. As an exploratory sample of 15 respondents from three affiliated organizations, these figures indicate encouraging early sentiment rather than confirmed effect sizes.

Table 1. Preliminary Exploratory Survey Results (n = 15)

Question Area	**Agreement Percentage**
Workflow Fragmentation	67%
Requirement Challenges	87%
Documentation Burden	87%
Communication Gaps	80%
Limited Tool Intelligence	73%
AI Focused Only on Coding	93%
Need for Predictive AI	93%
Need for Integrated AI Ecosystem	93%
AI Improves Delivery Quality	93%
Willingness to Adopt	87%

Framework Modules and Underlying AI Technologies

Figure 1 (below) presents the proposed conceptual framework and the sequential and feedback interactions between its seven modules. Client requirements enter the ecosystem through the Requirement Intelligence Module and flow downstream through Project Coordination, Documentation, Software Engineering Assistance, and Communication Intelligence; each downstream module also returns status and risk signals upstream (e.g., a detected code or testing issue in Software Engineering Assistance can trigger a re-estimation in Project Coordination), and all modules feed the Organizational Intelligence Dashboard, which aggregates cross-module

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signals for management-level decision-making. This bidirectional flow — rather than a single one-way pipeline is what allows the ecosystem to support proactive risk detection instead of only downstream reporting.

The first module, Requirement Intelligence, focuses on analyzing client requirements, generating user stories, identifying requirement ambiguities, and detecting missing functional specifications. It would draw primarily on large language models (LLMs) for natural-language understanding and retrieval-augmented generation (RAG) to ground requirement clarification in prior project documentation, improving requirement clarity and reducing misunderstandings during the initial stages of software development.

The second module, Project Coordination Intelligence, supports project planning, sprint scheduling, task assignment, workload balancing, and progress monitoring. This module could combine LLM-based planning assistance with predictive machine learning models trained on historical sprint data to introduce predictive planning capabilities that reduce project delays and improve team productivity.

The third module, Documentation Intelligence, automates the generation of software requirement specifications, meeting summaries, API documentation, technical reports, and project-related documentation. This module relies principally on LLMs for text generation and RAG techniques to retrieve project-specific context, reducing repetitive documentation effort and improving consistency.

The fourth module, Software Engineering Assistance, provides intelligent support for system design recommendations, code explanation, testing suggestions, bug identification, and development guidance. This module would draw on code-specialized LLMs and static-analysis-informed AI techniques to assist technical teams throughout software implementation.

The fifth module, Communication Intelligence, enhances internal team communication and stakeholder interactions by generating progress updates, client reports, meeting summaries, and communication recommendations, using LLM-based summarization grounded in project data via RAG.

The sixth module, Risk Prediction and Decision Support, uses predictive machine learning models to identify possible project delays, resource conflicts, budget risks, and requirement inconsistencies before they affect project delivery, potentially supplemented by knowledge graphs that map dependencies between requirements, tasks, and personnel to trace the source of emerging risks.

The Organizational Intelligence Dashboard integrates all module outputs into a unified monitoring system, using agentic AI techniques to orchestrate cross-module queries and knowledge-graph-based representations to expose workflow visibility and strategic insight for management-level operations.

The proposed framework establishes a unified intelligent ecosystem that integrates fragmented software development operations into a centralized AI-driven environment.

Illustrative Workflow Scenario

To clarify how information flows between modules during an actual project, consider a scenario in which a client requests a new e-commerce checkout feature. The Requirement Intelligence Module analyses the client's request, generates draft user stories, and flags a missing specification regarding payment-failure handling, prompting a clarification request back to the client. Once requirements are confirmed, the Project Coordination Intelligence Module converts the finalized user stories into sprint tasks, estimates effort using historical velocity data, and assigns tasks based on current team workload. As development proceeds, the Software Engineering Assistance Module offers architecture suggestions for the payment integration and flags a potential security issue during code review; this flag is propagated to the Risk Prediction and Decision Support Module, which raises the project's risk score and recommends an additional testing cycle, in turn adjusting the sprint timeline held by the Project Coordination Intelligence Module. In parallel, the Documentation Intelligence Module generates an updated API specification for the payment integration, and the Communication Intelligence Module drafts a client-facing progress update reflecting the revised timeline and the reason for the delay. All of these events the requirement clarification, the risk flag, the schedule adjustment, and the documentation update are aggregated by the Organizational Intelligence Dashboard, giving project leadership a single, real-time view of the feature's status without needing to consult each tool separately.

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Discussion

The proposed conceptual framework highlights the growing necessity for intelligent ecosystem-level AI support within software development organizations. Existing software project management and development platforms primarily focus on isolated workflow management and task coordination [14,15], whereas the proposed framework extends beyond these limitations by integrating organizational intelligence, software engineering assistance, and decision-support functionalities into a single environment, as detailed in the comparison with existing AI-enabled platforms in Section 1.1.

One of the major advantages of the proposed framework is its ability to reduce operational fragmentation. Many software organizations currently rely on separate tools for requirement management, documentation, communication, task coordination, and software development support. This separation often creates inefficiencies, communication gaps, and duplicated efforts. By integrating these functions within a unified AI-assisted ecosystem, operational consistency and workflow efficiency could be improved [10,12].

The framework also introduces predictive and adaptive intelligence capabilities, particularly through the risk prediction and decision support module. Unlike traditional project management systems that mainly react to project events, the proposed ecosystem is designed to proactively surface possible risks, delays, and operational bottlenecks, allowing organizations to take preventive action, as illustrated in the workflow scenario in Section.

Implementation Challenges

Realizing this framework in practice would raise several implementation challenges that must be addressed before deployment. Data privacy is a primary concern, since the ecosystem would require access to sensitive client requirements, proprietary source code, and internal communications; appropriate data segregation, access control, and encryption would be required to prevent unauthorized exposure. Model reliability and hallucination risk present a second challenge: LLM-based modules such as Requirement Intelligence and Documentation Intelligence can generate plausible but inaccurate content, which is particularly risky in specification and API documentation where errors could propagate into implementation. Mitigations such as retrieval grounding, human review checkpoints, and confidence scoring would need to be built into each module rather than treated as an afterthought. A third challenge is organizational resistance to AI adoption: project teams accustomed to established tools and manual coordination practices may be reluctant to trust AI-generated risk scores or task assignments, requiring careful change management and transparent explanation of how AI recommendations are produced. Governance is required when AI systems influence project management decisions organizations would need clear policies defining which decisions the ecosystem may recommend versus which require human sign-off, along with audit trails for AI-influenced decisions.

Ethical Considerations and Human Oversight

Because the proposed ecosystem would support organizational decision-making rather than only technical tasks, ethical considerations extend beyond typical coding-assistant concerns. Transparency is important so that project stakeholders understand when a recommendation, risk score, or generated document originates from AI rather than a human team member. Accountability must remain with human decision-makers: the framework is intended to support, not replace, project managers and technical leads, and outputs from the Risk Prediction and Decision Support and Organizational Intelligence Dashboard modules should be treated as advisory inputs rather than automated determinations. Human oversight mechanisms — such as mandatory review of AI-generated specifications before client delivery, and manager approval for AI-suggested task reassignments would need to be embedded into each module's workflow to maintain accountability and to guard against over-reliance on AI outputs in organizational decision-making.

Future Implementation Potential

The framework has significant future implementation potential. As artificial intelligence technologies continue to evolve, the proposed ecosystem could be expanded into a fully functional organizational AI operating system capable of supporting software development workflows, business operations, and strategic decision-making processes [11,12,13]. Future studies should focus on prototype development and evaluation within real software organizations using measurable outcomes such as development time, documentation quality, project delivery performance, defect rates, and stakeholder satisfaction, benchmarked against current tool-fragmented workflows.

Limitations

The current study is limited to a conceptual framework without practical implementation or empirical validation. The preliminary survey involved only 15 participants drawn from three organizations connected to the author, which constrains generalizability and introduces potential selection bias; the results should be interpreted only as exploratory practitioner sentiment. The findings nonetheless indicate that software professionals in this sample experience notable challenges related to requirement management, documentation burden, communication inefficiencies, and fragmented operational workflows, and expressed interest in an integrated AI-assisted ecosystem beyond isolated coding assistance. These indicative findings motivate, but do not substitute for, future prototype-based evaluation with a larger and more diverse participant pool.

Conclusions

Software development organizations continue to face operational and engineering challenges due to increasing project complexity, fragmented workflows, and limited intelligent support systems. Although artificial intelligence has made considerable progress in coding assistance and automation, a gap remains in unified AI-driven organizational support for software development environments, particularly relative to existing point-solution AI tools such as coding assistants and AI-augmented project trackers.This study proposed a conceptual framework for an intelligent AI-assisted ecosystem spanning requirement intelligence, project coordination, documentation automation, software engineering assistance, communication management, risk prediction, and organizational decision support. Anticipated benefits, including reduced workflow fragmentation and improved organizational productivity, are supported by exploratory practitioner feedback but have not yet been empirically demonstrated and require validation through prototype implementation and controlled evaluation.Future work should prioritize building a working prototype of at least the Requirement Intelligence and Project Coordination modules, deploying it within a participating organization, and measuring outcomes such as documentation turnaround time, requirement rework rate, and stakeholder-reported communication clarity against the organization's existing tool-fragmented baseline. Addressing the data privacy, reliability, adoption, and governance challenges identified in Section 4.1 will be a prerequisite for any such deployment.

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References

1. Dwivedi YK, Kshetri N, Hughes L, Slade EL, Jeyaraj A, Kar AK, et al. So what if ChatGPT wrote it? Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy. Int J Inf Manage. 2023;71:102642.
2. White J, Fu Q, Hays S, Sandborn M, Olea C, Gilbert H, et al. A Prompt Pattern Catalog to Enhance Prompt Engineering with ChatGPT. arXiv [Preprint]. 2023.
3. Nijkamp E, Pang B, Hayashi H, Xiong C, Savarese S. CodeGen: An Open Large Language Model for Code with Multi-Turn Program Synthesis. arXiv [Preprint]. 2023.
4. Bubeck S, Chandrasekaran V, Eldan R, Gehrke J, Horvitz E, Kamar E, et al. Sparks of Artificial General Intelligence: Early Experiments with GPT-4. arXiv [Preprint]. 2023.
5. Ahmad A, Li K, Feng C, Asim SM. Artificial intelligence in software engineering: A systematic literature review. IEEE Access. 2024;12:18213–18245.
6. Humayun M, Niazi M, Jhanjhi NZ, Alshayeb M. Software engineering trends and future directions: The role of artificial intelligence. Comput Stand Interfaces. 2024;88:103741.
7. Kitchenham B, Charters S. Guidelines for performing systematic literature reviews in software engineering. EBSE Technical Report. 2007.
8. Pressman RS, Maxim BR. Software Engineering: A Practitioner's Approach. 9th ed. New York: McGraw-Hill; 2024.
9. Sommerville I. Software Engineering. 11th ed. Boston: Pearson; 2023.
10. Davenport TH, Mittal N. How generative AI is changing knowledge work. Harv Bus Rev. 2024;102(2):54–63.

11. Gartner Inc. Top strategic technology trends for 2026. Stamford (CT): Gartner Research; 2026.
12. McKinsey & Company. The state of AI in 2025: Adoption, impact and future directions. New York: McKinsey Global Institute; 2025.
13. Stanford Institute for Human-Centered Artificial Intelligence. AI Index Report 2025. Stanford University; 2025.
14. Schwaber K, Sutherland J. The Scrum Guide: The definitive guide to Scrum. Scrum.org; 2020.
15. Kerzner H. Project Management: A Systems Approach to Planning, Scheduling, and Controlling. 13th ed. Hoboken: Wiley; 2022.
16. GitHub. GitHub Copilot documentation. GitHub Inc.; 2025. Available from: https://docs.github.com/copilot
17. Atlassian. Rovo and AI features in Jira. Atlassian Corp.; 2025. Available from: https://www.atlassian.com/software/jira
18. Microsoft. AI features in Azure DevOps. Microsoft Corp.; 2025. Available from: https://learn.microsoft.com/azure/devops

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OP 07

An IoT Prototype Simulation for Real-Time Patient Vital Signs Monitoring with Cloud Integration and Condition-Specific Alerts

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Abstract

Introduction:

Monitoring patients' vital signs is the most sophisticated diagnostic tool in modern healthcare. Existing IoT-based healthcare monitoring systems are limited to measuring one or two critical healthcare metrics and lack automated, condition-specific, cloud-triggered alert mechanisms, both locally and remotely.

Objective/s:

To design and implement a low-cost IoT simulation prototype based on ESP32 in the Wokwi environment to monitor heart rate, systolic blood pressure, diastolic blood pressure, peripheral oxygen saturation, respiratory rate, and body temperature, integrated with ThingSpeak real-time cloud storage to generate threshold-based local alerting and condition-specific mobile push notifications and local alerts.

Methods:

The System was developed using an ESP32 microcontroller with dual cores and MicroPython firmware as the central processor. All vital sign readings were simulated using calibrated potentiometers within the Wokwi simulated platform. Potentiometer readings were transmitted to the ThingSpeak cloud via the system's GUEST Wi-Fi. Eleven React rules were implemented to detect threshold breaches to trigger condition-specific ThingHTTP POST requests on the ntfy push notification service.

Results:

All 11 test cases passed under the predefined React rules. All six vital signs successfully generated the LED flash and buzzer activation during threshold breaches. ThingSpeak cloud upload was confirmed by an HTTP confirmation code. The condition-specific mobile push notifications were delivered when a threshold was breached.

Conclusion:

The proposed simulation reliably monitors all six vital signs. It generates condition-specific, real-time alerts locally and remotely and stores readings in the cloud, demonstrating meaningful deployment in resource-constrained environments.

Keywords: *Alerts, cloud storage, ESP32, IoT, MicroPython*

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Introduction

Continuous vital signs monitoring allows clinicians to diagnose patients early based on heart rate (HR), blood pressure (BP), respiratory rate (RR), peripheral oxygen saturation (SpO_2), and temperature, in real time, to enable timely therapeutic interventions (Michard & Saugel, 2024). Advances in bedside monitoring have enhanced real-time surveillance of patients' vital signs. However, there is a considerable gap in equipment cost, infrastructure requirements, and the lack of staff in community care setups in low- and middle-income countries (Phelan, et al., 2022).

A cost-effective, less complex, and transformative Internet of Things (IoT)-based solution can address this gap. (Verma, et al., 2023). Furthermore, extend the monitoring capacity of remote and home-care settings (Abdulmalek, et al., 2022). A system can be designed using an ESP32 microcontroller, which consists of a dual-core processor and Wi-Fi connectivity (Espressif Systems, 2024).

Real-time data ingestion is visualized and stored in the ThingSpeak cloud, while React and ThingHTTP applications are responsible for threshold-based alert generation (MathWorks, 2026). Condition-specific push notification provided by the ntfy.sh notification service provides condition-specific push notifications immediately for care workers (ntfy.sh, 2026).

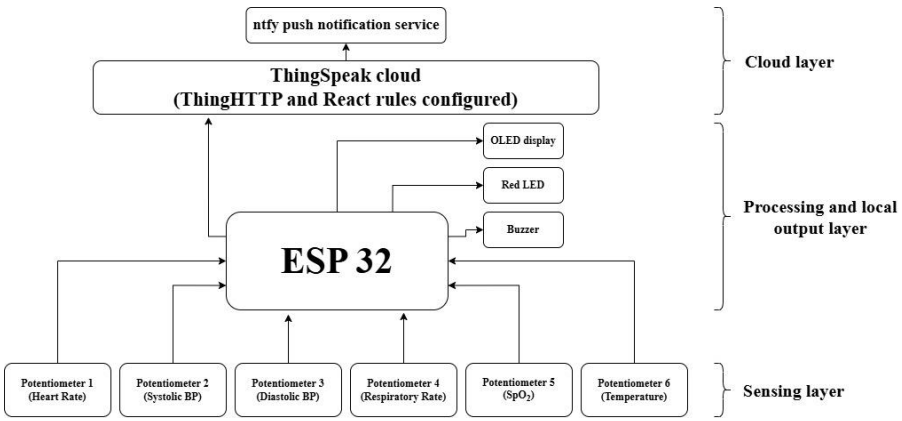
Existing systems demonstrate low-cost IoT solutions for monitoring patient vital signs. A study based on an affordable ESP32 microcontroller, MA30102 sensor, and the Blynk IoT platform monitored patients with approximately 99% clinical accuracy and limited monitoring to HR and SpO_2, but it does not offer parameterized alert generation pipelines (Krishnapriya & Prema, 2025).

Another system utilized an ESP32, a web infrastructure, and a mobile application to continuously monitor SpO_2, HR, and temperature. It incorporated threshold-based alerts for mobile platforms and web pop-ups, but lacked cloud-based data storage for tracking long-term vital signs patterns. The generated alerts are not condition-specific and do not report the affected metric, measured value, or normal range (Vyas et al., 2025).

Disease-specific cloud-integrated IoT systems are also designed to monitor the recovery patterns of maxillofacial patients (Kamma et al., 2025) and asthma (Chakraborty et al., 2023) based on targeted populations; they involve specialized sensors and cloud analytics, but they are not designed to broaden multi-sign monitoring. Therefore, the study focuses on the design and implementation of a real-time prototype IoT simulation in the Wokwi environment to simultaneously monitor six vital signs of the patient while delivering local threshold-based visual and auditory alerts and storing all the readings in the ThingSpeak cloud to generate condition-specific mobile push notifications via ThingHTTP and ntfy based on threshold breaches as a low-cost design for rural and care home settings.

Methods

The proposed system consists of three functional layers: a sensing layer, a processing and local output layer, and the cloud layer. The ESP 32 microcontroller running MicroPython firmware acquires data, evaluates thresholds, and transmits them to the cloud, while the SSD1306 Organic Light Emitting Diode (OLED) display, a red Light Emitting Diode (LED) connected via a 220 Ω resistor to the esp:2 pin, and a buzzer connected to esp:15 operate in the local output, providing immediate bedside visual and alerts (Wokwi, 2024) to get the attention of care



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workers. The cloud layer consists of the ThingSpeak cloud platform for data storage and the ntfy mobile push notification service for delivering mobile alerts.

Figure 1. Three-tier IoT system architecture of the proposed solution

Since the study uses a simulation rather than a patient to monitor six vital signs, each sign is represented by a calibrated potentiometer on the Wokwi platform to test condition-specific alert generation. All potentiometers are labeled with the respective vital signs, and they are connected to an Analog-to-Digital Converter 1(ADC 1) pin set.

Wokwi-GUEST virtual Wi-Fi network will establish the end-to-end seamless simulated wireless connectivity with ThingSpeak cloud, triggering React rules, delivering ThingHTTP webhooks, and receiving notifications from the ntfy application.

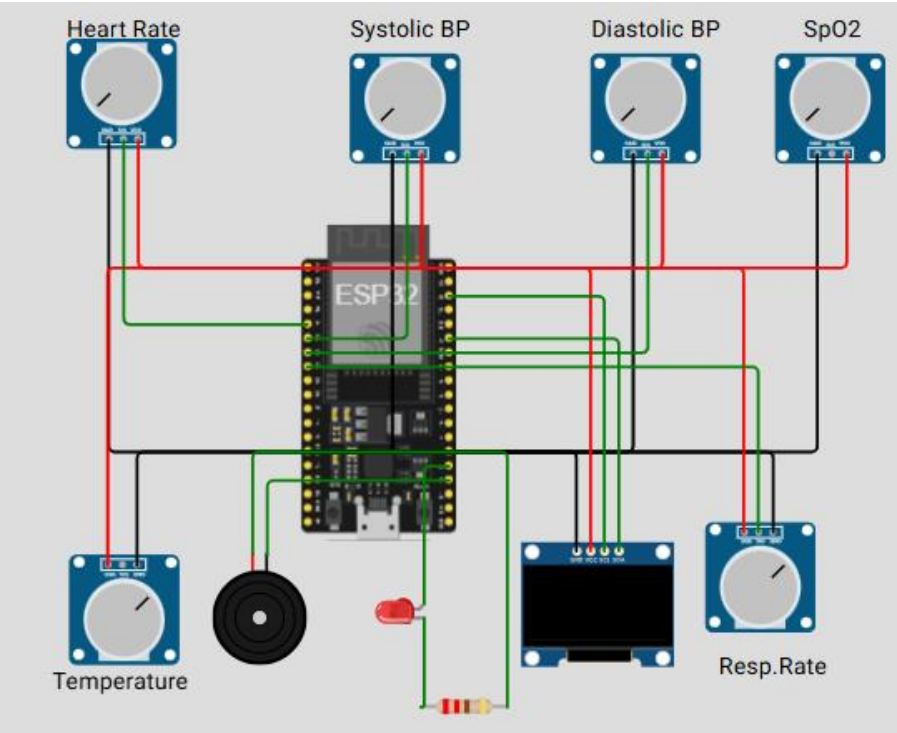

Figure 2. Implemented a patient's vital signs monitor in the Wokwi simulation environment

Table 1. System connectivity among sensors and ESP32

Component	Role	Interface/ Pin
ESP 32	Core processor with Wi-Fi connectivity	The core microcontroller that connects all sensor nodes
Potentiometers	Simulate the input of the sensors within the Wokwi environment	ADC 1 pin set (esp 32,33,34,35,36,39)
SSD1306 OLED	Real-time metric display	esp 21 to SDA and esp 22 to SCL
Red LED and 220 Ω resistor	Generate lighting alerts on threshold breach	esp 2
Buzzer	Noise alerts on threshold breach	esp 15

All clinical thresholds are defined in Table 2 except high SpO_2 because it is clinically acceptable. (World Health Organization, 2013).

Table 2. Thresholds of all the vital signs measured by the proposed solution

Vital sign	Unit	Normal range	Low threshold	High threshold
Heart Rate	Bpm	60-100 bpm	< 60 bpm	>100 bpm

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Systolic BP	mmHg	90-140 mmHg	< 90 mmHg	>140 mmHg
Diastolic BP	mmHg	60-90 mmHg	< 60 mmHg	>90 mmHg
Respiratory Rate	br/min	12-20 br/min	< 12 br/min	>20 br/min
Peripheral oxygen saturation	%	95-100%	< 95%	N/A
Body temperature	℃	35.0-37.5℃	< 35.0 ℃	>37.5℃

Sensor readings are transmitted to the ThingSpeak cloud through an HTTP GET request to update the Application Programming Interface (API). Each vital sign was assigned to a dedicated channel field. Transmission occurs every 20 seconds, a rate set by ThingSpeak's free-tier limit. Eleven ThingSpeak React rules were configured based on high and low thresholds to prevent notification flooding. Each React rule triggers whenever the threshold is breached until the reading normalizes. The triggered React rule activated a corresponding ThingHTTP application to issue an HTTP POST request on the ntfy platform for the subscribed topic. Each notification contains a sensor value, a clinically informative message specifying the affected vital sign, measured value, and normal range, constructed from the ThingHTTP channel variable by providing meaningful clinical insights to remote careworkers, enabling them to monitor patients without needing to access dashboards.

During every sensor reading cycle, the main MicroPython processing loop evaluates the threshold. İf any out-of-range vital sign is detected, a local alert sequence will be initiated to notify the emergency healthcare staff by generating noise alerts through 300 ms buzzer activation and issuing warnings through a red LED with three rapid flash cycles with a 150 ms brake. Furthermore, the SSD1306 OLED displays any abnormal reading with an exclamation mark. The Wi-Fi status will be displayed in the top-right corner of the OLED with “W+” or “W!” icons. Once all vital signs are within normal limits, the local alerts will be suppressed.

The ThingSpeak cloud and ntfy were selected based on three criteria: Cost effectiveness, notification specificity, and alert pipeline capability. Compared to Firebase and MQTT, ThingSpeak provides a built-in no-code alert pipeline including ThingHTTP and React applications. If Firebase or MQTT is implemented, it is required to configure additional cloud functions and complexities to implement threshold-based monitoring. Furthermore, ntfy is more cost-effective than IFTTT and does not require any subscription fee or account-based registration.

Results

On startup, OLED initializes before the Wi-Fi connection is established. The ESP 32 established a Wi-Fi connection with the ThingSpeak cloud over the Wokwi-GUEST network within 8-12 seconds by indicating “W+” on the OLED.

Readings will be uploaded to the ThingSpeak cloud at 20-second intervals, and each ingestion will be confirmed by the Hypertext Transfer Protocol (HTTP) 200 status code in the ThingSpeak response. Every vital sign is written to its own channel and displayed in a live-updating graph, confirming data acquisition from the ADC, MicroPython processing, Wi-Fi transmission, and cloud storage functions.

Local alerts respond correctly to threshold-crossing potentiometer readings. For both high and low critical vital sign values reported across 11 distinct test conditions, the LED flashed, the buzzer sounded, and the OLED displayed the vital signs and deviations at one-second intervals. When multiple signs are breached, OLED marks each independently with LED and buzzer alerts until all signs are normalized.

At the cloud layer, all 11 test conditions trigger the corresponding React rule on data insertion to invoke ThingHTTP applications and issue an HTTP POST request to the ntfy endpoint. Within a 5-15-second time window, the condition-specific push notifications were triggered and delivered to the subscribed ntfy application service. Each notification message includes a measured vital sign, normal range, and an alert message.

Table 4. Test cases on each vital sign of a patient

Condition	Simulated value	Normal range	LED/ Buzzer	Cloud upload	ntfy alert
High heart rate	175 bpm	60-100 bpm	√	√	√
Low heart rate	42 bpm		√	√	√

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High systolic BP	185 mmHg	90-140 mmHg	√	√	√
Low systolic BP	75 mmHg		√	√	√
High diastolic BP	105 mmHg	60-90 mmHg	√	√	√
Low diastolic BP	45 mmHg		√	√	√
High respiratory rate	25 br/min	12-20 br/min	√	√	√
Low respiratory rate	9 br/min		√	√	√
Low SpO_2	88%	95-100%	√	√	√
High temperature	38.9℃	35.0-37.5℃	√	√	√
Low temperature	34.2℃		√	√	√

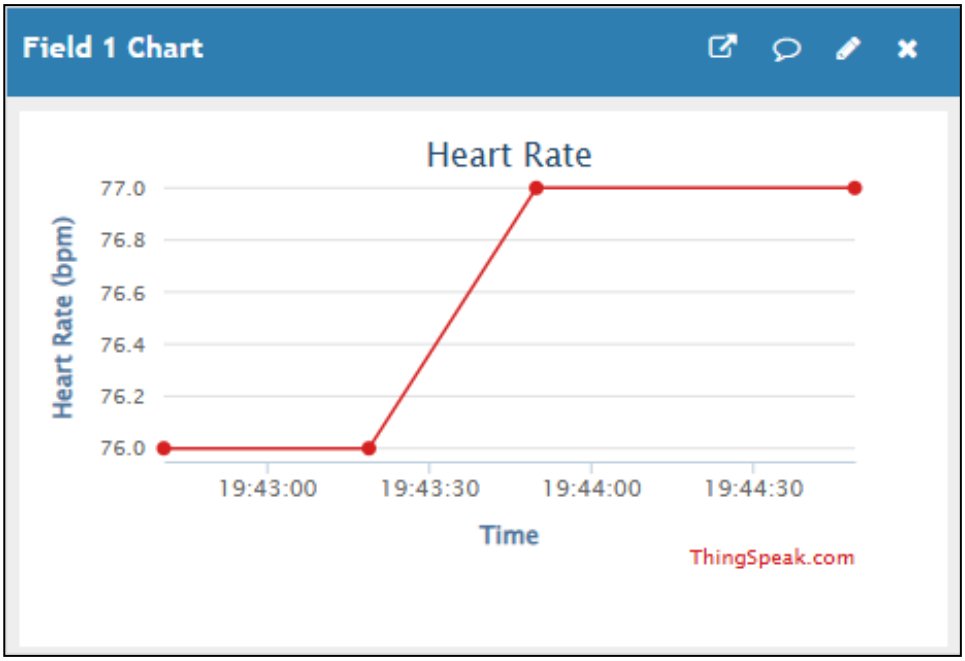

Figure 3. Patient's heart rate over time in the ThingSpeak dashboard

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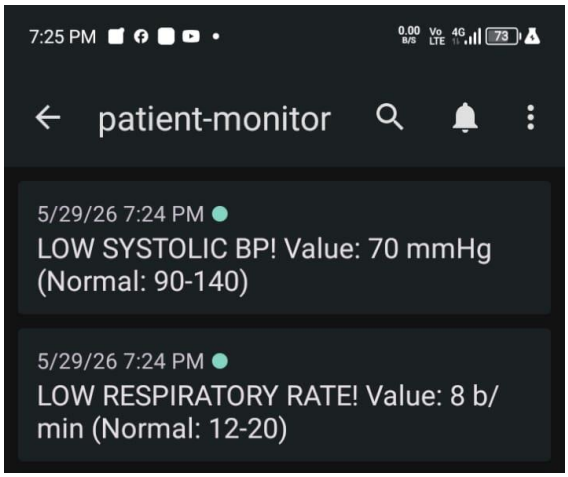

Figure 4. notify push notifications

Table 4. Timings of each function in the proposed solution

Function	Timings
Wi-Fi connection establishment for system initialization	8-12 seconds
Main loop cycle (ADC reading, evaluating the thresholds, refreshing the OLED, and executing local alerts)	1 second
Transmit data to the cloud	1-3 seconds
Push notification delivery	5-15 seconds

Discussion

The study presents a comprehensive design by using the ESP32 microcontroller and MicroPython firmware to simultaneously monitor six vital signs of patients and store every reading in the ThingSpeak cloud while generating real-time alerts, both local hardware and cloud-triggered mobile push notifications, whenever a threshold is breached. All 11 predefined rules are tested with relevant test cases in the Wokwi simulated environment.

Findings were consistent with the previous studies. ESP 32 performs data processing before transmitting it to the cloud. The study advanced the monitoring system of previous studies by adding a condition-specific automated alerting mechanism using ThingHTTP and React functions to measure six vital signs with cost-effective ntfy push notification delivery.

The study contains several critical gaps. All sensor inputs were simulated using potentiometers rather than clinical sensors to simulate the patient's vital signs in the Wokwi simulated environment to check the system logic, threshold-breach conditions, and alert pipelines, and they do not simulate Wi-Fi latency, packet loss, and connection instability. Therefore, the use of real physical devices is required with real network conditions.

The proposed solution uses HTTP traffic without encryption for data transmissions, which is highly vulnerable and inappropriate for the deployment of critical data handling such as patient information. Therefore, it is essential to implement more secure connections using HTTPS with TLS. Both API keys for ThingSpeak and ntfy are essential to be stored in an encrypted flash memory on the ESP32. Role-based access control must be implemented on ThingSpeak and ntfy to prevent unauthorized access. To identify the patients, hash functions must be used, and the solution must be validated with relevant healthcare data regulations before any clinical deployment. Additionally, audit logins must be implemented as a solution for incident response and clinical governance.

The current alert management process is designed to trigger React rules on the first occurrence only. A real-world deployment of the solution needs to be concerned about alert fatigue. Therefore, it is recommended to implement a system with a tiered approach to trigger alerts on the first breach and, if the vital sign has not returned to the normal range within some duration, generate another alert to a senior clinician. This approach reduces notification burdens as well as pressure on clinical staff routines.

Before implementing the solution in the clinical environment, it is essential to perform sensor calibration. Furthermore, the system must be validated with sensor devices against healthcare equipment such as oxymeters and clinical thermometers, to determine whether these sensors can provide the expected outcome by standing within the range. A strong Internet connectivity is essential to maintain the smooth functionality of the proposed solution, and it should be separated from guest Wi-Fi services, which are provided to the patients by the hospital to ensure the confidentiality and integrity of the entire system. But if the Internet is unavailable, the system must be configured to function with technologies such as Global System for Mobiles (GSM) communication modules as substitutes. Healthcare staff must be provided with essential training to handle the dashboards of the system with the support of specialist technicians. Furthermore, it is essential to extend the system to monitor multiple patients through a multi-channel ThingSpeak architecture with a unified dashboard. İt enables the deployment of a ward-level monitoring system rather than monitoring a single patient.

The clinical usefulness and scalability can be achieved by enhancing the solution as ESP32-based wearable modules to monitor mobile patients rather than static bedside monitoring. The system can be further enhanced to analyse patients' vital signs trends using MATLAB in ThingSpeak itself without additional infrastructure. AI-based anomaly detection can be introduced, and the system can be integrated with electronic health record systems to keep these records. Therefore, it is an effective solution to deploy within the rural clinics and communities due to the cost effectiveness and it reduces the complexities of conventional bedside monitoring

Finally, a comprehensive study needs to be conducted to measure the vital signs of the prototype solution against reference standards in a real-world hospital setting for a patient population to ensure system validity before real-world implementation.

Conclusions

The study implemented a low-cost prototype simulator of an IoT patient vital sign monitor with an ESP32 microcontroller, ThingSpeak cloud storage, and the ntfy push notification service to monitor HR, BP, SpO_2, RR, and body temperature. The system continuously monitors these vital signs, records them in cloud infrastructure, and, if any abnormal health condition is detected, generates local and remote alerts to notify healthcare employees. 11 test cases were conducted to ensure proper functionality and validate the system. The ntfy push notification service was used as a remote alert application. The study demonstrates the functional efficiency and correctness of the proposed prototype solution. It is important to assess the feasibility and efficiency of the solution rather than the clinical performance because the validation of the technology with the required sensor hardware is essential before physical deployment within a healthcare environment.

Since the system was designed in the Wokwi simulation environment and uses potentiometers to simulate readings and validate the logic, it is essential to implement this solution in a real-world environment with real sensor nodes to capture patients' healthcare metrics.

As future recommendations, it is essential to support real-world implementation through validation with real sensor devices, network testing, and healthcare regulatory compliance with encryption. Furthermore, the system must be scaled up to multi-patient monitoring.

This infrastructure is a meaningful deployment for resource-constrained clinical settings, community healthcare facilities, and care-home environments where continuous patient monitoring is essential. With these conditions, the architecture provides a foundation for a credible, low-cost, and clinically deployable patient monitoring platform that improves patient safety.

References

Abdulmalek, S. et al., 2022. IoT-Based Healthcare-Monitoring System towards Improving Quality of Life: A Review. *Healthcare (Basel), Switzerland,* 10(10), p. 1993.

A., Choupdar, G. K., A. & T, P., 2025. ICT and IoT-Based Smart Post-Harvest Solutions.pdf (ICT and IoT-Based Smart Post-Harvest Solutions). *Agrospheres: e-Newsletter,* 06 June, 6(6), pp. 15-18.

Ajisegiri, E. et al., 2022. Development of a Smart Grain Storage Silo Using the Internet of. *International Journal of Artificial Intelligence and Machine Learning ·,* 5 July, 2(2), pp. 1-22.

Andre Esteva, B. K. R. A. N. J. K. S. M. S. H. M. B. &. S. T., 2017. Dermatologist-level classification of skin cancer with deep neural networks. *Nature.*

Areej Alotaibi 1, *. D. A., 2025. Skin Cancer Detection Using Transfer Learning and Deep Attention Mechanisms. *Nationala Library of Medicine.*

Chakraborty, A., Gupta, R. D., Kabir, Z. M. & Dhar, S., 2023. Development of an IoT-enabled cost-effective asthma patient monitoring system: Integrating health and indoor environment data with statistical analysis and data visualization. *Cleaner and Responsible Consumption,* 24(2), p. 100142.

Chen, X. & Moraga, P., 2024. Dengue forecasting and outbreak detection in Brazil using LSTM: integrating human mobility and climate factors. *Infectious Disease Modelling,* 11(1), pp. 338-354.

Chumpu, R., Khamsemanan, N., Nattee, C. & Samy, A. M., 2019. The association between dengue incidences and provincial-level weather variables in Thailand from 2001 to 2014. *PLOS ONE,* 14(12), p. e0226945.

Erico Tjoa, C. G., n.d. [Online]
Available at: https://arxiv.org/abs/1907.07374

Espressif Systems, 2024. *ESP32 Technical Reference Manual,* s.l.: Espressif Systems.

European Centre for Disease Prevention and Control, 2021. *Factsheet about Dengue,* Stockholm: Centre for Disease Prevention and Control.

Fransson, P. et al., 2025. An explainable covariate compartmental model for predicting the spatio-temporal patterns of dengue in Sri Lanka. *PLOS Computational Biology,* 21(9), p. e1013540.

Geert Litjens, T. K. B. E. B. A. A. A. S. F. C. M. G. J. A. v. d. L. B. v. G. C. I. S., n.d. *A Survey on Deep Learning in Medical Image Analysis.* [Online]
Available at: https://arxiv.org/abs/1702.05747

Gharbi, M. et al., 2011. Time series analysis of dengue incidence in Guadeloupe, French West Indies: Forecasting models using climate variables as predictors. *BMC Infectious Diseases,* 11(1).

Godliauskas, Povilas & Smite, Darja., 2024. *The well-being of software engineers: a systematic literature review and a theory..* [Online]
Available at: https://www.researchgate.net/publication/386382938_The_well-being_of_software_engineers_a_systematic_literature_review_and_a_theory
[Accessed 15 5 2026].

Guo, P. et al., 2017. Developing a dengue forecast model using machine learning: A case study in China. *PLoS Negl Trop Dis,* 11(10), p. e0005973.

Hyuna Sung PhD, J. F. M. M. R. L. S. M. M. L. M. I. S. M. M. P. A. J. D. P. F. B. B. M. P., 2021. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *CA: A Cancer Journal for Clinicians,* 2.

Islam, M. A., Hasan, M. N. & Tiwari, A., 2023. Correlation of Dengue and Meteorological Factors in Bangladesh: A Public Health Concern. *International Journal of Environmental Research and Public Health,* 1 January, 20(6), p. 5152.

Jarman, A. et al., 2023. Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology,* 19 September. Volume 1.

Jayadas, T. T. P. et al., 2023. A spatial dengue risk map for the Jaffna District of Northern Sri Lanka. *Vingnanam Journal of Science,* 18(1), pp. 13-22.

Kamma, V. et al., 2025. Integrating IoT and Cloud Analytics for Real-Time Monitoring of Post-Surgical Recovery in Maxillofacial Patients. *Vascular and Endovascular Review,* 8(1), pp. 304-311.

Karasinghe, N., Peiris, S., Jayathilaka, R. & Dharmasena, T., 2024. Forecasting weekly dengue incidence in Sri Lanka: Modified Autoregressive Integrated Moving Average modelling approach. *PLOS ONE,* 19(3), pp. e0299953-e0299953.

Kennedy, S. I., Zadeh, A. A., Choi, J., & Alborz, S., 2024. *Agile Practices and IT Development Team Well-Being: Unveiling the Path to Successful Project Delivery.* [Online]
Available at: http://researchgate.net/publication/385263215_Agile_Practices_and_it_Development_Team_Well-Being_Unveiling_the_Path_to_Successful_Project_Delivery
[Accessed 19 5 2026].

Krishnapriya, G. & Prema , S., 2025. Cost-Effective IoT-Based Real-Time Vital Sign Monitoring: An Affordable Telehealth Solution. *Telehealth and Medicine Today,* Volume 10, p. 611.

Kumar, S., 2025. *Agile Development Models - Software Engineering.* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/software-engineering-agile-development-models/
[Accessed 22 January 2026].

Kumar, S., 2026. *Waterfall Model - Software Engineering.* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/waterfall-model/
[Accessed 21 January 2026].

Kurian, N. C. et al., 2023. Robust Semi-Supervised Learning for Histopathology Images Through Self-Supervision Guided Out-of-Distribution Scoring. *ieeexplore.*

Lambrechts, L., Scott, T. W., Gubler, D. J. & Halstead, S. B., 2010. Consequences of the Expanding Global Distribution of Aedes albopictus for Dengue Virus Transmission. *PLoS Neglected Tropical Diseases,* 25 May, 4(5), p. e646.

Lee, D.-H., n.d. [Online]
Available at: https://www.researchgate.net/publication/280581078_Pseudo-Label_The_Simple_and_Efficient_Semi-Supervised_Learning_Method_for_Deep_Neural_Networks

Majeed, M. A., Mohd, Z., Zulkafli, Z. & Wayayok, A., 2023. A Deep Learning Approach for Dengue Fever Prediction in Malaysia Using LSTM with Spatial Attention. *International Journal of Environmental Research and Public Health,* 20(5), p. 4130.

MathWorks, 2026. *ThingSpeak Documentation.* [Online]
Available at: https://www.mathworks.com/help/thingspeak/

Mazhar, B. et al., 2024. Development of Data-driven Machine Learning Models and their Potential Role in predicting dengue outbreaks. *Journal of Vector Borne Diseases,* 16 January. 503-514.

Michard, F. & Saugel, B., 2024. New sensors for the early detection of clinical deterioration on general wards and beyond - a clinician's perspective. *Journal of Clinical Monitoring and Computing,* 39(2), pp. 435-442.

Mingxing Tan, Q. V. L., n.d. [Online] Available at: https://arxiv.org/abs/1905.11946

Mohamed A. Kassem 1ORCID, K. M. H. 2. D. 3. A. M. E., 2021. Machine Learning and Deep Learning Methods for Skin Lesion Classification and Diagnosis: A Systematic Review. *MDI.*

Muhammad Danish Ali 1, M. A. I. 2. L. 3. D. 4. a. K. K., n.d. Explainable AI-Based Multi-Class Skin Cancer Detection Enhanced by Meta-Learning with Generative DDPM Data Augmentation. *MDPI.*

Nandani, E. J. K. P. & Bandara, A. M. D. P., 2025. Forecasting Dengue Outbreaks in Kalutara District using Hybrid Machine Learning Techniques. *Journal of Science of the University of Kelaniya,* 18(2), pp. 145-152.

ntfy.sh, 2026. *ntfy.sh.* [Online] Available at: https://ntfy.sh/

Ong, S. Q. et al., 2023. Predicting dengue transmission rates by comparing different machine learning models with vector indices and meteorological data. *Scientific Reports,* 13(1).

Phelan, H., Yates, V. & Lillie, E., 2022. Challenges in healthcare delivery in low- and middle-income countries. *Anaesthesia and Intensive Care Medicine,* 23(8), p. 501–504.

Rahman, S. Z., Senthil, R., Ramalingam, V. & Gopal, R., 2023. Predicting Infectious Disease Outbreaks with Machine Learning and Epidemiological Data. *Journal of Advanced Zoology,* 44(S-4), p. 110:121.

Rahulan, K., Ranagala, R. M. & Roshan, G. P., 2024. Dengue Outbreak Control and Prevention: A Case Study of Gampaha District, Sri Lanka. *Sri Lankan Journal of Medical Administration,* 25(1), pp. 46-53.

Ramprasaath R. Selvaraju, M. C. A. D. R. V. D. P. D. B., n.d. [Online]
Available at: https://arxiv.org/abs/1610.02391

Ranwala, L., Wedisinghe, Y., Perera, S. & Jayamanne, D., 2021. Real-time laboratory surveillance of Dengue antigen (NS1) - Best proposed early warning and response system for Dengue in Sri Lanka? - Results from a pilot study. *Ceylon Medical Journal,* 27 12, 66(3), p. 121.

Riedl, René & Oettl, Christian & Stangl, Fabian & Hevner, Alan, 2025. *How an Agile Software Process Increases Developers' Job Satisfaction: A Stress Perspective Based on the Effort-Reward-Imbalance Model.* [Online] Available at:
https://www.researchgate.net/publication/388232797_How_an_Agile_Software_Process_Increases_Developers'_Job_Satisfaction_A_Stress_Perspective_Based_on_the_Effort-Reward-Imbalance_Model
[Accessed 20 5 2026].

Rietze, Sarah & Zacher, Hannes., 2023. *Agile work practices: opportunities and risks for occupational well-being..* [Online] Available at:https://www.researchgate.net/publication/374921519_Agile_work_practices_opportunities_and_risks_for_occupational_well-being [Accessed 18 5 2026].

Rosi, A. et al., 2026. Real-Time Mosquito Breeding Site Detection Using a Quantized YOLOv8-Tiny Model on an FPGA-Based Drone Platform. *EAI Endorsed Transactions on Internet of Things,* Volume 11.

Sahu, H., Kashyap, R. & Dewangan, B. K., n.d. Hybrid deep learning-based semi-supervised model for Medical Imaging. *ieeexplore.*

Sharafaddini, A. M. & Mansouri, N., 2024. Enhanced Skin Cancer Classification Using Deep Learning and Gradient Boosting Techniques. *ieeexplore.*

Shaswat, . T., 2024. Role of Big Data and IoT in Optimizing Post-Harvest Management. *International Journal of Research Publication and Reviews,* October, 5(10), p. 3.

S. K. et al., 2018. IoT Based Monitoring And Control For Vegetables And Fruits Storage. *International Journal of Advance Research, Ideas and Innovations in Engineering (IJARIIE),* 4(2), p. 5.

Tissera, H. A. et al., 2020. Severe Dengue Epidemic, Sri Lanka,. *www.nc.cdc.gov,* 26(4).

Tuan, D. A. & Dang, T. N., 2024. Leveraging Climate Data for Dengue Forecasting in Ba Ria Vung Tau Province, Vietnam: An Advanced Machine Learning Approach. *Tropical Medicine and Infectious Disease,* 9(10), p. 250.

Uduwanage, H. U. et al., 2025. Prediction of Dengue Outbreaks in Sri Lanka Using Machine Learning Techniques. *Sri Lanka Journal of Medicine,* 21 4, 34(1), pp. 15-26.

Verma, H., Chauhan, N. & Awasthi, K. L., 2023. A Comprehensive review of 'Internet of Healthcare Things': Networking aspects, technologies, services, applications, challenges, and security concerns. *Computer Science Review,* Volume 50.

Viviane, . I. et al., 2023. IoT-Based Real-Time Crop Drying and Storage Monitoring System. *International Journal of Distributed Sensor Networks,* 26 September, Volume 2023, p. 11.

Vyas, H., Shukla, H. & Jivani, M. N., 2025. A Portable IoT-Based Health Monitoring Framework Using ESP32 for Isolated and Home-Based Patient Care. *Journal on Electronic and Automation Engineering,* 4(2), pp. 240-245.

Vyas, M. et al., 2019. Post harvesting Onion Storage Methodology using IOT.pdf (Post harvesting Onion Storage Methodology Using IOT). *International Journal of Advanced Research in Computer and Communication Engineering,* May.8(5).

Withanage, G. P., Viswakula, S. D., Nilmini Silva Gunawardena, Y. I. & Hapugoda, M. D., 2018. A forecasting model for dengue incidence in the District of Gampaha, Sri Lanka. *Parasites & Vectors,* 11(1).

Wokwi, 2024. *Wokwi: online electronics simulator.* [Online]
Available at: https://wokwi.com

Wong, N., Jackson, V., & van der Hoek, A., 2023. *Mental Wellbeing at Work: Perspectives of Software Engineers.* [Online]
Available at:
https://www.researchgate.net/publication/370180529_Mental_Wellbeing_at_Work_Perspectives_of_Software_Engineers [Accessed 20 5 2026].

World Health Organization, 2013. *Pocket book of hospital care for children: guidelines for the management of common childhood illnesses.* 2 ed. s.l.:WHO.

Xu, J. et al., 2020. Forecast of Dengue Cases in 20 Chinese Cities Based on the Deep Learning Method. *International Journal of Environmental Research and Public Health,* 17(2), p. 453.

Yu, K. et al., 2024. Using UAV Images and Deep Learning in Investigating Potential Breeding Sites of Aedes albopictus. *Acta Tropica,* pp. 107234-107234.

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OP 08

Effect of Soil Shear Strength Parameters on Slope Stability: A Numerical Study Using GeoStudio

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Abstract

Background:
Slope stability is a critical consideration in geotechnical engineering because slope failures can cause significant damage to infrastructure, the environment, and human life. Soil shear strength parameters, particularly cohesion (c) and angle of internal friction (φ), together with slope geometry, are key factors influencing slope stability.

Objective/s:
To investigate the influence of cohesion, friction angle, and slope angle on the factor of safety (FoS) of slopes using numerical modelling in GeoStudio (SLOPE/W).

Methods:
A two-dimensional homogeneous slope model was developed using the SLOPE/W module in GeoStudio. The Bishop Simplified limit equilibrium method was selected because it provides a suitable balance between accuracy and computational efficiency for homogeneous slopes with circular failure surfaces. Parametric analyses were conducted by independently varying cohesion (5–30 kPa), friction angle (20°–40°), and slope angle (20°, 30°, and 45°), while maintaining a constant soil unit weight of 18 kN/m³.

Results:
Increasing cohesion increased the FoS from 1.251 to 4.410, while the friction angle increased the FoS from 1.654 to 2.163. In contrast, increasing the slope angle reduced the FoS from 2.503 at 20° to 1.256 at 45°. The results indicate that all three parameters significantly influence slope stability. Cohesion produced the largest overall increase in FoS within the investigated range, while friction angle and slope angle also demonstrated substantial effects on slope performance.

Conclusion/s:
Both soil shear strength parameters and slope geometry significantly affect slope stability and should be considered together in geotechnical design and assessment. The findings provide useful insights for preliminary slope design and risk assessment. Numerical modelling using GeoStudio was shown to be effective for evaluating slope behaviour. However, the results are based on a simplified homogeneous slope model with constant unit weight. Future studies should consider groundwater conditions, seismic loading, and heterogeneous soil profiles.

Keywords: *cohesion, factor of safety, GeoStudio, slope stability, soil shear strength*

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OP 09

A Comparative Life Cycle Cost and Embodied Carbon Assessment of Reinforced Concrete and Structural Steel Frames for a Low-Rise Residential Building in the Central Province of Sri Lanka

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Abstract

Background: Structural frame selection impacts life-cycle cost and embodied carbon in residential buildings. Although structural steel offers potential construction-speed advantages, analysing construction duration fell outside this study's scope. Because international comparisons reflect developed-economy conditions with differing labour rates, supply chains, and construction practices, locally calibrated evidence is essential before applying international findings to Central Province residential construction.

Objectives: This study compared equivalent reinforced concrete and structural steel frames for a low-rise residential building in Sri Lanka's Central Province, evaluating life-cycle cost, upfront embodied carbon, and cost-carbon trade-offs.

Methods: A representative 240 m² two-storey building, reflecting typical regional low-rise housing scales, was modelled in Tekla Structural Designer under consistent assumptions. Material quantities were calibrated using anonymised Central Province bills of quantities. Net Present Value life-cycle cost assessment applied a 3 % discount rate across a 30-year investment horizon, a 50-year base-case service life, and a 100-year durability period. Upfront embodied carbon (A1–A5) used generic emission factors, excluding operational carbon and end-of-life impacts.

Results: Reinforced concrete achieved a 45.3 % lower 50-year Net Present Value life-cycle cost of LKR 11.52 million, compared with LKR 16.74 million for structural steel. Upfront embodied carbon was 8.4 % lower for reinforced concrete at 44.54 tCO_2e versus 48.28 tCO_2e for steel. Reduced concrete volume in the steel frame was outweighed by the expense and emissions of structural steel sections and protective coatings.

Conclusions: Reinforced concrete performed better in both cost and carbon within the defined assumptions. These findings assist engineers in early design-stage decision-making by demonstrating that sustainability efforts should focus on optimising familiar local concrete systems rather than assuming steel substitution automatically reduces impact. This assessment is limited to Central Province prices and generic emission factors without product-specific Environmental Product Declarations and cannot be generalised to other regions.

Keywords: *embodied carbon, life-cycle cost assessment, reinforced concrete, Sri Lanka, structural steel*

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OP 01

From Human Counsellors to AI Chatbots: Factors Influencing Help-Seeking Behaviour Among University Undergraduates

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Abstract

Background:
Artificial Intelligence (AI) chatbots have become increasingly popular among university students due to their ability to provide immediate, accessible, and personalized support. As traditional help-seeking services often face barriers such as limited accessibility, privacy concerns, and fear of judgment, AI chatbots have emerged as alternative sources of academic and emotional assistance. Understanding the factors influencing students' willingness to seek help through AI chatbots is important for enhancing technology-based support systems in higher education.

Objectives:
This study aimed to examine the influence of perceived usefulness, perceived ease of use, privacy, fear of judgment, and accessibility on AI chatbot help-seeking behaviour among university undergraduates.

Methods:
A quantitative cross-sectional survey design was employed. Data were collected from 103 undergraduate students at the University of Peradeniya using a structured questionnaire. The study was guided by the Technology Acceptance Model (TAM) and Help-Seeking Behaviour Theory. Reliability analysis, descriptive statistics, Pearson correlation analysis, and multiple regression analysis were conducted using SPSS.

Results:
The findings revealed significant positive relationships between all independent variables and AI chatbot help-seeking behaviour. Multiple regression analysis indicated that the model explained 88.9% of the variance in help-seeking behaviour ($R^2 = 0.889$). Perceived usefulness ($\beta = 0.469$, $p < 0.001$), perceived ease of use ($\beta = 0.276$, $p < 0.001$), and accessibility ($\beta = 0.272$, $p < 0.001$) emerged as significant predictors of AI chatbot help-seeking behaviour. However, privacy ($p = 0.198$) and fear of judgment ($p = 0.993$) were not significant predictors.

Conclusion:
The study concludes that technology acceptance factors and accessibility play a significant role in influencing AI chatbot help-seeking behaviour among university students. The findings highlight the growing potential of AI chatbots as supplementary support tools within higher education and provide insights for institutions seeking to integrate AI-based student support services.

Keywords: *Accessibility, Artificial Intelligence Chatbots, Help-Seeking Behaviour, Perceived Ease of Use, Perceived Usefulness*

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Introduction

Artificial Intelligence (AI) has emerged as one of the most transformative technologies of the twenty-first century, influencing numerous sectors including healthcare, education, business, and communication. Recent advances in generative AI have led to the widespread adoption of AI-powered chatbots capable of engaging in human-like conversations, providing information, offering recommendations, and supporting decision-making processes. Among university students, AI chatbots such as ChatGPT, Gemini, and Claude have become increasingly popular due to their ability to provide immediate, personalized, and accessible assistance.

University students frequently encounter academic, social, financial, and psychological challenges throughout their educational journey. Consequently, help-seeking behaviour plays a critical role in promoting student wellbeing and academic success. Help-seeking behaviour refers to the process through which individuals actively seek assistance from external sources when facing personal, emotional, or academic difficulties (Rickwood et al., 2005). Traditionally, students seek support from friends, family members, lecturers, academic advisors, or professional counsellors. However, several barriers often discourage students from accessing formal support services, including fear of judgment, concerns regarding privacy, stigma associated with seeking help, and limited accessibility of counselling services.

The rapid development of AI chatbots has introduced new possibilities for addressing these barriers. Unlike traditional counselling services, AI chatbots offer continuous availability, immediate responses, anonymity, and convenience. These characteristics make them particularly attractive to digitally literate students who are accustomed to obtaining information and support through technological platforms. As a result, AI chatbots are increasingly being utilized not only for academic assistance but also for emotional support, stress management, and problem-solving.

The adoption of AI technologies is commonly explained through the Technology Acceptance Model (TAM), developed by Davis (1989). TAM proposes that users' acceptance of technology is primarily determined by two factors: perceived usefulness and perceived ease of use. Perceived usefulness refers to the degree to which an individual believes that a technology enhances performance or assists in achieving desired outcomes. Perceived ease of use refers to the extent to which a technology is perceived as effortless to use. Numerous studies have validated TAM across different technological contexts, including educational technologies, online learning platforms, mobile applications, and artificial intelligence systems.

Recent research has demonstrated the relevance of TAM in understanding AI chatbot adoption. Lo (2023) reported that university students are more likely to use ChatGPT when they perceive it as useful for learning and academic support. Similarly, Farrokhnia et al. (2024) found that the perceived efficiency, convenience, and usefulness of generative AI significantly influence students' intentions to adopt AI technologies within educational settings. These findings suggest that perceived usefulness and ease of use remain important determinants of AI adoption among higher education students.

While TAM provides a strong explanation for technology acceptance, help-seeking behaviour involves additional psychological and contextual factors. Therefore, this study also draws upon Help-Seeking Behaviour Theory, which emphasizes factors such as accessibility, confidentiality, stigma, and fear of negative evaluation as important determinants of support-seeking decisions (Rickwood et al., 2005). In educational settings, students may avoid seeking assistance due to concerns about being judged by others or fears regarding the confidentiality of personal information. AI chatbots potentially reduce these barriers by providing private, anonymous, and easily accessible support.

Recent studies have further highlighted the growing role of AI chatbots in education. Kasneci et al. (2023) argued that generative AI tools have the potential to enhance personalized learning, provide immediate feedback, and support self-directed learning. Likewise, Chan and Hu (2023) found that students value AI technologies because of their accessibility, convenience, and ability to provide rapid responses. These characteristics may significantly influence students' willingness to seek help through AI-based platforms.

Despite growing international interest in AI chatbot adoption, empirical evidence from Sri Lanka remains limited. Furthermore, few studies have simultaneously examined both technological acceptance factors and help-seeking behaviour factors in explaining AI chatbot usage. Therefore, this study aims to investigate the influence of

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perceived usefulness, perceived ease of use, privacy, fear of judgment, and accessibility on AI chatbot help-seeking behaviour among undergraduate students at the University of Peradeniya.

Unlike previous studies that have primarily applied the Technology Acceptance Model to explain AI adoption or Help-Seeking Behavior Theory to explain psychological support-seeking, this study integrates both perspectives within a single framework. This integration provides a more comprehensive understanding of AI chatbot help-seeking behavior by considering both technology acceptance factors and psychological determinants. The findings contribute to the growing literature on AI-supported student services in higher education, particularly within the Sri Lankan context.

Conceptual Framework

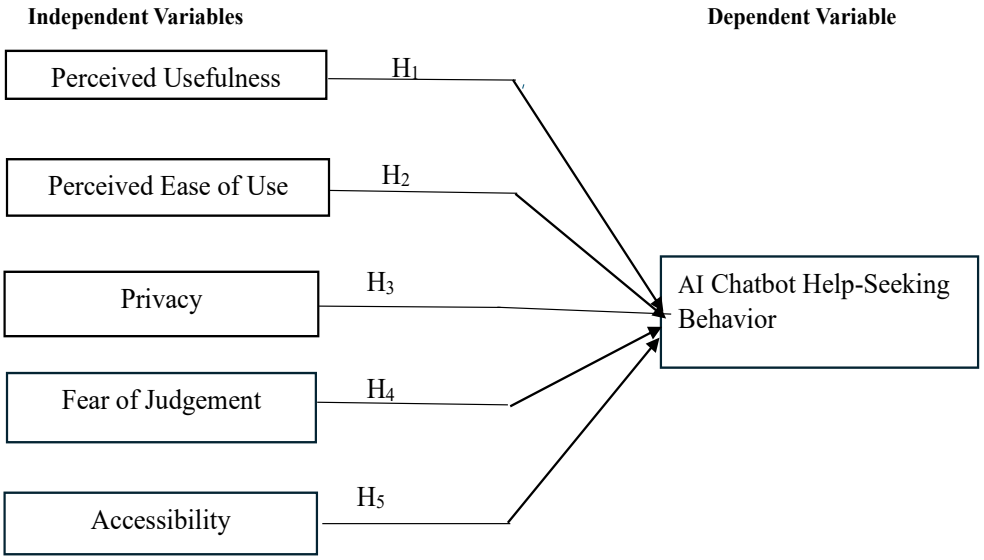

Figure 1 Developed by author using the Technology Acceptance Model (Davis, 1989) and Help-Seeking Behaviour Theory (Rickwood et al., 2005

The conceptual framework of this study was developed based on the Technology Acceptance Model (TAM) proposed by Davis (1989) and Help-Seeking Behaviour Theory proposed by Rickwood et al. (2005). The framework illustrates the hypothesized relationships between the independent variables and AI chatbot help-seeking behaviour among university undergraduates.

The Technology Acceptance Model serves as the primary theoretical foundation of the study and suggests that users' acceptance of technology is primarily influenced by perceived usefulness and perceived ease of use. Perceived usefulness refers to the degree to which individuals believe that using AI chatbots enhances their ability to solve problems, obtain support, and achieve desired outcomes. Perceived ease of use refers to the extent to which individuals perceive AI chatbots as simple and effortless to use. According to TAM, technologies that are perceived as useful and easy to use are more likely to be adopted and continuously utilized by users.

In addition to technological acceptance factors, the study incorporates Help-Seeking Behaviour Theory to explain the psychological and contextual factors that may influence students' decisions to seek support through AI chatbots. Based on this theory, privacy, fear of judgment, and accessibility were identified as important determinants of help-seeking behaviour. Privacy refers to students' perceptions of confidentiality when interacting with AI chatbots, fear of judgment refers to concerns regarding negative evaluation when seeking support, and accessibility refers to the ease and availability of obtaining assistance through AI platforms.

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The conceptual framework proposes that perceived usefulness, perceived ease of use, privacy, fear of judgment, and accessibility directly influence AI chatbot help-seeking behaviour among university undergraduates. Accordingly, five hypotheses (H_1–H_5) were developed to examine the relationships between these variables.

Research Objectives

The objectives of this study were:

- To examine the influence of perceived usefulness on AI chatbot help-seeking behaviour among university undergraduates.
- To examine the influence of perceived ease of use on AI chatbot help-seeking behaviour among university undergraduates.
- To examine the influence of privacy on AI chatbot help-seeking behaviour among university undergraduates.
- To examine the influence of fear of judgment on AI chatbot help-seeking behaviour among university undergraduates.
- To examine the influence of accessibility on AI chatbot help-seeking behaviour among university undergraduates.

Research Hypotheses

H_1: Perceived usefulness significantly influences AI chatbot help-seeking behaviour.

H_2: Perceived ease of use significantly influences AI chatbot help-seeking behaviour.

H_3: Privacy significantly influences AI chatbot help-seeking behaviour.

H_4: Fear of judgment significantly influences AI chatbot help-seeking behaviour.

H_5: Accessibility significantly influences AI chatbot help-seeking behaviour.

Research Design

This study employed a quantitative cross-sectional research design. A survey-based approach was selected because it enables the collection of data from a relatively large number of participants within a limited period while facilitating statistical examination of relationships between variables.

Study Population and Sample

The target population consisted of undergraduate students enrolled at the University of Peradeniya. Participants were selected using convenience sampling due to the accessibility of respondents and the exploratory nature of the study.

A total of 103 valid responses were obtained and included in the final analysis. Only undergraduate students who had experience using AI chatbots were eligible to participate in the study.

Data Collection Instrument

Data were collected using a structured self-administered questionnaire. The questionnaire consisted of three sections.

Section A gathered demographic information including gender, age, faculty, year of study, and previous experience with AI chatbots.

Section B examined patterns of AI chatbot usage, including frequency of use, primary purposes for use, and previous experiences with counselling services.

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Section C consisted of Likert-scale statements measuring the study constructs. Participants responded using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

The questionnaire measured:

Perceived Usefulness (4 items)

Perceived Ease of Use (4 items)

Privacy (4 items)

Fear of Judgment (4 items)

Accessibility (4 items)

Help-Seeking Behavior (5 items)

Theoretical Framework

Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Davis (1989), is one of the most widely used theoretical frameworks for explaining and predicting individuals' acceptance and use of information technology. The model proposes that users' intentions to adopt and continue using a technological system are primarily influenced by two key determinants: perceived usefulness and perceived ease of use.

Perceived usefulness refers to the extent to which an individual believes that using a particular technology will enhance their performance or help achieve desired outcomes. Perceived ease of use refers to the degree to which an individual believes that using the technology requires minimal effort. According to TAM, when users perceive a technology as useful and easy to use, they are more likely to develop positive attitudes toward it and subsequently adopt it for their intended purposes.

Over the past three decades, TAM has been extensively applied in studies examining the adoption of various technologies, including online learning platforms, mobile applications, e-learning systems, social media platforms, and artificial intelligence tools. Recent studies have also utilized TAM to explain students' adoption of AI-powered technologies such as ChatGPT and other generative AI chatbots. Findings consistently indicate that perceived usefulness and perceived ease of use are significant predictors of users' intentions to adopt and continue using AI technologies.

In the context of the present study, TAM serves as the primary theoretical framework because AI chatbot help-seeking behaviour is fundamentally associated with students' acceptance and utilization of AI technology. Students are more likely to seek assistance through AI chatbots when they perceive these systems as useful in addressing academic, personal, or emotional concerns and when they find them easy to access and interact with. Therefore, perceived usefulness and perceived ease of use were incorporated as key independent variables in this study.

Help-Seeking Behaviour Theory

While TAM provides a strong explanation for technology adoption, help-seeking behaviour involves additional psychological and contextual factors that extend beyond technological acceptance. Therefore, this study also draws upon Help-Seeking Behaviour Theory as a supporting theoretical perspective.

Help-seeking behaviour has been widely examined within counselling, educational, and health psychology. One of the most influential conceptualizations was proposed by Rickwood et al. (2005), who defined help-seeking behaviour as an adaptive coping process in which individuals actively seek assistance from external sources to address personal, emotional, academic, or psychological difficulties. The theory suggests that individuals' decisions to seek help are influenced by a range of factors, including accessibility of support services, perceived confidentiality, social stigma, fear of negative evaluation, and availability of assistance.

Within higher education settings, students frequently encounter challenges such as academic stress, emotional difficulties, and personal concerns. However, many students hesitate to seek formal support due to barriers such

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as fear of judgment, concerns about privacy, and limited accessibility of counselling services. These barriers can significantly influence whether students choose to seek assistance and from whom they seek support.

The emergence of AI chatbots has introduced a new avenue for help-seeking by providing immediate, accessible, and relatively anonymous forms of assistance. As a result, factors such as privacy, fear of judgment, and accessibility have become increasingly relevant in understanding students' willingness to utilize AI chatbots as sources of support. Consequently, these variables were incorporated into the present study based on the principles of Help-Seeking Behaviour Theory.

Integration of TAM and Help-Seeking Behaviour Theory

The present study integrates the Technology Acceptance Model (Davis, 1989) and Help-Seeking Behaviour Theory (Rickwood et al., 2005) to develop a comprehensive understanding of AI chatbot help-seeking behaviour among university undergraduates. TAM provides the technological perspective by explaining how perceived usefulness and perceived ease of use influence students' acceptance of AI chatbots. In contrast, Help-Seeking Behaviour Theory provides the psychological and contextual perspective by explaining how privacy, fear of judgment, and accessibility influence students' decisions to seek assistance through AI-based platforms.

The integration of these theories is particularly appropriate because AI chatbot help-seeking behaviour involves both technology adoption and support-seeking processes. While students must first perceive AI chatbots as useful and easy to use, their willingness to seek assistance also depends on factors such as perceived confidentiality, freedom from judgment, and ease of access. Together, these theories provide a comprehensive framework for examining the factors that influence AI chatbot help-seeking behaviour among university undergraduates.

Accordingly, the present study proposes that perceived usefulness, perceived ease of use, privacy, fear of judgment, and accessibility directly influence AI chatbot help-seeking behaviour. The conceptual framework developed from these theoretical foundations guided the formulation of the study hypotheses and empirical investigation.

Data Analysis

Data were analysed using the Statistical Package for Social Sciences (SPSS). The analysis included reliability analysis using Cronbach's Alpha, descriptive statistics, Pearson correlation analysis, and multiple regression analysis.

Cronbach's Alpha values were used to assess the internal consistency of the measurement scales. Descriptive statistics were used to summarize respondents' perceptions of the study variables. Pearson correlation analysis was conducted to determine relationships between variables, while multiple regression analysis was employed to identify significant predictors of AI chatbot help-seeking behaviour.

Statistical significance was assessed at the 0.05 significance level.

Results

Demographic Profile of Respondents

A total of 103 undergraduate students from the University of Peradeniya participated in the study. The demographic characteristics of the respondents are presented in Table 1.

Table 1. Demographic Profile of Respondents (N = 103)

Variable	Category	Frequency	Percentage (%)
Gender	Male Female	53 50	51.5% 48.5%
Age	18-21 years 21-23 years 24-26 years	12 45 46	11.7 43.7 44.7

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Year of Study	First Year Second Year Third Year Final Year	12 40 39 12	11.7 38.8 37.9 11.7
Faculty	Arts Management Science Agriculture Dental Science Engineering Medicine	38 37 15 5 5 2 1	36.9 35.9 14.6 4.9 4.9 1.9 1.0

The sample consisted of 53 male respondents (51.5%) and 50 female respondents (48.5%), indicating a relatively balanced gender distribution. The majority of respondents were between 21–23 years (43.7%) and 24–26 years (44.7%), representing 88.4% of the total sample. Regarding academic standing, most participants were in their second year (38.8%) and third year (37.9%) of study. In terms of faculty representation, the largest proportion of respondents belonged to the Faculty of Arts (36.9%) and the Faculty of Management (35.9%), followed by the Faculty of Science (14.6%). Smaller proportions were drawn from the Faculties of Agriculture, Dental Sciences, Computing, and Medicine.

Reliability Analysis

Cronbach's Alpha was used to assess the internal consistency of the measurement scales. The reliability coefficients are presented in Table 2.

Table 2: Reliability Analysis

Variable	**Number of Items**	**Cronbach's Alpha**
Perceived Usefulness	4	0.766
Perceived Ease of Use	4	0.915
Privacy	4	0.891
Fear of Judgement	4	0.509
Accessibility	4	0.942
Help-Seeking Behaviour	5	0.865

The results indicate acceptable to excellent reliability for most constructs. According to Nunnally and Bernstein (1994), Cronbach's Alpha values above 0.70 indicate satisfactory internal consistency. Perceived Ease of Use, Privacy, Accessibility, and Help-Seeking Behaviour demonstrated high reliability. Although the Fear of Judgment construct produced a relatively lower alpha value (0.509), it was retained due to its theoretical importance within the study framework.

Descriptive Statistics

Descriptive statistics were calculated to examine respondents' perceptions of each study variable.

Table 3: Descriptive Statistics

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Accessibility recorded the highest mean score (M = 4.604, SD = 0.498), suggesting that students strongly agreed that AI chatbots are readily available whenever support is required. Help-Seeking Behaviour also demonstrated a relatively high mean score (M = 4.103, SD = 0.451), indicating a generally positive attitude toward using AI chatbots for assistance. The remaining variables similarly recorded mean values above 3.8, reflecting favourable perceptions toward AI chatbot usage.

Variable	Mean	Standard Deviation
Perceived Usefulness	3.890	0.438
Perceived Ease of Use	3.995	0.330
Privacy	3.888	0.425
Fear of Judgement	3.915	0.482
Accessibility	4.604	0.498
Help-Seeking behaviour	4.103	0.451

Pearson Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships between the independent variables and AI Chatbot Help-Seeking Behaviour.

Table 4: Correlation Analysis

Variable	Pearson Correlation (r)	Significance
Perceived Usefulness	0.893	$p < 0.001$
Perceived Ease of Use	0.750	$p < 0.001$
Privacy	0.793	$p < 0.001$
Fear of Judgement	0.653	$p < 0.001$
Accessibility	0.882	$p < 0.001$

All independent variables demonstrated statistically significant positive relationships with AI Chatbot Help-Seeking Behaviour. Perceived Usefulness exhibited the strongest relationship (r = 0.893), followed by Accessibility (r = 0.882). These findings suggest that students who perceive AI chatbots as useful and accessible are more likely to engage in AI-based help-seeking behaviour.

Multiple Regression Analysis

Multiple regression analysis was conducted to identify the factors that significantly predict AI Chatbot Help-Seeking Behaviour.

Model Summary

Table 5: Model Summary

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Model	R	R^2	Adjusted R^2	Standard Error of Estimate	Durbin-Watson
1	0.943	0.889	0.884	0.154	1.874

The model summary indicates a strong relationship between the independent variables **(Perceived Usefulness, Perceived Ease of Use, Privacy, Fear of Judgement, and Accessibility)** and **AI Chatbot Help-Seeking Behaviour**. The multiple correlation coefficient **(R = 0.943)** demonstrates a very strong positive association between the predictors and the dependent variable.

The coefficient of determination **(R^2 = 0.889)** indicates that approximately **88.9% of the variance in AI Chatbot Help-Seeking Behaviour is explained by the five independent variables included in the regression model.** The adjusted R^2 value **(0.884)** suggests that after adjusting for the number of predictors, the model still explains **88.4% of the variance**, indicating a strong predictive capability.

The standard error of estimate **(0.154)** indicates that the observed values of AI Chatbot Help-Seeking Behaviour deviate from the predicted values by approximately 0.154 units, demonstrating a relatively high level of prediction accuracy.

The Durbin–Watson statistic of 1.874 is close to the ideal value of 2, suggesting that the residuals are independent and that there is no significant autocorrelation problem. Therefore, the assumption of independence of errors was satisfied.

ANOVA Results

Table 6: ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	18.445	5	3.689	155.80	<0.001
Residual	2.297	97	0.024		
Total	20.742	102			

The overall regression model was statistically significant ($F = 155.80$, $p < 0.001$), indicating that the independent variables collectively predict AI Chatbot Help-Seeking Behaviour.

Regression Coefficients

Table 7: Regression Coefficients

Varaible	B	Std.Error	t	p-value
Constant	-0.421	0.188	-2.237	0.028
Perceived Usefulness	0.469	0.077	6.117	<0.001
Perceived Ease of Use	0.276	0.076	3.612	<0.001
Privacy	0.089	0.069	1.295	0.198
Fear of Judgement	-0.001	0.051	-0.009	0.993

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Accessibility	0.272	0.068	3.969	<0.001

Perceived Usefulness, Perceived Ease of Use, and Accessibility emerged as significant predictors of AI Chatbot Help-Seeking Behaviour. However, Privacy and Fear of Judgment did not significantly influence help-seeking behaviour when all variables were analysed simultaneously.

Hypothesis Testing

Table 8: Hypothesis Testing Results

Hypothesis	**Decision**
H_1	Supported
H_2	Supported
H_3	Not Supported
H_4	Not Supported
H_5	Supported

The hypothesis testing results indicate that Perceived Usefulness (H1), Perceived Ease of Use (H2), and Accessibility (H5) were supported, showing a significant positive impact on AI Chatbot Help-Seeking Behaviour. However, Privacy (H3) and Fear of Judgement (H4) were not supported, as they did not show significant effects. Overall, the findings suggest that practical factors such as usefulness, ease of use, and accessibility are more influential in determining AI chatbot help-seeking behaviour than privacy and psychological concerns.

Table 8: Multicollinearity Assessment

Predictor Variable	**Tolerance**	**VIF**
Perceived Usefulness	0.642	1.558
Perceived Ease of Use	0.671	1.490
Privacy	0.812	1.232
Fear of Judgement	0.854	1.171
Accessibility	0.734	1.362

The multicollinearity assessment showed that all tolerance values exceeded **0.10**, while all VIF values were below the recommended threshold of **5.00**. Therefore, the independent variables did not demonstrate problematic multicollinearity, confirming that each predictor contributed uniquely to explaining AI Chatbot Help-Seeking Behaviour.

Overall Regression Assumption Summary

Table 9: Overall Regression

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Assumption	Statistical Test	Result	Decision
Model Fit	R^2	0.889	Strong explanatory power
Multicollinearity	VIF & Tolerance	VIF = 1.171–1.558	No issue detected
Independence of Errors	Durbin–Watson	1.874	Assumption satisfied
Normality	Histogram & P–P Plot	Approximately normal residuals	Assumption satisfied
Linearity	Residual Scatterplot	Random pattern	Assumption satisfied
Homoscedasticity	Residual Scatterplot	Constant variance	Assumption satisfied

The regression assumptions were assessed to ensure the reliability and validity of the multiple regression model. The results confirmed that all major assumptions required for regression analysis were satisfied. The multicollinearity assessment indicated that all Variance Inflation Factor (VIF) values were below the recommended threshold of 5, while tolerance values exceeded 0.10, confirming the absence of significant multicollinearity among the independent variables.

The Durbin–Watson statistic was within the acceptable range, indicating that the residuals were independent and that no autocorrelation problem existed. Furthermore, the histogram of standardized residuals and the Normal P–P Plot demonstrated that the residuals followed an approximately normal distribution. The scatterplot of standardized residuals against predicted values showed a random pattern without systematic trends, confirming the assumptions of linearity and homoscedasticity.

Therefore, the regression model satisfied the required statistical assumptions, indicating that the model results are appropriate for interpreting the relationship between the selected predictor variables and AI Chatbot Help-Seeking Behaviour.

Discussion

The present study investigated the factors influencing AI chatbot help-seeking behaviour among undergraduate students at the University of Peradeniya. Guided by the Technology Acceptance Model (Davis, 1989) and Help-Seeking Behaviour Theory (Rickwood et al., 2005), the study examined the effects of perceived usefulness, perceived ease of use, privacy, fear of judgment, and accessibility on students' willingness to seek support through AI chatbots.

The findings revealed that perceived usefulness was the strongest predictor of AI chatbot help-seeking behaviour. This finding strongly supports the Technology Acceptance Model, which proposes that users are more likely to adopt technologies when they perceive them as beneficial and capable of improving their performance (Davis, 1989). Students who believed that AI chatbots provide valuable guidance, support, and problem-solving assistance were significantly more likely to engage in help-seeking behaviour through these platforms. This finding is consistent with Lo (2023), who reported that perceived usefulness is a critical determinant of students' intention to use ChatGPT for academic and personal support. Similarly, Farrokhnia et al. (2024) found that students' perceptions of efficiency and usefulness significantly influence their acceptance of generative AI technologies.

Perceived ease of use also emerged as a significant predictor of AI chatbot help-seeking behaviour. This finding is consistent with previous TAM research, which suggests that technologies requiring minimal effort are more

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likely to be accepted by users. Students appear more willing to engage with AI chatbots when these systems are simple to access, easy to communicate with, and require minimal technical effort. This finding supports Venkatesh and Davis (2000), who identified perceived ease of use as an important determinant of technology acceptance. Furthermore, Chan and Hu (2023) reported that students value AI tools that provide intuitive and user-friendly interactions, further supporting the present findings.

Accessibility was another significant predictor of AI chatbot help-seeking behaviour. Among all examined variables, accessibility recorded the highest mean score, indicating that students highly value the ability to obtain support regardless of time and location. This finding aligns with recent research highlighting that the availability and convenience of AI systems strongly influence adoption decisions. Kasneci et al. (2023) argued that a key advantage of generative AI tools is their ability to provide immediate and continuous assistance. Similarly, Tlili et al. (2023) found that students perceive AI chatbots as accessible learning companions that complement traditional educational support services. The present study extends these findings by demonstrating that accessibility contributes not only to educational technology adoption but also to students' willingness to seek support through AI-based platforms.

The findings may also reflect the unique context of undergraduate students at the University of Peradeniya. As one of the largest residential universities in Sri Lanka, students frequently encounter academic pressure, adjustment challenges, and the need for timely assistance. In such circumstances, AI chatbots may be perceived as convenient supplementary sources of support that can be accessed immediately without the scheduling limitations associated with traditional support services. Furthermore, increasing digital familiarity among university students may contribute to their willingness to use AI chatbots for information seeking, academic assistance, and problem-solving purposes.

Contrary to expectations, privacy did not significantly predict AI chatbot help-seeking behaviour in the regression analysis, despite demonstrating a strong positive correlation. This finding differs from traditional help-seeking literature, which often identifies confidentiality concerns as important factors influencing support-seeking decisions. One possible explanation is that contemporary university students have become increasingly accustomed to interacting with digital platforms and may therefore evaluate AI chatbots based on their practical benefits rather than privacy considerations alone. Although students may perceive AI chatbots as relatively private and confidential, privacy did not provide a significant unique contribution when stronger technological predictors were considered. Similar observations have been reported in recent AI adoption research, where perceived usefulness and convenience frequently outweigh privacy concerns among younger technology users.

Fear of judgment also failed to emerge as a significant predictor within the regression model. This finding contrasts with Help-Seeking Behaviour Theory, which frequently identifies fear of negative evaluation as a barrier to seeking support (Rickwood et al., 2005). Traditionally, students may avoid counselling services because of concerns regarding stigma, embarrassment, or social evaluation. However, the present findings suggest that AI chatbot help-seeking behaviour may be influenced more strongly by perceived utility and convenience than by attempts to avoid judgment. One possible explanation is that today's university students are highly familiar with digital technologies and increasingly view AI chatbots as routine educational and information-support tools rather than sensitive counselling platforms. Consequently, practical considerations such as usefulness, convenience, and accessibility may outweigh psychological concerns when deciding whether to seek assistance. This suggests that AI-mediated help-seeking may differ fundamentally from traditional face-to-face help-seeking, where fear of judgment and confidentiality concerns often represent stronger barriers.

Although the Fear of Judgment construct was retained due to its theoretical importance, its relatively low Cronbach's Alpha value (0.509) indicates limited internal consistency among the measurement items. This lower reliability may have reduced the reliability of the construct and limited its ability to explain unique variance in the regression model, which may partly account for its non-significant predictive effect. Therefore, findings related to fear of judgment should be interpreted with caution. Future research should refine and validate the measurement items to enhance the reliability and conceptual accuracy of this construct.

Although privacy and fear of judgment showed significant positive correlations with AI chatbot help-seeking behaviour, they did not remain significant predictors in the regression model. This pattern may indicate that

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privacy and fear of judgment share variance with technology acceptance variables, particularly perceived usefulness and accessibility. When these stronger predictors are entered simultaneously into the regression model, the unique contribution of privacy and fear of judgment becomes negligible, despite their significant bivariate relationships with help-seeking behaviour. This suggests that students who perceive AI chatbots as useful, accessible, and convenient may simultaneously perceive them as sufficiently private and less threatening, reducing the independent influence of psychological and privacy-related factors.

Overall, the findings indicate that technology acceptance factors play a more substantial role than psychological barriers in influencing AI chatbot help-seeking behaviour. While privacy and fear of judgment remain theoretically relevant considerations, students appear primarily motivated by the practical advantages offered by AI chatbots, particularly their usefulness, ease of use, and accessibility. These findings reinforce the continued relevance of the Technology Acceptance Model in explaining AI adoption and highlight the emerging role of AI chatbots as supplementary support tools within higher education environments.

The study contributes to existing literature by integrating technology acceptance and help-seeking perspectives within a single analytical framework. Furthermore, it provides empirical evidence from the Sri Lankan higher education context, where research on AI chatbot adoption and digital support systems remains limited. The findings extend current understanding by demonstrating that AI chatbot help-seeking behaviour among university students is influenced primarily by technology acceptance factors, particularly perceived usefulness, ease of use, and accessibility, rather than psychological barriers alone.

The findings have important implications for higher education institutions. Universities may integrate AI chatbots into existing student support systems to provide immediate academic guidance, administrative information, and preliminary emotional support. However, AI chatbots should complement rather than replace professional counselling services, particularly for students experiencing complex psychological difficulties. Institutions should also establish clear policies regarding ethical AI use, transparency, data governance, confidentiality, and responsible AI implementation to ensure student trust and the safe use of AI-supported services. By adopting a balanced approach that combines technological innovation with appropriate human support mechanisms, universities can enhance accessibility to student services while maintaining the quality, safety, and ethical standards of support provision.

Limitations of the Study

Despite its contributions, this study has several limitations that should be considered when interpreting the findings.

First, the study was conducted using a sample of undergraduate students from the University of Peradeniya. Although the university represents one of the leading higher education institutions in Sri Lanka, the majority of respondents were from the Faculties of Arts and Management. Students from other faculties, universities, or professional disciplines may demonstrate different perceptions toward AI chatbot use due to variations in technological exposure, academic culture, learning requirements, and familiarity with digital tools. Therefore, caution should be exercised when generalizing these findings beyond the present study population. Future research should include students from multiple universities and diverse academic disciplines to enhance external validity and improve the generalizability of findings.

Second, the study employed a convenience sampling technique. While this method facilitated efficient data collection, it may have introduced sampling bias and limited the representativeness of the sample. Future studies using probability sampling techniques may provide more robust findings and improve the generalizability of results.

Third, the study included only undergraduate students who had previous experience using AI chatbots. Therefore, the findings primarily explain continued AI chatbot use and help-seeking behaviour among existing users rather than the initial adoption decision. Students who have never used AI chatbots may be influenced by different technological, psychological, or contextual factors when deciding whether to adopt such tools. Future research should compare AI chatbot users and non-users to develop a more comprehensive understanding of initial AI chatbot adoption.

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Fourth, the research adopted a cross-sectional design, collecting data at a single point in time. Consequently, the study was unable to establish causal relationships between the independent variables and AI chatbot help-seeking behaviour. Longitudinal studies are recommended to examine how perceptions, attitudes, and help-seeking behaviours toward AI chatbots change over time.

Fifth, data were collected through self-reported questionnaires. Self-report measures may be affected by social desirability bias, response bias, and inaccuracies in participants' perceptions. Although respondents were assured of confidentiality, some individuals may have provided socially acceptable responses rather than their actual opinions or experiences.

Sixth, the study focused on variables derived from the Technology Acceptance Model and Help-Seeking Behaviour Theory. However, other potentially influential factors such as trust in artificial intelligence, perceived accuracy of chatbot responses, digital literacy, emotional intelligence, previous counselling experiences, and attitudes toward mental health services were not examined. Incorporating these variables in future research may provide a more comprehensive understanding of AI chatbot adoption and help-seeking behaviour.

Finally, although most constructs demonstrated satisfactory reliability, the Fear of Judgment construct recorded a relatively low Cronbach's Alpha value (0.509), indicating limited internal consistency. This lower reliability may have reduced the construct's ability to explain unique variance in AI chatbot help-seeking behaviour and may have contributed to the non-significant regression finding. Therefore, results related to this construct should be interpreted with caution. Future studies should refine and validate the measurement items to improve the reliability and internal consistency of the scale.

Despite these limitations, the study provides valuable insights into the factors influencing AI chatbot help-seeking behaviour among university undergraduates and contributes to the growing body of literature on artificial intelligence adoption within higher education contexts.

Conclusion

This study examined the factors influencing AI chatbot help-seeking behaviour among undergraduate students at the University of Peradeniya by integrating the Technology Acceptance Model and Help-Seeking Behaviour Theory. The findings demonstrated that perceived usefulness, perceived ease of use, and accessibility significantly predict students' willingness to seek support through AI chatbots. These results indicate that students are more likely to engage with AI chatbots when they perceive them as valuable, user-friendly, and easily accessible. Although privacy and fear of judgment showed positive relationships with AI chatbot help-seeking behaviour, they did not significantly contribute as predictors in the final model.

Theoretically, this study extends existing knowledge by applying technology acceptance and help-seeking perspectives to understand AI-mediated support-seeking behaviour among university students. The findings highlight that both technological perceptions and psychological considerations contribute to students' decisions to use AI chatbots for assistance, providing a foundation for further research on AI-supported help-seeking in educational contexts.

From a practical perspective, the study suggests that universities can consider AI chatbots as complementary tools to enhance student support services. By focusing on usability, accessibility, and perceived value, institutions can develop AI-based systems that assist students with academic guidance, information access, and initial support needs while complementing existing human-centred services.

Future studies should compare AI chatbot help-seeking behaviour with traditional help-seeking from counsellors, lecturers, peers, and family members. Longitudinal research may investigate how students' perceptions evolve as AI technologies become increasingly integrated into higher education. Researchers may also examine additional predictors including trust in AI, perceived accuracy, digital literacy, AI literacy, prior counselling experiences,

emotional intelligence, and perceived credibility of chatbot responses. Comparative studies across universities and cultural settings would further enhance understanding of AI-supported help-seeking behaviour.

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References

1. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 1989;13(3):319–340.
2. Rickwood D, Deane FP, Wilson CJ, Ciarrochi J. Young people's help-seeking for mental health problems. Aust e-J Adv Ment Health. 2005;4(3):218–251.
3. Davis FD, Bagozzi RP, Warshaw PR. User acceptance of computer technology: a comparison of two theoretical models. Manage Sci. 1989;35(8):982–1003.
4. Venkatesh V, Davis FD. A theoretical extension of the Technology Acceptance Model: four longitudinal field studies. Manage Sci. 2000;46(2):186–204.
5. Venkatesh V, Morris MG, Davis GB, Davis FD. User acceptance of information technology: toward a unified view. MIS Q. 2003;27(3):425–478.
6. Ajzen I. The theory of planned behavior. Organ Behav Hum Decis Process. 1991;50(2):179–211.
7. Fishbein M, Ajzen I. Belief, attitude, intention and behavior: an introduction to theory and research. Reading (MA): Addison-Wesley; 1975.
8. Nunnally JC, Bernstein IH. Psychometric theory. 3rd ed. New York: McGraw-Hill; 1994.
9. Fitzpatrick KK, Darcy A, Vierhile M. Delivering cognitive behavioral therapy to young adults with symptoms of depression and anxiety using a fully automated conversational agent (Woebot): a randomized controlled trial. JMIR Ment Health. 2017;4(2):e19.
10. Winkler R, Söllner M. Unleashing the potential of chatbots in education: a state-of-the-art analysis. Acad Manag Proc. 2018;2018(1):15903.
11. Okonkwo CW, Ade-Ibijola A. Chatbots applications in education: a systematic review. Comput Educ Artif Intell. 2021;2:100033.
12. Dwivedi YK, Hughes L, Ismagilova E, Aarts G, Coombs C, Crick T, et al. Artificial intelligence (AI): multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. Int J Inf Manage. 2021;57:101994.
13. Kasneci E, Sessler K, Küchemann S, Bannert M, Dementieva D, Fischer F, et al. ChatGPT for good? On opportunities and challenges of large language models for education. Learn Individ Differ. 2023;103:102274.
14. Tlili A, Shehata B, Adarkwah MA, Bozkurt A, Hickey DT, Huang R, et al. What if the devil is my guardian angel? ChatGPT as a case study of using chatbots in education. Smart Learn Environ. 2023;10(1):15.
15. Lo CK. What is the impact of ChatGPT on education? A rapid review of the literature. Interact Learn Environ. 2023;31(8):1–15.
16. Cotton DRE, Cotton PA, Shipway JR. Chatting and cheating? Ensuring academic integrity in the era of ChatGPT. Innov Educ Teach Int. 2023;60(6):1–12.
17. Chan CKY, Hu W. Students' voices on generative artificial intelligence in higher education: perspectives, benefits and challenges. Educ Sci. 2023;13(11):1127.
18. Dwivedi YK, Kshetri N, Hughes L, Slade EL, Jeyaraj A, Kar AK, et al. So what if ChatGPT wrote it? Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy. Int J Inf Manage. 2023;71:102642.
19. Sallam M. ChatGPT utility in healthcare education, research, and practice: systematic review on the promising perspectives and valid concerns. Healthcare. 2023;11(6):887.
20. Baidoo-Anu D, Ansah LO. Education in the era of generative artificial intelligence: understanding the potential benefits of ChatGPT in promoting teaching and learning. Educ Sci. 2023;13(11):1125.
21. Farrokhnia M, Banihashem SK, Noroozi O, Wals A. A SWOT analysis of ChatGPT: implications for educational practice and research. Comput Educ Artif Intell. 2024;5:100194.

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22. Zhai X. ChatGPT user studies in education: a review of the literature. Educ Technol Res Dev. 2024;72(2):1–24.

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OP 02

A Quantitative Study on Emotional Intelligence and Conflict Resolution Styles As Predictors of Relationship Satisfaction

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Background:

Relationship satisfaction (RS) is an important predictor of wellbeing and relationship stability. Although emotional intelligence (EI), tendency to forgive (TTF), and Effective Conflict Resolution Styles (ECRS) influence relationship outcomes, limited research has examined their combined role within the Sri Lankan context.

Objective/s:

This study investigated EI, TTF, and ECRS as predictors of RS among adults in romantic relationships in the Western Province of Sri Lanka. Guided by the Ability Model of Emotional Intelligence, EI was hypothesized to mediate the relationships between TTF, ECRS, and RS.

Methods: A predictive correlational design was employed. Data were collected from 114 adults using convenience sampling. Participants completed the Tendency to Forgive Scale (TTF), Conflict Resolution Styles Inventory (CRSI), Relationship Assessment Scale (RAS), and Wong and Law Emotional Intelligence Scale (WLEIS). Hierarchical multiple regression and mediation analyses were conducted while controlling for age, gender, relationship status, relationship duration, educational qualification, and socioeconomic status.

Results:

EI significantly predicted RS after controlling for demographic variables ($\beta = .34$, $p = .001$), with the final model explaining 20.5% of the variance ($R^2 = .205$). ECRS initially demonstrated a significant negative association with RS ($\beta = -.21$, $p = .023$); however, this relationship became non-significant after controlling for EI and demographic variables. Mediation analysis indicated that EI significantly mediated the relationship between ECRS and RS (indirect effect = −0.107, 95% CI [−0.23, −0.03]). In contrast, EI did not significantly mediate the relationship between TTF and RS.

Conclusion/s:

EI emerged as a key predictor of RS. The findings suggest that the relationship between conflict resolution behaviours and RS may operate through emotional competencies. The absence of an association between TTF and RS may indicate that forgiveness alone is insufficient to enhance relationship satisfaction and may depend on additional interpersonal factors. Findings should be interpreted cautiously due to convenience sampling and the Western Province–based sample. Cultural influences may partly explain these findings, although they were not directly measured.

Keywords: *Effective Conflict Resolution Styles (ECRS), Emotional Intelligence (EI), Relationship Satisfaction (RS), Tendency to Forgive (TTF).*

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OP 03

The Relationship Between Stress, Academic Performance, And Employment Status Among University Students in Sri Lanka

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Background: Perceived stress is increasingly recognised as an important factor influencing academic outcomes among university students. Although extensive evidence exists in Western contexts, limited research has examined the relationship between stress and academic performance in Sri Lanka, particularly with respect to employment status. Understanding these relationships is essential for developing culturally appropriate interventions that promote student well-being and academic success.

Objective/s: This study investigated the relationship between perceived stress, academic performance, and employment status among undergraduate university students in Sri Lanka.

Methods: A quantitative cross-sectional design was employed. Data were collected from 128 undergraduate students in Sri Lanka through an online survey, with 123 valid responses included in the final analysis. Perceived stress was measured using the 14-item Perceived Stress Scale (PSS-14), while Academic performance was assessed using self-reported semester grades, which may be subject to reporting bias. Employment status was categorised as employed or unemployed. Employment status was categorised as employed or unemployed. Pearson correlation, independent samples t-tests, and multiple linear regression analyses were conducted using IBM SPSS Statistics.

Results: Perceived stress was significantly negatively associated with academic performance, $r(121) = -0.29$, $p = .002$. Multiple regression analysis revealed that perceived stress was a significant predictor of academic performance ($\beta = -0.31$, $p = .001$), although the model explained only 9.7% of the variance ($R^2 = .097$), suggesting that other factors also contribute to academic performance. In contrast, employment status was not a significant predictor ($\beta = 0.08$, $p = .36$). No significant difference in stress levels was observed between employed and unemployed students, $t(121) = -0.89$, $p = .37$.

Conclusion: Higher perceived stress was significantly associated with poorer academic performance among Sri Lankan university students, while employment status was not significantly associated with stress or academic performance in this sample. Given the cross-sectional design, convenience sampling, and simplified employment classification, these findings should be interpreted cautiously and do not imply causality. The results nevertheless highlight the importance of culturally responsive stress management interventions within higher education institutions.

Keywords: *academic performance, employment status, perceived stress, Sri Lanka, university students.*

Acknowledgment: The author wishes to thank the supervisor for guidance throughout the research process and all participants who contributed to this study. No external funding was received.

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OP 04

The Impact of Emotional Labor and Emotional Exhaustion on Equanimity among Healthcare Professionals in Sri Lanka's Western Province

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Background: Healthcare professionals routinely encounter emotionally demanding situations that require them to manage and regulate their emotions, known as emotional labour. Prolonged emotional labour may contribute to emotional exhaustion, potentially affecting equanimity, defined as the ability to maintain emotional balance under stressful conditions. Despite growing evidence on emotional labour and burnout, the role of equanimity among healthcare professionals in Sri Lanka remains underexplored.

Objectives: To examine the influence of emotional labour and emotional exhaustion on equanimity among healthcare professionals and to investigate differences in emotional labour, emotional exhaustion, and equanimity across demographic variables, including gender, age, educational qualification, marital status, professional role, years of experience, and weekly working hours.

Methods: A cross-sectional quantitative study was conducted among 119 healthcare professionals in Sri Lanka's Western Province using convenience sampling. Data were collected using the Modified Emotional Labor Scale (ELS), the Copenhagen Burnout Inventory (CBI), the Equanimity Scale-16 (ES-16), and a demographic questionnaire. Simple linear regression analyses examined the predictive relationships between emotional labour, emotional exhaustion, and equanimity, and one-way ANOVA was used to examine demographic differences.

Results: Emotional labour did not significantly predict equanimity ($\beta = .17$, $R^2 = .03$, $p = .060$). However, emotional exhaustion significantly predicted equanimity ($\beta = .31$, $R^2 = .10$, $p = .001$). Emotional labour differed significantly by gender ($p = .016$) and weekly working hours ($p = .004$). Equanimity differed significantly only by weekly working hours, whereas emotional exhaustion showed no significant demographic differences. No significant differences were observed across age, marital status, educational qualification, professional role, or years of experience.

Conclusions: Emotional exhaustion demonstrated a stronger association with equanimity than emotional labour. Given the cross-sectional design and convenience sampling, causal inferences cannot be drawn, and the findings may not be generalizable to all healthcare professionals. The findings highlight the importance of resilience training, workload management strategies, and psychological support programmes to promote psychological well-being and maintain equanimity in healthcare settings.

Keywords: *emotional exhaustion, emotional labour, equanimity, healthcare professionals, psychological well-being*

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OP 05

Exploring the relationship between stress and depression among advanced level students in Gampaha District, Sri Lanka

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Background: While substantial global literature establishes a link between academic stress and depression, findings vary across cultural contexts. This study investigates this relationship among Sri Lankan Advanced Level students in Gampaha District, a high-pressure setting dominated by intensive tuition classes.
Objectives: The general objective was to assess the relationship between stress and depression levels among Advanced Level students in Gampaha District, Sri Lanka. Specific objectives were to assess the prevalence of stress and depression within this sample.

Methods: A descriptive cross-sectional study was conducted with 388 students from private tuition classes in Gampaha District, using convenience sampling. Data were collected using the Depression, Anxiety, and Stress Scale (DASS-21). Due to the non-normal distribution of the data, Spearman's correlation was used to assess the primary relationship. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 30.0.

Results: Spearman correlation revealed a non-significant, very weak positive relationship between stress and depressive symptoms ($r = .014$, $p = .781$). This unexpected finding may be explained by the high-pressure academic environment triggering coping mechanisms or resilience factors that buffer the stress-depression pathway. Alternatively, cultural and contextual factors unique to Sri Lankan students may influence how stress and depression manifest. A high prevalence of moderate to severe symptoms was noted, with 33.5% of students reporting moderate depressive symptoms and 21.1% reporting moderate stress symptoms. In terms of overall distribution, 56.7% of students reported mild to extremely severe stress, while 76.5% reported mild to extremely severe depressive symptoms.

Conclusion: This non-significant finding suggests that within the Sri Lankan context, the stress-depression relationship may be influenced by factors such as resilience and cultural coping mechanisms. As these variables were not assessed, this remains a hypothesis for future research. Convenience sampling may limit generalizability. Future studies are needed to identify protective factors for culturally attuned interventions.

Keywords: *Adolescents, Depression, Mental Health, Sri Lanka, Stress*

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OP 6

Association of Emotional Resilience, Mood, and Working Hours with Sedentary Behaviour in Young Employees

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Abstract

Background: Sedentary behaviour is a growing public health concern worldwide and contributes to adverse health outcomes, including cardiovascular diseases and diabetes. Although sedentary behaviour is prevalent among young desk-based employees in Sri Lanka, limited evidence exists regarding the psychological determinants influencing this behaviour.

Objective/s: This study aimed to examine the association of emotional resilience, mood, and working hours with sedentary behaviour among young desk-based employees in the Western Province of Sri Lanka.

Methods: A cross-sectional quantitative study was conducted among 126 desk-based employees aged 22-35 years recruited through convenience sampling in the Western Province of Sri Lanka. Data were collected using standardized self-report instruments, including the Brief Resilience Scale (BRS), the Positive and Negative Affect Schedule (PANAS), and the International Physical Activity Questionnaire- Short-Form (IPAQ-SF).

Results: Emotional resilience was negatively associated with sedentary behaviour ($\beta = -0.19$, $p = .031$). Negative mood was positively associated with sedentary behaviour ($\beta = 0.58$, $p < .001$). Furthermore, negative mood emerged as the strongest predictor of sedentary behaviour in the final regression model ($\beta = 0.57$, $p < .001$), explaining 34% of the variance ($R^2 = .34$). Exploratory mediation analysis showed that negative mood significantly mediated the relationship between emotional resilience and sedentary behaviour (indirect effect = −86.69, 95% CI [−167.57, −28.48]), suggesting a potential psychological pathway through which resilience may be associated with sedentary behaviour. In contrast, positive mood and working hours were not significantly associated with sedentary behaviour ($p > .05$).

Conclusion/s: These findings underscore the critical role of psychological factors, particularly negative mood and emotional resilience, in influencing sedentary behaviour among young desk-based employees. They highlight the importance of workplace health strategies integrating resilience-building programmes, mental health support for employees, and interventions to reduce sedentary time, including scheduled movement breaks and organisational policies, which may contribute to healthier behaviours, improved employee well-being, and workplace productivity.

Keywords: *desk-based employees, emotional resilience, negative mood, positive mood, sedentary behaviour*

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OP 01

Beyond Functionality: Empathy-Driven UI/UX for Emotionally Supportive Digital Mental Health

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Introduction: Many digital mental health applications prioritise functionality over emotional experience. For individuals living with depression, this results in interfaces that feel overwhelming, impersonal, or difficult to engage with. Design is rarely treated as an active component of care, leaving a significant gap in emotionally responsive digital support.

Objectives: This study investigates how empathy-driven, design-led UI/UX approaches can contribute to more emotionally supportive digital mental health experiences for users living with depression, with particular attention to emotional tone, colour psychology, accessibility, cultural and faith-sensitive personalisation, multilingual localisation, and trust-based engagement.

Methods: A qualitative, design-led methodology was adopted. An anonymous survey (n=30), five semi-structured interviews, and supplementary reflective conversations informed the iterative design and development of InBetween, a prototype depression-focused web application. Evaluation combined moderated and unmoderated usability testing, centring emotional experience, perceived safety, and trust over task-completion metrics.

Results: Participants responded more strongly to how the interface made them feel than to feature complexity. Visual softness, gentle interaction pacing, privacy-aware features, and optional personalisation were associated with increased perceptions of emotional comfort, safety, and trust. Cultural context, language, and spiritual preference further shaped user engagement.

Conclusions: UI/UX design is not a neutral layer in digital mental health systems. When grounded in empathy, colour psychology, accessibility, cultural sensitivity, and trust-based engagement, design can meaningfully shape how emotionally supportive and approachable a system feels for users living with depression.

Keywords: *accessibility, cultural sensitivity, digital mental health, empathy-driven design, emotional design*

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Introduction

Digital mental health technologies have become increasingly accessible, offering scalable support for individuals experiencing psychological distress. However, engagement remains a significant challenge for individuals living with depression, whose symptoms often include low energy, reduced motivation, and difficulty concentrating [1,2]. When applications present complex layouts or cognitively demanding interactions, they can exacerbate emotional fatigue rather than alleviate it [1]. Emotionally neutral or purely functional interfaces may feel overwhelming or alienating to users in distress, leading to disengagement when support is needed most [1,2].

A key limitation of current systems is the peripheral positioning of UI/UX design. While many platforms incorporate evidence-based therapeutic content, UI/UX design is often underemphasised relative to clinical functionality rather than treated as a psychologically meaningful component of care [3,4]. Research in emotional design, human-computer interaction, and colour psychology suggests visual tone, layout clarity, and interaction pacing influence how safe, calm, and supported users feel [13,14,15]. For individuals living with depression, these design elements may build trust and sustain engagement despite cognitive and motivational barriers [4,15].

Many systems adopt generalised, 'one-size-fits-all' approaches that overlook the contextual nature of mental health experiences. Cultural background, spiritual beliefs, and language shape how individuals conceptualise distress and seek help [5,6]. Despite this, few tools offer optional, user-controlled pathways reflecting these dimensions. Although multilingual interfaces improve accessibility, they often prioritise literal translation over emotional tone or cultural nuance [7]. Early financial commitment may also create psychological pressure before users establish comfort and trust [2,8].

This paper presents In-between, a design-led digital mental health prototype investigating how empathy-driven UI/UX supports emotional experience for individuals living with depression. It integrates empathy-driven design principles, accessibility-informed layouts, culturally and spiritually optional personalisation, multilingual emotional localisation, and low-pressure engagement models. This study examines how these design decisions influence emotional comfort, trust, and engagement.

Methods

Research design. The research utilised a qualitative, design-led approach grounded in human-centred design (HCD) principles [4]. Rather than treating design as a static output, the research positioned UI/UX as a method of inquiry into emotional experience, trust, and engagement [4]. This methodology addresses a limitation in e-mental health research, where detailed HCI design features are often omitted from treatment evaluations [3]. By prioritising contextual insight over statistical generalisability, this study seeks to define design requirements for sustained digital engagement [3,4].

Participants. The study focused on young adults (aged 18–35), a population for whom sociocultural pressures significantly shape mental health needs and help-seeking behaviours [6]. Participants were recruited from diverse cultural and geographical backgrounds to explore mental health stigma, trust, and digital help-seeking. Among the survey participants (n = 30), 60% identified as South Asian, 33.3% as Western/European, and the remainder as Southeast Asian. Participants were born across Sri Lanka (60%), the United States, Italy, Japan, and the United Kingdom, representing collectivist and individualistic cultural contexts. The interview participants (n = 5) similarly represented diverse cultural backgrounds, including Sri Lankan, Italian, British, and American participants. This diversity enabled exploration of how cultural background shaped perceptions of mental health stigma, emotional safety, trust, and willingness to engage with digital mental health technologies. Many participants reported hesitating to seek professional mental health support due to stigma, privacy concerns, or uncertainty [5,9], making them particularly relevant for exploring trust and early-stage engagement.

Data collection. An anonymous online survey (n=30) explored experiences with mental health applications, focusing on emotional safety, tone, visual comfort, privacy, and trust. Five semi-structured interviews with participants from diverse cultural backgrounds explored emotional needs, cultural influences, faith-related perspectives, and expectations of digital mental health tools. Supplementary reflective conversations informed understanding of emotional comfort, cultural sensitivity, and trust in digital mental health experiences. Competitor analysis identified design gaps. Although the interview sample was small, the study adopted an exploratory, design-led qualitative approach aimed at generating rich contextual insights rather than statistical representation. The interview sample was not selected to demonstrate formal thematic saturation. Instead, its adequacy was

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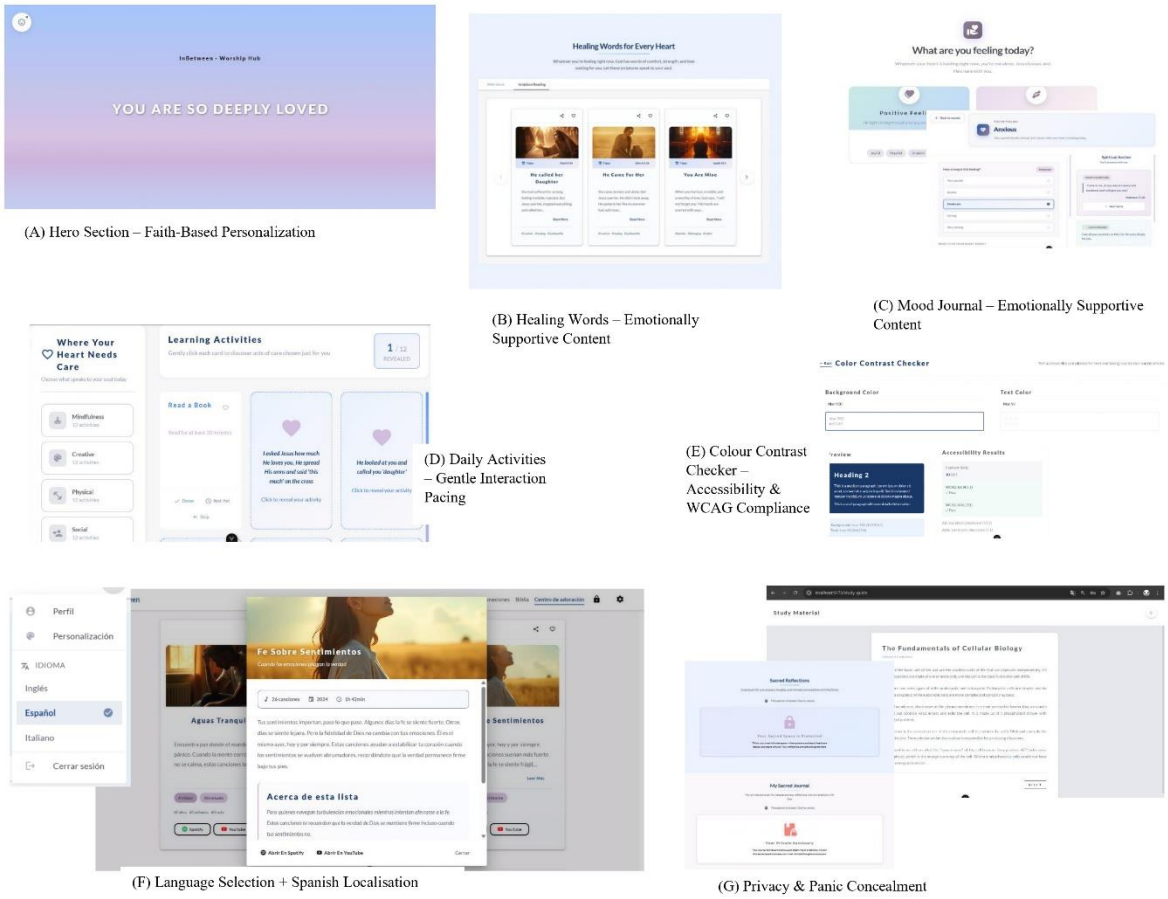
considered in terms of information power [18], reflecting the focused aim, the specificity of the participant group, and the depth afforded by the semi-structured interview format.

Data analysis. Survey responses, interview transcripts, and insights from supplementary reflective conversations were reviewed iteratively to examine participants' perspectives on the study's design considerations, including emotional comfort, trust, privacy, interaction pacing, cultural sensitivity, and optional personalisation. Participant insights were interpreted alongside the literature review, competitor analysis, and design research to refine the prototype's design requirements. Given the exploratory nature of the research, the analysis focused on synthesising design insights rather than developing a formal thematic framework.

Design-led prototyping. InBetween was developed as an iterative research artefact rather than a production system. The design process focused on emotional tone, visual softness, interaction pacing, privacy awareness, and optional personalisation. Accessibility followed WCAG 2.1 AA guidelines, with attention to how readability, contrast, and layout contribute to emotional ease rather than technical compliance. The scope of the prototype focused on selected empathy-driven design features central to the research objectives, including the optional faith-based personalisation mode and the trust-based free engagement model. The prototype was developed as a research artefact to investigate these concepts rather than as a commercial application.



(A) Hero Section – Faith-Based Personalization

(B) Healing Words – Emotionally Supportive Content

(C) Mood Journal – Emotionally Supportive Content

(D) Daily Activities – Gentle Interaction Pacing

(E) Colour Contrast Checker – Accessibility & WCAG Compliance

(F) Language Selection + Spanish Localisation

(G) Privacy & Panic Concealment

Figure 1: key interface components of the InBetween research prototype

Figure 1 illustrates key interface components of the InBetween research prototype. These include the optional faith-based personalisation mode (Fig. 1A), emotionally supportive content (Fig. 1B–C), gentle interaction pacing (Fig. 1D), accessibility-informed design (Fig. 1E), multilingual localisation (Fig. 1F), and privacy-aware features, including panic concealment and protected spaces (Fig. 1G).

High-resolution interface illustrations of the research prototype are available at: https://onedrive.live.com/?id=%2Fpersonal%2Fe4a88a26f4179d86%2FDocuments%2FInBetween%20Research

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Evaluation. Evaluation prioritised emotional experience over performance-based usability metrics. Both moderated and unmoderated usability testing were conducted. Criteria included emotional comfort, clarity of interaction, perceived safety, privacy awareness, and cultural and contextual appropriateness. Feedback was gathered through reflective questioning about participants' emotional experience of the interface. Findings informed design refinements.

Ethical considerations. Participation was voluntary, with informed consent obtained before data collection. Participants were not required to disclose distressing personal experiences. Data were collected anonymously, and all responses were handled confidentially. Cultural and spiritual considerations were treated with respect, with all personalisation features remaining optional and user-controlled.

The evaluation aligned with the exploratory, design-led objectives of this research. Rather than employing standardised usability questionnaires or validated psychological well-being measures, the evaluation focused on understanding participants' perceptions of emotional safety, trust, comfort, and engagement when interacting with the prototype. This approach was appropriate because the study aimed to explore empathy-driven design requirements rather than assess clinical outcomes or benchmark overall usability. To complement qualitative findings, the prototype also underwent accessibility-focused evaluation throughout development. Colour contrast validation, WCAG 2.1 AA accessibility checks, semantic structure verification, and automated accessibility assessment tools evaluated interface accessibility and ensured that empathy-driven design decisions were supported by recognised accessibility standards.

Results

Emotional comfort and visual tone. Participants reported that the interface's visual softness, predictable layouts, and non-judgmental language, identified as essential for a digital therapeutic bond [10], made interactions feel less overwhelming and more emotionally comfortable.

Interaction pacing and cognitive load. Users with anxiety and depression are easily overwhelmed by detailed interfaces and information overload [11]. To address this, step-based journaling and one-card daily activities were perceived as manageable, supporting engagement without the pressure or fatigue associated with standard web-based resources [11].

Trust, privacy, and emotional safety. Privacy-oriented features, including concealment mechanisms and lockable content, increased perceived safety and supported engagement [1]. These mechanisms enabled users to explore sensitive areas of the application comfortably, particularly in shared or restrictive environments where privacy is limited [1]. Trust was identified as a prerequisite rather than an outcome of engagement.

Personalisation and contextual sensitivity. Optional personalisation modes, including faith-based content, were positively received when presented as user-controlled rather than prescriptive [12]. Participants appreciated choosing how to interact, reinforcing the importance of autonomy in emotionally sensitive contexts [9,12]. Cultural background, language, and spiritual beliefs significantly shaped how users related to the interface [9].

Multilingual emotional localisation. Participants using native languages reported greater comfort and emotional alignment. Consistent with multilingual verification processes used in large-scale European mental health projects [7], native speaker assessment showed several phrases required substantive adaptation to maintain emotional tone and cultural naturalness. As noted in prior research, cultural responsiveness must extend beyond language translation [5]; failing to validate emotional impact may undermine the application's intended sense of safety [5,7].

Design over feature complexity. Participants valued the emotional quality of the interaction over feature richness; users responded more strongly to the warmth and bond created by the interface than to the number of available tools [10]. Participant feedback on the trust-based pricing model reinforced this finding: access to substantive support without upfront financial commitment was described as compassionate and realistic. The model reduced psychological pressure during initial engagement, effectively addressing a documented barrier to technology adoption in mental health [1,8].

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Design iterations. User feedback informed refinements. Initially prominent mood information was made more subtle after participants reported feeling exposed. Privacy feature cues became more visible following participant requests. Feedback on concealment highlighted the importance of culturally realistic privacy design, with participants suggesting alternatives reflecting their own environments.

Discussion

The findings support the argument that UI/UX design is not a neutral layer in digital mental health systems. Participants perceived InBetween as conveying tone, care, and intention rather than a purely functional tool. This aligns with evidence that empathy-driven design can influence perceptions of safety, approachability, and trust within digital systems [4,10].

Many users do not approach digital interventions ready to engage because of fatigue or other symptomatic barriers identified in prior literature [1]. Design elements that reduce psychological pressure, such as progressive disclosure and gentle pacing, appeared to better support hesitant users than stimulation-focused engagement features. This finding raises questions about conventional engagement strategies such as notifications and interactive prompts [1].

Participants identified culture, language, and spiritual beliefs as influencing emotional safety, understanding, and trust in digital mental health technologies. These findings suggest that culturally meaningful design choices may strengthen users' perceptions of emotional safety and trust [5,12,16,17]. Drawing on participant insights and culturally responsive mental health literature, this study proposes optional, user-controlled personalisation as a design recommendation rather than a universal requirement [5,12,16,17]. Similarly, the implementation of emotionally localised multilingual content, verified by native speakers for cultural warmth rather than linguistic accuracy, is presented as a design implication informed by the study findings and existing literature, offering a replicable methodological contribution for future digital mental health research [7].

Participant feedback on pricing extends existing design thinking. Building on participant feedback and literature on financial barriers, this study frames financial commitment as a design choice with emotional implications for vulnerable users, positioning engagement models as an extension of empathetic care [8,10]. The three-tier structure of InBetween suggests commercial and empathetic goals need not conflict when emotional readiness, rather than conversion alone, guides structural decisions.

This study has limitations. The participant group was small, and findings are interpretive rather than generalisable. Formal thematic saturation was not explicitly assessed during data collection. Given the exploratory nature of this research, the interviews were intended to generate rich contextual insights rather than provide exhaustive thematic coverage. Future studies with more diverse participant groups could strengthen transferability and validate the framework across broader cultural contexts. The prototype was not longitudinally evaluated or clinically validated. Cultural, linguistic, and faith-related dimensions were explored at a preliminary level and would benefit from deeper investigation. Clinical or long-term evaluation would require a staged approach. An initial stage could combine the qualitative measures used here with validated instruments, including the System Usability Scale (SUS) and psychological well-being measures, administered before and after use, to assess whether perceived emotional safety and trust correspond to changes in usability and well-being. A subsequent longitudinal stage would deploy the prototype with a larger, more diverse participant group over several months to examine sustained engagement, retention, and whether emotional comfort is maintained or diminishes over prolonged use outside a research setting. Given the sensitivity of the population, clinical evaluation would require collaboration with mental health practitioners for safety monitoring, referral pathways for participants experiencing distress, and ethical oversight appropriate to clinical or near-clinical deployment.

Conclusions

This study suggests that empathy-driven UI/UX design can shape how emotionally supportive and approachable digital mental health systems feel for individuals living with depression. Visual tone, interaction pacing, privacy-aware features, optional personalisation, emotionally localised language, and trust-based engagement contributed to greater emotional comfort, safety, and trust.

The finding that emotional experience is as important as functional capability in shaping user engagement has significant implications for how digital mental health systems are designed and evaluated. Beyond features and task completion, systems should be evaluated by the emotional conditions they create: conditions under which users feel safe enough to begin, gentle enough to continue, and respected enough to return.

Drawing on participant findings and existing literature, this study contributes a design-led approach to empathy-driven UI/UX for depression, encompassing a colour psychology and accessibility rationale; an optional faith and culture personalisation model; a native speaker verification framework for multilingual emotional localisation; and a trust-based engagement and pricing model. These contributions are intended as design recommendations rather than generalisable outcomes. Together, these contributions position UI/UX design as core to emotional care in digital mental health by creating experiences that meet users where they are and support them gently.

References

1. Borghouts J, Eikey E, Mark G, De Leon C, Schueller SM, Schneider M, et al. Barriers to and facilitators of user engagement with digital mental health interventions: systematic review. J Med Internet Res. 2021;23(3):e24387.
2. Stiles-Shields C, Montague E, Lattie EG, Kwasny MJ, Mohr DC. What might get in the way: barriers to the use of apps for depression. Digit Health. 2017;3:2055207617713827.
3. Søgaard Neilsen A, Wilson RL. Combining e-mental health intervention development with human computer interaction (HCI) design to enhance technology-facilitated recovery for people with depression and/or anxiety conditions: an integrative literature review. Int J Ment Health Nurs. 2019;28(1):22–39.
4. Slovak P, Munson SA. HCI contributions in mental health: a modular framework to guide psychosocial intervention design. In: Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24); 2024. Article 692.
5. Narayan S, Mok H, Ho K, Kealy D. "I don't think they're as culturally sensitive": a mixed-method study exploring e-mental health use among culturally diverse populations. J Ment Health. 2022;32(1):241–247.
6. Willis HA, Neblett EW. Developing culturally-adapted mobile mental health interventions: a mixed methods approach. mHealth. 2023;9:1.
7. van Lent LGG, Hodakova S, Hanft-Robert S, Mösko M, Rao C, Kerremans K, et al. Evaluating an intervention to promote access to mental healthcare for low language proficient migrants and refugees across Europe (MentalHealth4All). BMJ Open. 2025;15(7):e095868.
8. Singh R, Singh VP, Raj R, Yadav R, Rabby F, Chauhan S. Financial barriers and strategic solutions in technology adoption for mental health stigma. In: Sharma R, Rabby F, Bansal R, Sachdeva T, Mrabet J, editors. Confronting Mental Health Stigma with AI and Machine Learning. Wiley; 2026.
9. Sien SW. Designing for inclusivity and accessibility of mental health technologies. In: CHI EA '23: Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems. ACM; 2023.
10. Malouin-Lachance A, Capolupo J, Laplante C, Hudon A. Does the digital therapeutic alliance exist? Integrative review. JMIR Ment Health. 2025;12:e69294.
11. Bernard R, Sabariego C, Cieza A. Difficulties encountered by people with depression and anxiety on the web: qualitative study and web-based expert survey. J Med Internet Res. 2019;21(10):e12514.
12. Berkley-Patton J, Thompson CB, Moore E, Hawes S, Bohn A, Pelletier Brantley K, et al. Engaging the faith community in designing a church-based mental health screening and linkage to care intervention. Metrop Univ. 2021;32(1):104–123.
13. Mikellides B. Colour psychology: the emotional effects of colour perception. In: MacDonald L, editor. Colour Design: Theories and Applications. 2nd ed. Woodhead Publishing; 2017. p. 193–214.
14. Elliot AJ, Maier MA. Color psychology: effects of perceiving color on psychological functioning in humans. Annu Rev Psychol. 2014;65:95–120.
15. Jonauskaite D, Mohr C. Do we feel colours? A systematic review of 128 years of psychological research linking colours and emotions. Psychon Bull Rev. 2025;32(4):1457–1486.
16. Arora PG, Parr KM, Khoo O, et al. Cultural adaptations to youth mental health interventions: a systematic review. J Child Fam Stud. 2021;30:2539–2562.
17. Vahdaninia M, Simkhada B, van Teijlingen E, Blunt H, Mercel-Sanca A. Mental health services designed for Black, Asian and Minority Ethnics (BAME) in the UK: a scoping review. Ment Health Soc Incl. 2020;24(2):81–95.

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ISBN: 978-624-6610-01-2
Proceedings of the ESOFT International Conference 2026
ESU, Kandy, Sri Lanka
August 30, 2026

18. Malterud K, Siersma VD, Guassora AD. Sample size in qualitative interview studies: guided by information power. Qual Health Res. 2016;26(13):1753–1760.

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OP 02

The Effect of Generative AI Tools on Efficiency in Graphic Design Processes: An Empirical Analysis.

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Abstract

The rapid growth of Artificial Intelligence (AI)-based design tools has transformed creative industries by enhancing workflow efficiency, automating repetitive tasks, and improving the quality of design outputs. However, the adoption of AI-based design tools in Sri Lanka's Eastern Province remains limited due to a lack of awareness, insufficient training opportunities, and concerns regarding creativity and control.

This study examines the relationship between AI-based design tools and workflow efficiency, focusing on three key dimensions: Frequency of AI Feature Usage, Quality Assurance, and Automation.

Workflow efficiency was measured using questionnaire items related to productivity, task completion speed, consistency of design outputs, and overall workflow performance.The study adopted a positivist research philosophy and a deductive approach. Quantitative data were collected through a cross-sectional survey of 178 designers in Batticaloa, selected from a population of 758 using cluster sampling. Data were analysed using descriptive statistics, reliability and validity testing, correlation analysis, and multiple regression analysis to examine the relationships between the study variables.

The findings revealed significant positive associations between Frequency of AI Feature Usage, Quality Assurance, Automation, and workflow efficiency. Among the predictors, Quality Assurance demonstrated the strongest influence, followed by Frequency of AI Feature Usage and Automation. These findings suggest that greater engagement with AI-based design tools is associated with higher workflow efficiency. However, due to the cross-sectional nature of the study, the results indicate associations rather than causal effects. The study provides practical insights for designers, educators, policymakers, and industry stakeholders by highlighting the importance of structured AI training, improved access to AI technologies, and greater awareness to support effective AI adoption and strengthen Sri Lanka's creative industry.

Keywords - *Artificial Intelligence (AI), Automation, Creative Industry, Workflow Efficiency, Quality Assurance*

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Introduction

The rapid advancement of artificial intelligence (AI) is transforming creative industries worldwide by enhancing workflow efficiency, automating repetitive tasks, and improving the quality of design outputs. By 2030, AI-driven tools are expected to generate over $1.3 trillion in annual revenue, demonstrating their growing economic and creative significance [1].

AI is widely used in sectors such as graphic design, journalism, music, and film for ideation, content creation, and editing, thereby reshaping traditional creative processes and increasing productivity [6]. Countries such as China, India, and Singapore have accelerated AI adoption through strong digital ecosystems and policy support, enabling them to achieve higher efficiency and economic growth through advanced technologies like AI and VFX [2].

Despite these global advancements, the adoption of AI-based design tools in Sri Lanka, particularly in the Eastern Province, remains limited. Challenges such as lack of awareness, insufficient training opportunities, underdeveloped digital infrastructure, and concerns over loss of creative control have slowed adoption among designers and studios. As a result, many professionals continue to rely on traditional methods, reducing their competitiveness compared to regional leaders. Theoretical frameworks such as the Technology Acceptance Model (TAM) and Diffusion of Innovations Theory explain how factors like perceived usefulness, ease of use, complexity, and trialability influence adoption [7]. Additionally, concepts such as Lean Management, Total Quality Management (TQM), and Sociotechnical Systems Theory highlight how AI can enhance efficiency, improve service quality, and balance human creativity with technological support [5].

Empirical studies confirm that AI acts as a key driver of productivity by reducing workload, speeding up creative processes, and improving output quality. AI integration minimizes operational bottlenecks and enhances consistency, leading to higher client satisfaction and economic benefits [3]. However, research emphasizes that AI should complement rather than replace human creativity to maintain authenticity and originality in design work [8].

This study focuses on designers in Sri Lanka's Eastern Province, using a quantitative approach to examine how AI-based design tools influence workflow efficiency through usage frequency, quality assurance practices, and automation levels. The findings aim to support policymakers, educators, and industry stakeholders in promoting effective AI adoption and strengthening the country's creative sector.

Method

This study adopted a positivist research philosophy and a deductive research approach to objectively examine the relationship between AI-based design tools and workflow efficiency among designers in the Eastern Province of Sri Lanka. The research was guided by established theories, including the Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), Diffusion of Innovations Theory, and Scientific Management Theory, enabling the development and testing of hypotheses through quantitative analysis. A cross-sectional survey design was employed to collect standardized data at a single point in time, providing a reliable snapshot of current AI adoption and its association with workflow efficiency.

The target population consisted of 758 designers and editors working in the Eastern Province of Sri Lanka. Using cluster sampling, a sample of 178 respondents was selected for the study. Data were collected through a structured questionnaire comprising items measuring Frequency of AI Feature Usage (FU), Quality Assurance (QA), Automation (AU), and Efficiency in Workflows (EW). Workflow efficiency was operationalized using questionnaire items that assessed productivity, task completion speed, consistency of design outputs, reduction of repetitive work, and overall workflow performance. Responses were recorded using a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).

The questionnaire was adapted from established literature related to AI adoption and workflow efficiency and was reviewed by the research supervisor and research module lecturer to ensure its content validity, clarity, and alignment with the research objectives before distribution. The reliability and construct validity of the instrument were subsequently evaluated using Cronbach's Alpha, the Kaiser–Meyer–Olkin (KMO) Measure, and Bartlett's Test of Sphericity, confirming that the instrument was suitable for statistical analysis.

The collected data were analysed using descriptive statistics, correlation analysis, and multiple regression analysis to examine the relationships between the study variables. Participation in the study was voluntary, informed consent was obtained from all respondents prior to data collection, and no personally identifiable information was collected. All responses were treated confidentially and used solely for academic research purposes.

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Instrument Validation: The questionnaire used in this study was developed based on previous literature related to AI-based design tools and workflow efficiency. The instrument was reviewed by the research supervisor and research module lecturer to ensure its content validity, clarity, and alignment with the research objectives before data collection. The reliability and construct validity of the final instrument were subsequently confirmed through Cronbach's Alpha, the Kaiser–Meyer–Olkin (KMO) Measure, and Bartlett's Test of Sphericity, indicating that the questionnaire was suitable for statistical analysis.

Results

Table 1: Data Analysis Results

Analysis Area	Variable / Test	Result / Value	Interpretation
Demographic Analysis	Sample Characteristics	178 designers from the Eastern Province of Sri Lanka	The sample primarily consisted of young, early-career designers with balanced gender representation and diploma-level qualifications.
Reliability & Validity	Cronbach's Alpha	Acceptable reliability for FU, QA, AU, and EW	All constructs demonstrated satisfactory internal consistency.
	KMO & Bartlett's Test	KMO > 0.50, $p < 0.001$	The data were suitable for factor analysis and construct validation.
Descriptive Statistics	Mean, SD, Skewness & Kurtosis	Moderate mean values; Skewness/Kurtosis within ±2	AI adoption and workflow efficiency were moderate, and the data were approximately normally distributed.
Normality Testing	Kolmogorov–Smirnov & Shapiro–Wilk	Acceptable normality	The assumptions for parametric statistical analyses were satisfied.
Model Summary	R	0.748	Strong positive association between the independent variables and workflow efficiency.
	R^2	0.559	The model explained **55.9%** of the variance in workflow efficiency.
	Adjusted R^2	0.552	The regression model remained stable after adjustment.
ANOVA	F-test	F = 73.608, $p < 0.001$	The regression model was statistically significant.
Correlation Analysis	FU → EW	r = 0.574, $p < 0.001$	Frequency of AI Feature Usage was positively associated with workflow efficiency.
	QA → EW	r = 0.561, $p < 0.001$	Quality Assurance was positively associated with workflow efficiency.
	AU → EW	r = 0.483, $p < 0.001$	Automation was positively associated with workflow efficiency.
Regression Coefficients	FU	**B = 0.270, β = 0.364, $p < 0.001$**	Frequency of AI Feature Usage was a significant positive predictor of workflow efficiency.
	QA	**B = 0.272, β = 0.380, $p < 0.001$**	Quality Assurance was the strongest predictor of workflow efficiency.

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	AU	**B = 0.220, β = 0.285, $p < 0.001$**	Automation was a significant positive predictor of workflow efficiency.
Multicollinearity	Tolerance & VIF	**FU:** Tolerance = 0.838, VIF = 1.193**QA:** Tolerance = 0.879, VIF = 1.137**AU:** Tolerance = 0.887, VIF = 1.128	All tolerance values were above 0.10 and all VIF values were below 5, indicating that multicollinearity was not a concern in the regression model.
Regression Equation	Final Model	**EW = 0.714 + 0.270(FU) + 0.272(QA) + 0.220(AU)**	The model showed that all three predictors contributed positively to workflow efficiency, with Quality Assurance having the strongest standardized effect.
Hypothesis Testing	H_1	Accepted	Frequency of AI Feature Usage was significantly associated with workflow efficiency.
	H_2	Accepted	Quality Assurance was significantly associated with workflow efficiency.
	H_3	Accepted	Automation was significantly associated with workflow efficiency.

Discussion

This study aimed to establish the impact of AI-based design tools on workflow efficiency among AI designers and editors in the Eastern Province of Sri Lanka. The statistical findings indicate that Frequency of AI Feature Usage (FU), Quality Assurance (QA), and Automation (AU) are all significantly associated with workflow efficiency. The regression model explained **55.9%** of the variation in workflow efficiency ($R^2 = 0.559$), suggesting that these three dimensions are important determinants of efficient design workflows. However, because the study employed a cross-sectional research design, the findings demonstrate statistically significant associations rather than direct causal relationships [4].

The main research objective was successfully achieved by establishing that AI-based design tools are positively associated with workflow efficiency. Designers who reported greater engagement with AI technologies also reported higher productivity, reduced manual effort, and better workflow organization. These findings are consistent with previous studies, which indicate that AI technologies support creative professionals by automating routine activities while allowing designers to focus on higher-value creative tasks [9].

The first sub-objective examined the impact of **Frequency of AI Feature Usage (FU)** on workflow efficiency. The results revealed a significant positive relationship ($r = 0.574$, $p < 0.001$). Regression analysis also showed that FU was a significant predictor ($\beta = 0.364$, $B = 0.270$, $p < 0.001$), indicating that designers who use AI features more frequently report higher workflow efficiency. This finding supports the Technology Acceptance Model (TAM), which suggests that regular technology use increases perceived usefulness and encourages continued adoption.

The second sub-objective investigated the influence of **Quality Assurance (QA)** on workflow efficiency. QA demonstrated the strongest contribution among all predictors ($\beta = 0.380$, $B = 0.272$, $p < 0.001$), indicating that AI-assisted quality assurance is strongly associated with improved workflow performance. This result is consistent with Total Quality Management principles, which emphasize that reducing errors and rework improves operational efficiency.

The third sub-objective examined the relationship between **Automation (AU)** and workflow efficiency. Automation also showed a significant positive relationship with workflow efficiency ($r = 0.483$, $p < 0.001$) and remained a significant predictor in the regression model ($\beta = 0.285$, $B = 0.220$, $p < 0.001$). These findings support previous research identifying intelligent automation as an important contributor to productivity in digital design environments [8].

The regression diagnostics further strengthened the findings. Multicollinearity was not evident, as all predictor variables recorded acceptable Tolerance values (0.838–0.887) and low VIF values (1.128–1.193), confirming that the independent variables contributed independently to the model.

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Overall, all research objectives were successfully achieved. Frequency of AI Feature Usage, Quality Assurance, and Automation were found to be significant predictors of workflow efficiency among designers in the Eastern Province of Sri Lanka. However, because the study was conducted using a cross-sectional survey within a single geographical region, the findings should be interpreted as associations and may not be fully generalizable to other regions. Future research should employ longitudinal designs and broader geographical samples to further validate these findings.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted only among AI designers and editors in the Eastern Province of Sri Lanka. Therefore, the findings may not be fully generalizable to designers in other provinces of Sri Lanka or in international contexts, where technological infrastructure, organizational practices, and AI adoption levels may differ. Second, the study employed a cross-sectional survey design, which captured participants' perceptions at a single point in time. As a result, the findings demonstrate significant associations between AI-based design tools and workflow efficiency but do not establish causal relationships. Furthermore, the regression model explained 55.9% of the variance in workflow efficiency, indicating that other factors not examined in this study may also influence workflow performance. Future research should consider using longitudinal research designs, larger and more geographically diverse samples, and additional variables such as organizational support, digital literacy, user experience, and technological readiness to provide a more comprehensive understanding of AI adoption and its impact on workflow efficiency.

Conclusion

This study examined the impact of AI-based design tools on workflow efficiency among designers in Sri Lanka's Eastern Province, with a particular focus on three key dimensions: frequency of AI feature usage, quality assurance, and automation. The findings clearly demonstrate that all three factors contribute positively to improving workflow efficiency. Frequent use of AI features enables designers to become more familiar and confident with intelligent tools, allowing them to complete tasks faster and with greater consistency. Similarly, strong quality assurance practices supported by AI reduce errors, minimize rework, and enhance the reliability and professionalism of design outputs. Automation further improves efficiency by reducing repetitive manual tasks, allowing designers to focus more on creativity, innovation, and higher-level problem-solving.

The results of the study are strongly supported by statistical evidence, showing significant positive relationships between all independent variables and workflow efficiency. Among them, quality assurance showed the strongest influence, followed by frequency of AI usage and automation.

These findings align with established theories such as the Technology Acceptance Model, Task-Technology Fit Theory, and Lean Management principles, all of which emphasize that technology improves performance when it is effectively integrated into work processes. The study also highlights that AI should not be seen as a replacement for human creativity but rather as a supportive tool that enhances productivity while maintaining creative control and originality.

Methodologically, the study adopted a positivist philosophy with a deductive approach, using a cross-sectional survey design and cluster sampling to collect quantitative data from designers in Batticaloa. This approach ensured objectivity, reliability, and generalizability of findings, making it possible to identify clear patterns in AI adoption and workflow performance. The research addresses an important gap in the context of Sri Lanka's creative industry, where AI adoption remains relatively limited despite its global growth. In conclusion, the study confirms that integrating AI-based design tools significantly enhances workflow efficiency and highlights the importance of increasing awareness, providing structured training, and improving access to AI technologies. These efforts will help strengthen the competitiveness, productivity, and modernization of the regional creative sector.

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cooperation made it possible to collect the necessary data for analysis and played a crucial role in the successful completion of this research.

References

[1] Albert, 2025. "AI Statistics in 2025: Key Trends and Usage Data." [Online]. Available: https://www.digitalsilk.com/digital-trends/ai-statistics/.

[2] E. Duester, "Digital Artwork and AI: A New Paradigm for Work in the Contemporary Art Sector in China," European Journal of Cultural Management and Policy, vol. 14, 2024.

[3] Z. Lixuan, K. W., and C. A., "The Rise of AI Art: A Look Through Digital Artists' Eyes," SSRN Electronic Journal, 2024.

[4] Longhurst and B. Bea, "AI & Graphic Design," AI & Graphic Design, p. 39, 2024.

[5] G. Peiyuan and F. Fei, "A Systematic Review of the Role of Artificial Intelligence in Design Education," 2024, p. 103.

[6] W. Quan, "Artificial Intelligence in the Creative Industries: A Systematic Literature Review," International Journal of Latest Research in Humanities and Social Science (IJLRHSS), vol. 8, 2025.

[7] A. Rahima, A. R. Abdel-Qader, T. Sawsan, and A. Al, "Artificial Intelligence Tools in Media and Journalism: Roles and Concerns," 2023.

[8] C. Richard Christopher Jude, T. Jakob Adrian, and C. Ronaldo R., "Artificial Intelligence in Digital Art: A Comparative Analysis on Impacts to Artists," International Journal of Arts, Recreation and Sports, vol. 4, no. 1, p. 27, 2025.

[9] T. Yuying, Z. Ningning, C. Mariana, and W. Zhigang, "Exploring the Impact of AI-Generated Image Tools on Professional and Non-Professional Users in the Art and Design Fields," Virtual Community of Pathological Anatomy, University of Castilla La Mancha, p. 458, 2024.

[10] H. Hong et al., "The Application and Impact of Artificial Intelligence Technology in Graphic Design: A Critical Interpretive Synthesis," Heliyon, vol. 10, no. 21, p. e39737, 2024.

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OP 03

The Tapestry of Inclusive Creative Entrepreneurship: A study over decentralizing Creative Entrepreneurship through Entrepreneur-Academic Cooperatives under Micro Apparel Business in Sri Lanka.

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Abstract

Background:

As a small island in the Indian Ocean, the creative entrepreneurship in Sri Lanka possesses deep cultural heritage and strong individual identities, as well as the capability to contribute to the global clothing. However, the impact of centralized economic models on the financial sustainability and creative agency of these Sri Lankan creative entrepreneurs remains challenging.

Objective/s:

The purpose of this study is to investigate the decentralization of creative entrepreneurship, expanding from the centre of the western province to the edge of the western province, focusing on micro-businesses and pop-up businesses in the apparel sector, through the establishment of Entrepreneur-Academic cooperatives within the defined framework. [RQ1, RQ2, RQ3]

Methods:

The study itself assesses how these cooperative frameworks, related knowledge & skills transfer, affect the socioeconomic empowerment, Implementation of creative strategies, and entrepreneurial autonomy of the creative business practices. The investigation includes thematic analysis [TA] drawing from qualitative data gathered through semi-structured interviews with a pool of strategized micro & pop-up creative entrepreneurs (n=10) selected through purposive sampling. Alongside this, a questionnaire complemented by academia being utilized in the analysis. Additionally, secondary data were extracted from literature to support the study with further academic and contextual references.

Results:

The findings of this research have been clearly justified and showcased within a comprehensive thematic analysis framework emphasizing the 'Tapestry of inclusivity' formed by bridging institutional academic knowledge with creative entrepreneurship, with inclusive buffers and extracted 3 themes to obtain optimum inclusivity.

Conclusion/s:

The study proves that entrepreneur-academic cooperatives are a highly adaptive framework and optimize inclusive creative entrepreneurship in Western Province, Sri Lanka. Specifically, linking design thinking with micro-business enhances design quality and market positioning, which ultimately led to growth in the Creative Economy.

Keywords: *Creative Entrepreneurship, Decentralization, Pop-up Apparel Business, Entrepreneur-Academic Cooperative, Inclusive Creative Economy.*

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Introduction

In the global contemporary economy, creative textile and apparel entrepreneurship has emerged as the pivotal driver of economic growth, innovation and cultural preservation in a country (1) However, the macroeconomic landscape is dominated by mass-scale commercial apparel exporters, and they remain heavily centralized within urban hubs in developing nations like Sri Lanka. This scenario makes the foundational pillars of countries' creative identity [Local Creative Entrepreneurs] heavily marginalized. Many of these creative entrepreneurs possess uniquely rooted design aspects and the agile capability to respond to niche consumer demands with their own strong identities (2,3) Their silent and undiscovered value often faces barriers to fair trade, financial stability and deserved market exposure. Operating from small-scale home studios and shared workshops, they enrich the local fashion ecosystem, navigating a landscape that inherently favors corporate monopolies. Despite their immense potential to contribute to regional humanity and socio-economic equity by enrooting innovations, this sector remains an unattended domain in terms of real-world inclusive entrepreneurial scope (4).

Compared to modern, number-driven mass production and its scalability, these local creative entrepreneurs operate on a paradigm of meticulous handiwork and slow production cycles. This systematic mismatch has created a resistance between decentralized sustainable economic models and the creative anatomy of local Micro & Pop-up creative entrepreneurship, and it is highly questionable (5). The traditional micro-level creative entrepreneur's anatomy is based on exploitative intermediaries, which intercept their financial returns and authentic creative agency (6). To rectify these disparities, there is an urgent need to re-evaluate how creative entrepreneurship is modelled in the local economy, as it needs a shift from top-down commercial pipelines towards an inclusive, decentralized ecosystem (1).

Regardless of the anatomy errors, there are some societal and cultural barriers works as a decentralization buffer (7). Especially women creative entrepreneurs, entrepreneurs with disabilities, and remote creative entrepreneurs from urban-peripheral margins face the language barrier, accessibility over technology, mythical beliefs and generational constraints (4).

Conceptual implementation of "The Tapestry of Inclusivity" introduces a neo-mechanism to Creative Entrepreneur-Academic cooperatives. The creative infusion from academia, with Structured market and design research mixed with strategic knowledge, is paired with local creative entrepreneurs and their experience as a framework to achieve collaborative synergy. This collaborative framework aims to democratize access to design innovation, business literacy, and Industry 4.0 strategies without stripping their local identity (8). The purpose of this study is to investigate social economic situation, knowledge preservation, and current gaps in local creative entrepreneurship anatomy to implement Entrepreneur-Academic cooperation within the Western Province, mapping across to the remote borders via a framework to decentralize creative entrepreneurship to obtain maximum inclusivity, and it is followed with below Research questions;

RQ1 (Decentralization and Spatial Dynamics): *How does creative entrepreneurship in the apparel sector (Specifically micro and pop-up businesses in Western Province) transition and establish itself from the urban core of the Western Province to its peripheral edges*?

RQ2 (Mechanics of Entrepreneur- Academic Cooperatives): *What structural features and operational mechanisms of Entrepreneur- Academic Cooperatives effectively support micro and pop-up apparel ventures during peripheral expansion?*

RQ3 (Framework Efficacy & Outcomes): *To what extent does the proposed cooperative framework foster sustainable economic viability and creative autonomy of peripheral apparel ventures?*

Table 1: Conceptual Framework Mapping

Objective Component	Operationalized Theme	Core Constructs	Expected Outcomes
Spatial Shift *(Center to Edge of Western Province)*	*Peripheral Decentralization & Spatial Dynamics*	*Geographic mobility, rent arbitrage, local market accessibility*	*Mapping of peripheral creative hubs, identification of expansion drivers*
Business Scope *(Micro-business & Pop-ups in Apparel)*	*Agile Creative Ventures & Business Agility*	*Organizational scale, resource constraints, adaptive retail models*	*Profiling of micro-apparel operational strategies and survival rates*

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Intervention Mechanism *(Entrepreneur-Academic Cooperatives)*	*Knowledge Transfer & Cooperative Governance*	*Resource sharing, mentorship, academic R&D, co-creation models*	*Standardized cooperative framework for regional entrepreneurship*
Defined Framework	*Systemic Impact & Sustainable Growth*	*Venture resilience, localized economic contribution, scalable policy design*	*Empirically validated framework for regional creative economy policy*

Methods

Data collection

The study conducted a qualitative research design to approach and discover the intricacies of creative entrepreneurship decentralization as a micro and pop-up business and the collaborative dynamics of the highly competitive urban and peripheral setting. Given the explorative nature of the study, a thematic analysis framework was used to interpret real-life, uncensored data from local creative entrepreneurs *[n=10],* followed by semi-structured interviews from Western Province [WP], Sri Lanka (9,10). To achieve a robust multi-stakeholder assessment, academics from the local fashion design *[n=1]* & Marketing faculties *[n=1]* supported the study with an open-ended questionnaire. Apart from the primary qualitative data collection, the study relied on participatory observation and reliable secondary data from literature reviews.

Selection & Sampling

To engage clear and definitive participants within the independent micro and pop-up apparel entrepreneurship scope, a purposive sampling approach was implemented (11). This sample group was strategically segmented into five entrepreneur categories based on an inclusive point of view (Table 01*[EC1, EC2, EC3, EC4, EC5]*) into structured, formalized insights by defining themes (9). Geographically, the sample was selected along a defined cross-provincial corridor, originating from the urban center of the [WP] (Colombo Municipal boundaries) and extending outward through urban-peripheral lines to the exact boundary edge (Ruwanwella and Kegalle borderline communities).

Table 2: Entrepreneur Category Code: Based on purpose

Code	*Entrepreneur Category*	*Purpose*	*No of participants*
EC:1	*Urban-peripheral*	*Capturing geographical buffers*	*02*
EC:2	*Gender Inclusive*	*Capturing gender-based buffers*	*02*
EC:3	*Disability Impairments*	*Capturing impact of impairments*	*02*
EC:4	*Literacy & Language*	*Capturing Language buffers*	*02*
EC:5	*Tech-Accessibility*	*Capturing accessibility span*	*02*

Table 18 : Participant Pool no 01; Inclusive Creative Entrepreneurs.

With the ethical consideration all the participant (Table 2; Table 3) were Informed over consent, transparency, guaranteed anonymity, voluntary participation and left to withdraw Rights.

Thematic Saturation : Referring to Malteruds Information power model (12) it is clear that EC: n=10 samples and AC: n=2 is methodically sufficient for this exploratory qualitative scope, explicitly noting that code saturation was achieved by the 8th entrepreneur [*EC4P2*]

Interviews, as no new thematic codes were yielded after the 9th and 10th interviews [*EC5P1*], [*EC5P2*]. The two academics [AC:1, AC:2] served as a qualitative triangulation to validate institutional cooperative framework dynamics rather than as a standalone statistical sample.

Results

The primary data inputs from the study were processed via manual thematic coding, which yielded three distinct conceptual themes within the cooperative framework (9).

Coding Process: The author has followed Braun and Clarkes (13) six-phase thematic analysis process and synthesized open codes into latent themes.

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Coding Mechanics & Consistency: Two Coders independently coded the transcripts and met iteratively to establish inter-coder agreement and finalize the coding.

Based on the extracted codes from the semi-structured interviews with the Participants (Table 2) under the assigned inclusive point of view [E1:E5], it was clear that the creative entrepreneurs from urban-peripherals (E:1) have a significant Inclusivity buffer over travel and logistics. With the supporting statements below, the two selected candidates from marginal borders have confirmed there is a real-life need for logistics and pipelines.

> *"Even though we are from the western province, we feel we are far away from modest market opportunities, as Colombo resides. In fact, sometimes just for a two-hour client meeting, just cost us 5 hours' drive on return and more fuel wastage." EC1P2*

The other counterpart is that, with that logistic overhead, creative entrepreneurs (Table 2) are facing middlemen interference, and the significant marginal profits are lost as they do not have direct communication with Colombo's physical pop-up markets.

> *"Our entire effort is on production. That makes it even harder for us to allocate time for lengthy trips to the capital [Colombo] and do our sales on-the-spot [Pop-up Market]. Most of us have awareness over the middlemen's profits, but still, we do sell our things to middlemen due to those logistic barriers." EC1P1*

Theme 1: Disintermediation and alternative Digital Pipelines. The above participant data indicates that micro business owners operating towards the urban peripherals face heavy transportation and logistics overheads when they try to access Colombo markets. The lack of awareness of virtual and digital platforms that they (Table 2) can use to bring out the originality of their product is identified as the main reason they give up their authenticity to the middlemen via Entrepreneur-Academia discussions and participatory observations. The deployment of their digital identity, digital product passports [DPP] by Academia (Table 3), with their specializations [AC:1, AC:2] in shared digital platforms and the storefronts themselves, allowed them to bypass the commercial consignment middlemen and stabilize their profit margins.

With the participatory observations done by Academia (Table 3) over the pop-up market stalls done by the creative entrepreneurs (Table 02) and their products, it indicates that a lack of understanding of design thinking and the commercial aspects of apparel product development makes their products not competitive enough to capture the expectations of Colombo and sometimes foreign consumers. The below statements indicate their struggle with design language and literacy [EC:4] and tech accessibility [EC:5]

> *"I started all these things [creative apparel] because my grandmother was really good at stitching; apart from that, we do look at images of different products and replicate them with our hands-on experience. We basically call the look of the product as design, no extra depth." EC4P1*

Going forward, the creative entrepreneurs (Table 2) with disability and impairment buffers [EC:3] have indicated valuable insight into their product designs as below.

> *"...I encountered this disability with a certain story. No, all my designs are just products of what I have seen others doing, not representing my story. I hated every bit of it with the mistreatment. "EC3P2*

This reflects that they are losing the unmatched contextual value of their social challenges on disability & impairment products, as they are not aware of the design conceptualizations & Design Innovation.

Theme 2: Collaborative Design Innovation and Conceptualization. The strategic cooperation between Entrepreneurs (Table 2) and Academics (Table 3) tested the creative design thinking integration into the correct conceptualized design of their own story. With the Academic (Table 3) observational data comparing stage 01[week1] and stage 02 [week 16] of Creative Entrepreneurs (Table 2) after interactive creative design conceptualization practice, it was clearly visible that their product designs were admired for their contextuality.

When it comes to inclusivity, social recognition as a creative entrepreneur is considered a major requirement. Based on the data of the study, it indicates that some other mistreatments and the anxiety over expression have given some buffers to these entrepreneurs (Table 2).

> *"I always thought of myself as a product seller, not as a designer or creative entrepreneur. Maybe because all we wanted was to make a living. We barely believe anything beyond practical reality. "EC5P2*

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"After my husband passed away, who was a former director for a leading export company, I started this pop-up business. I was doing well in sales, but there is no growth as my professional networking is limited with my situation. People have empathy for me, but they doubt my reliability… "EC2P1

Theme 3: Operational well-being and professional Recognition. Parallel to the concerns surrounding entrepreneurial isolation, participants (Table 2) noted that the cooperative framework directly improved their sense of professional legitimacy. Being recognized as valid professional design partners rather than informal hobbyists within an Academic-Backed network substantially elevated their psychological motivation and entrepreneurial wellness.

Table 3 : Thematic coding matrix

Overarching Theme	Subthemes / Propositions	Initial Open Codes	Inclusivity Buffer Mapping	Representative Quotations No
Theme 1: *Spatial & Digital Decentralization*	*P1: Disintermediation* *P2: Alternative Digital Pipelines*	*• Middleman bypass* *• Direct-to-consumer pop-ups* *• Social commerce* *• Digital inventory management*	*• Urban-peripheral* *• Tech-Accessibility*	*[EC1P1], [EC1P2]* *[EC3P1], [EC51P1]*
Theme 2: *Collaborative Value Creation*	*P1: Collaborative Design Innovation* *P2: Conceptualization*	*• Co-creation workshops* *• Academic prototyping* *• Material experiment* *• Design refinement*	*• Literacy & Language* *• Tech-Accessibility*	*[EC4P1]* *[EC5P2]*
Theme 3: *Socio-Economic Empowerment*	*P1: Operational Well-being* *P2: Professional Recognition*	*• Work-life autonomy* *• Fair wage security* *• Formal brand identity* *• Peer credibility*	*• Gender Inclusive* *• Disability Impairments*	*[EC2P1]* *[EC3P2]*

Discussion

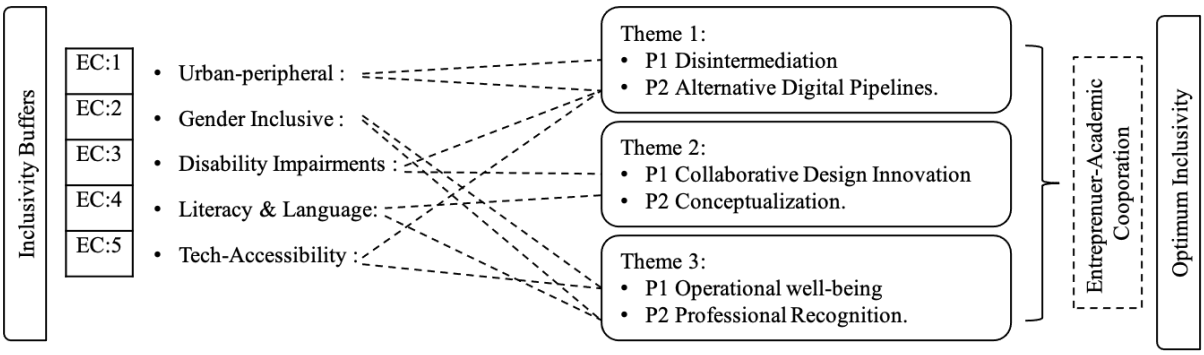

Figure 1 : Author-generated; Entrepreneur Academia Cooperative Framework derived from extracted themes.

The valuable findings demonstrate that 'The Tapestry of Inclusivity' operates effectively when institutional knowledge is decentralized away from exclusive corporate spaces and extended to independent silent contributors to the economy along regional transit corridors.

Based on the extracted themes (Figure 1) and the above results, it is justified that the creative entrepreneurs (Table 2) from urban-peripherals are facing questionable situations when it comes to inclusivity, supporting the statements derived according to Iahalagama (5). The independent micro-level fashion and apparel business sector requires agility, collaborative design tools, and professional recognition. When the two-stage (stage 01[week1]: stage 02 [week 16]) comparison after Entrepreneur-Academic Cooperatives signifies the dedicated academic consulting framework, these micro-scale creative entrepreneurs can successfully mitigate the challenges of urban centralization (14). Furthermore, this study highlights that

countering the geographical buffers & middlemen with Digital Design Networks and Digital Product Passports to achieve Disintermediation indicates positive results.

While Traditional University-Industry collaboration (UIC) models emphasize commercial technology transfer, patenting and corporate R&D partnerships (15) they largely exclude informal, non-technical micro ventures like pop-up businesses. Furthermore, while the Quadruple Helix Model (16) introduces civil society into academic-industry-government dynamics, it often lacks an operationalized mechanism for micro-level marginalized creative apparel businesses, and that signifies the value of the above framework (Figure 01).

Conclusion

The study concludes that the impactful nature of the entrepreneur-academic cooperatives worked as a highly adaptive framework for the betterment of Inclusive Creative Entrepreneurship in Western Province, Sri Lanka, which gives the foundation for the next step of the study to expand the framework across the entire country. By building concrete links between design thinking and micro-level business through a cross-provincial corridor, the model successfully managed to enhance their (Table 2) Design quality with equitable self-reported market positioning and operational confidence, as it fosters a self-sustaining creative economy. These outcomes reflect qualitative perceptions and participant-reported experiences rather than longitudinal quantitative metrics. The strategic implications of this research are highly actionable for creative industries, educators, and urban regional economic planners. For micro-level creative entrepreneurs, independent design practitioners, and university academia, this study serves as a practical, human-centred blueprint for establishing a systematic network that elevates inclusivity as 'Tapestry' across creative entrepreneurship and innovation.

While the findings demonstrate the localized efficacy of the Entrepreneur-Academic cooperative framework within the Western Province, recommendations for broader implementation across Sri Lanka must be approached with measured caution.

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References

1. Neugebauer J, Vokoun M. Economic and Political Dynamics of Globalization: A Review of Continuity and Change in Research Focus. Int J Econ Sci. 2024 May 16;13(1):30–57. doi:10.52950/ES.2024.13.1.003

2. Perera DrTR. An entrepreneurial Culture Led by Creativity and Innovation: Challenges and Competencies for Sri Lanka as a middle-income country. J Bus Econ Policy. 2019;6(1). doi:10.30845/jbep.v6n1p6

3. Gankandage A, Jayathilaka R. Unveiling the challenges: exploring start-up hurdles faced by small and medium-sized enterprise entrepreneurs in Sri Lanka. Humanit Soc Sci Commun. 2025 Mar 30;12(1):454. doi:10.1057/s41599-025-04775-2

4. Wijewardena N, Samaratunge R, Kumara AS, Newman A. With the help of the family! Using Sri Lankan informal sector women entrepreneurs' family resources to develop their creative self-efficacy. Womens Stud Int Forum. 2023 May;98:102699. doi:10.1016/j.wsif.2023.102699

5. Ihalagama HAAS. The Intangible Culture Illustrated by the Use of Clothing in Domestic Rituals of Traditional Sinhalese Society. J Desk Res Rev Anal. 2023 Dec 31;1(2):20–30. doi:10.4038/jdrra.v1i2.15

6. Buko J, Makowski A. A Limited Free Market Experiment in a Centrally Planned Economy: The Case of Polish Plant ZBM 'Ter-Zet'. Eur Res Stud J. 2021 Nov 1;XXIV(Issue 4):413–24. doi:10.35808/ersj/2596

7. Peiris PPM, Tatli A, Ozturk MB. Understanding women's performance of entrepreneurship in the Sri Lankan context. Int J Gend Entrep. 2024 May 16;16(2):164–96. doi:10.1108/IJGE-05-2022-0086

8. Kanthimathi T, Rathika N, Fathima AJ, K S R, Srinivasan S, R T. Robotic 3D Printing for Customized Industrial Components: IoT and AI-Enabled Innovation. In: 2024 14th International Conference on Cloud Computing, Data Science & Engineering (Confluence) [Internet]. Noida, India: IEEE; 2024 [cited 2026 May 30]. p. 509–13. Available from: https://ieeexplore.ieee.org/document/10463472/ doi:10.1109/Confluence60223.2024.10463472

9. Kiger ME, Varpio L. Thematic analysis of qualitative data: AMEE Guide No. 131. Med Teach. 2020 Aug 2;42(8):846–54. doi:10.1080/0142159X.2020.1755030

10. Nowell LS, Norris JM, White DE, Moules NJ. Thematic Analysis: Striving to Meet the Trustworthiness Criteria. Int J Qual Methods. 2017 Dec 1;16(1):1609406917733847. doi:10.1177/1609406917733847

11. Palinkas LA, Horwitz SM, Green CA, Wisdom JP, Duan N, Hoagwood K. Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. Adm Policy Ment Health Ment Health Serv Res. 2015 Sep;42(5):533–44. doi:10.1007/s10488-013-0528-y

12. Malterud K, Siersma VD, Guassora AD. Sample Size in Qualitative Interview Studies: Guided by Information Power. Qual Health Res.

13. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006 Jan 1;3:77–101. doi:10.1191/1478088706qp063oa

14. Perera LS, Samarakoon SMAK. Effect of Entrepreneurial Orientation on SMEs' Innovation Performance in Sri Lanka. Asian J Adv Res Rep. 2021 Mar 27;55–63. doi:10.9734/ajarr/2021/v15i230367

15. Perkmann M, Tartari V, McKelvey M, Autio E, Broström A, D'Este P, et al. Academic engagement and commercialisation: A review of the literature on university–industry relations. Res Policy. 2013 Mar;42(2):423–42. doi:10.1016/j.respol.2012.09.007

16. Carayannis EG, Campbell DFJ. 'Mode 3' and 'Quadruple Helix': toward a 21st century fractal innovation ecosystem. Int J Technol Manag. 2009;46(3/4):201. doi:10.1504/IJTM.2009.023374

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OP 04

The Impact of Short-Form Environmental Videos on Social Media (TikTok and Instagram Reels) on Sustainable Awareness Among University Students.

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Abstract

Short-form videos on platforms like TikTok and Instagram Reels are incredibly popular, but it is often unclear if they can effectively teach young people about the environment. This study explored whether watching brief environmental videos on these apps improves university students' sustainability awareness and their intention to adopt eco-friendly habits. We asked 50 undergraduate students to watch 10 shorts, selected environmental videos (each 20 to 45 seconds long) over the course of one week. Half of the students watched the videos on TikTok, while the other half watched them on Instagram Reels. We measured their environmental knowledge and their plans to act sustainably before and after the week. The results showed that after just seven days, the students' overall environmental awareness and their intentions to live sustainably improved significantly. Notably, the students who used TikTok showed a greater increase in awareness compared to those who used Instagram Reels. These findings suggest that short, engaging social media videos are a highly effective and accessible tool for environmental education. Universities and environmental organizations should consider using these popular platforms to share sustainability messages and inspire eco-friendly behavior among young adults.

Keywords: *Sustainable Awareness, University Students, Short-Form Environmental Videos, Social Media, Reels*

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Introduction

In the rapidly changing environment of digital communication, social media has emerged as one of the most influential platforms for information communication, particularly among younger people. Originally designed as tools for social interaction and entertainment, platforms such as TikTok and Instagram have evolved into powerful channels for education and awareness campaigns on a wide range of social issues, including environmental sustainability (Kaplan and Haenlein, 2010). Sustainability awareness refers to an individual's understanding of environmental challenges, ecological responsibility, and the interconnectedness between human behaviour and environmental outcomes. As climate change, biodiversity loss, and resource depletion continue to increase globally, promoting sustainability awareness among young populations has become a key priority for educators, policymakers, and environmental communicators alike (UNESCO, 2021).

Short-form video content, typically ranging from 15 to 60 seconds, has become one of the most widely consumed formats of content on social media platforms. TikTok, launched internationally in 2018, has rapidly grown to over one billion active users worldwide, with a significant proportion of users being young adults aged 18 to 25 years (Datareportal, 2024). Similarly, Instagram Reels, introduced in 2020 as a direct competitor to TikTok, has gained substantial popularity among university-aged users. These platforms provide personalized content experiences through recommendation systems that consider user preferences, viewing history, and engagement patterns (Zulli and Zulli, 2022). Environmental creators and organizations have increasingly used these platforms to share sustainability messages by employing visually engaging storytelling, brief educational content, and emotionally resonant narratives to capture audience attention within seconds (Hautea et al., 2021).

University students represent a particularly important audience for sustainability education and communication. As future professionals, decision-makers, and consumers, their attitudes and behaviours towards environmental issues will significantly influence societal responses to ecological challenges in the coming decades. Traditional sustainability education has mainly relied on formal classroom instruction, workshops, and institutional campaigns (Cotton and Winter, 2010). However, informal learning through social media exposure provides a complementary and potentially effective approach for developing environmental consciousness. Previous research has demonstrated that digital media can influence knowledge acquisition, attitude formation, and behavioural intentions across various health and social domains (Moorhead et al., 2013). Although social media provides new opportunities for informal sustainability education, the effectiveness of short-form environmental content in improving sustainability awareness and encouraging sustainable behavioural intentions among university students requires further investigation.

Existing studies have primarily examined general social media engagement, environmental information sharing, or online environmental campaigns, with limited attention given to the educational effectiveness of short-form environmental videos. In particular, there is insufficient empirical evidence regarding whether repeated exposure to brief environmental videos on platforms such as TikTok and Instagram Reels can improve sustainability awareness and behavioural intentions among university students. Furthermore, limited research has directly compared the effectiveness of these two dominant short-form video platforms in influencing sustainability-related outcomes. Therefore, this study addresses this research gap by investigating changes in sustainability awareness and behavioural intentions following structured exposure to environmental short-form videos and by comparing outcomes between TikTok and Instagram Reels exposure groups.

The research problem focuses on understanding whether exposure to short-form environmental content on TikTok and Instagram Reels can serve as an effective approach for enhancing sustainability awareness among university students. Although these platforms have significant reach among young audiences, the educational potential of ultra-short video formats for environmental communication has not been sufficiently evaluated. Furthermore, differences between TikTok and Instagram Reels in content presentation, user interaction features, and overall platform experience may influence how users engage with sustainability content; however, their influence on sustainability-related learning outcomes remains insufficiently explored (Shutsko, 2020). The rationale behind this study is to provide evidence-based insights into how short-form video exposure through two leading social media platforms influences environmental awareness and behavioural intentions, which can support future strategies for digital sustainability communication targeting young adults.

The aim of this study is to examine the effect of short-form environmental videos on TikTok and Instagram Reels on sustainability awareness and behavioural intentions among university students. Specifically, it seeks to achieve three objectives: evaluating whether one week of structured exposure to selected environmental short-form videos significantly improves sustainability awareness scores among university undergraduates; assessing whether such

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exposure leads to measurable changes in self-reported sustainable behavioural intentions; and comparing changes in awareness and behavioural intentions between participants exposed to content through TikTok and Instagram Reels.

This study focuses on measuring behavioural intentions rather than actual sustainable behaviours. Although increased behavioural intention represents a positive outcome, intentions do not always translate into real-world behavioural changes due to external factors such as convenience, financial limitations, social influences, and environmental conditions. Therefore, the findings should be interpreted as changes in sustainability awareness and willingness to engage in sustainable practices rather than evidence of confirmed lifestyle changes.

Methods

Study design and setting

A semi-experimental study with a pre-test and post-test was carried out in April 2025 among undergraduate students the study compared two groups, TikTok and Instagram Reels, to see how short environmental videos affect sustainability awareness and behavioural intentions. The study lasted nine days, including one day for the pre-test, seven days where students watched videos, and one day for the post test

Participants and sampling

Fifty full time undergraduate students were recruited through convenience sampling using campus notice boards, student WhatsApp groups, and lecture announcements. Inclusion criteria were age between 18 and 25 years, active user status on either TikTok or Instagram defined as usage of at least three days per week, ownership of a smartphone with internet access, and willingness to provide informed consent and complete both pre-test and post-test surveys.

Sample size justification

A sample of 50 participants (25 per group) was determined based on feasibility considerations for this exploratory study.

Group allocation

Participants were allocated to one of two groups based on their primary platform preference to ensure ecological validity and compliance. Those who reported TikTok as their primary short form video platform were assigned to the TikTok group (n=25), while those favoring Instagram were assigned to the Instagram Reels group (n=25). This pragmatic allocation ensured that participants viewed content on a platform they were familiar with, reducing novelty effects.

Participants were allocated according to their preferred social media platform rather than through random assignment. This pragmatic approach was adopted to maximize participant familiarity with the assigned platform, thereby improving compliance and ecological validity. However, this method may have introduced selection bias, as pre-existing differences between TikTok and Instagram users could have influenced the observed outcomes.

Data collection instruments

Data were collected using a structured online questionnaire administered via Google Forms at two time points, namely pre-test on day zero and post-test on day eight.

The questionnaire comprised three sections. Section one collected group of information including age, gender, faculty of study, course and average daily time spent on the assigned social media platform. Section two consisted of the Sustainability Awareness Scale, a 20-item instrument measuring environmental knowledge, perceived relevance of sustainability issues, and understanding of human environment interactions. Each item was rated on a five-point Likert scale ranging from one (strongly disagree) to five (strongly agree). Section three comprised the Sustainable Behavioural Intention Scale, a 10-item instrument assessing participants' intentions to adopt specific sustainable behaviors within the following month, including reducing single use plastics, using public transport, conserving water, and purchasing sustainable products. Items were rated on a five-point Likert scale with total scores ranging from 0 to 50.

Ethical considerations

Participation in this study was entirely voluntary.

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Results

Participant characteristics

All 50 recruited participants completed both pre-test and post-test surveys, yielding a zero percent attrition rate. The mean age of participants was 21 years, with ages ranging from 18 to 25 years. Twenty-nine participants (58%) were female and 21 (42%) were male. The average daily time spent on the assigned platform was 38 minutes. Demographic characteristics were comparable between the TikTok and Instagram Reels groups, as presented in Table 1.

Table 1: Demographic characteristics of participants (n=50)

Characteristic	**Total (n=50)**	**TikTok Group (n=25)**	**Reels Group (n=25)**
Age (years), mean	21.0	20.9	21.1
Gender – Female, n(%)	29 (58%)	14 (56%)	15 (60%)
Gender – Male, n(%)	21 (42%)	11 (44%)	10 (40%)
Daily platform use (min), mean	74	78	70

Changes in sustainability awareness

The primary outcome of sustainability awareness showed a statistically significant improvement from pre-test to post-test across the entire sample.

Sustainability awareness scores results are summarized in Table 2.

Table 2: Sustainability awareness scores by group (0–100 scale)

Group	**Pre-test Mean**	**Post-test Mean**	**Mean Change**	**95% CI**	**t-value**
TikTok (n=25)	57.6	69.4	+11.8	8.9–14.7	8.31
Reels (n=25)	59.2	66.8	+7.6	4.9–10.3	5.76
Total (n=50)	58.4	68.1	+9.7	7.3–12.1	8.12

Changes in sustainable behavioral intention

The secondary outcome of behavioral intention also demonstrated significant improvement. The overall mean behavioral intention score increased from 28 to 33.2.

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Table 3: Behavioral intention scores by group (0–50 scale)

Group	Pre-test Mean	Post-test Mean	Mean Change	95% CI	t-value
TikTok (n=25)	28.4	33.2	+4.8	3.2–6.4	6.32
Reels (n=25)	29.4	33.1	+3.7	2.1–5.3	4.74
Total (n=50)	28.9	33.2	+4.3	2.8–5.8	5.72

Compliance with viewing protocol

Self-reported compliance with the daily viewing protocol was high across both groups. In the TikTok group, 22 of 25 participants (88%) reported viewing all 10 assigned videos, while the remaining three viewed at least eight videos. In the Reels group, 20 of 25 participants (80%) completed all 10 videos, with the remaining five viewing at least seven videos. The mean number of videos viewed was 9.7 in the TikTok group and 9.4 in the Reels group, with no significant difference between groups ($p=0.16$).

Discussion

This study examined the effects of short-form environmental videos on TikTok and Instagram Reels on sustainability awareness and behavioural intentions among university students. The findings showed that one week of structured exposure to environmental videos significantly improved both sustainability awareness and sustainable behavioural intentions, suggesting that social media can be an effective tool for informal environmental education.

Sustainability awareness increased significantly, with a large effect size, indicating that short-form videos may efficiently communicate environmental messages through engaging, visual, and emotionally appealing content. However, while TikTok users demonstrated greater improvements in awareness compared to Instagram Reels users, the study did not directly measure platform-specific factors such as algorithms, engagement patterns, or communication styles. Therefore, differences between platforms should be considered possible explanations rather than confirmed causes.

Behavioural intention improvements were statistically significant but smaller than awareness gains, and no significant differences were found between TikTok and Instagram Reels. This suggests that while short-form videos can improve awareness, additional factors such as social influence, accessibility, and practical opportunities may be required to encourage actual sustainable behaviours.

The high video completion rate indicates that short-form environmental content is engaging and practical for university students, requiring minimal time while producing measurable outcomes. The findings highlight the potential for universities, environmental organisations, and policymakers to use platforms such as TikTok and Instagram Reels as supplementary tools for sustainability education and youth engagement.

Overall, the study demonstrates that short-form environmental videos can enhance sustainability awareness among university students, while further research is needed to understand long-term behavioural changes and the specific platform features influencing learning outcomes.

Limitations

Several limitations should be considered when interpreting the findings of this study. First, the exploratory nature of the research and the relatively small sample size of 50 undergraduate students recruited through convenience sampling from a single university limit the generalisability of the findings. The participants may not fully represent university students from different educational, cultural, or socio-economic backgrounds. Therefore, caution should be exercised when extending these findings to broader populations. Future studies should consider larger and more diverse samples

involving multiple universities and geographical regions to improve external validity.

Second, the semi-experimental design and pragmatic allocation of participants based on platform preference limit the ability to establish definitive causal relationships between platform exposure and observed outcomes. Differences that existed between TikTok and Instagram Reels users prior to the intervention, such as content preferences, usage habits, or levels of environmental interest, may have influenced the results. Future research should adopt randomised controlled designs to minimise potential selection bias and strengthen causal interpretations.

Third, the study relied on self-reported measures of video-viewing compliance and behavioural intentions. Although self-reported data provide valuable insights into participants' perceptions and intentions, they may be influenced by response bias, recall bias, and social desirability bias. Participants may have reported behaviours or intentions that they considered socially acceptable rather than accurately reflecting their actual engagement or future actions. Future studies should incorporate objective measurements, such as platform analytics, video completion data, behavioural observations, or follow-up assessments, to provide more reliable evidence.

Fourth, the intervention period was limited to seven days, with measurements collected immediately after the exposure period. While significant short-term improvements were observed, the study does not provide evidence regarding whether changes in sustainability awareness and behavioural intentions are maintained over time. Longitudinal studies with extended follow-up periods are required to determine the long-term effectiveness of short-form environmental videos.

Finally, the absence of a no-exposure control group limits the ability to attribute the observed improvements solely to the video intervention. External factors, such as exposure to environmental information through news, academic activities, or other social media content, may have contributed to changes in participants' awareness and behavioural intentions. Future research should incorporate control groups, larger samples, objective engagement measures, and longer observation periods to address these limitations and provide stronger evidence regarding the effectiveness of short-form environmental communication.

Overall, while the study provides evidence that short-form environmental videos can positively influence sustainability awareness and behavioural intentions among university students, the findings should be interpreted as immediate post-intervention outcomes. Further longitudinal research is necessary to determine whether these improvements are sustained and translated into actual sustainable behaviours over time.

Conclusions

This study suggests that short-form environmental videos delivered through TikTok and Instagram Reels may contribute to improvements in sustainability awareness and behavioural intentions among university students following a short-term intervention. Although statistically significant improvements were observed after one week of exposure, the persistence of these effects over an extended period remains uncertain. Therefore, the findings should be interpreted as evidence of short-term changes in awareness and behavioural intentions rather than confirmation of sustained behavioural change.

Furthermore, this study measured participants' behavioural intentions rather than their actual sustainable behaviours. While behavioural intention is considered an important predictor of future action, it does not necessarily translate into real-world behaviour due to external factors such as accessibility, financial considerations, social influences, and environmental conditions. Consequently, the findings should not be interpreted as evidence that participants adopted more sustainable lifestyles, but rather as an indication of increased awareness and willingness to engage in sustainable practices.

References

Ajzen I. The theory of planned behavior. Organ Behav Hum Decis Process. 1991;50(2):179211.

Anderson M, Jiang J. Teens, social media and technology 2018. Washington: Pew Research Center; 2018.

Bandura A. Social cognitive theory. Ann Child Dev. 1989;6:1-60.

Basch CH, Hillyer GC, Jaime C. COVID-19 on TikTok: harnessing an emerging social media platform to convey

important public health messages. Int J Adolesc Med Health. 2022;34(5):367-369.

Bhandari A, Bimo S. Why's everyone on TikTok now? The algorithmized self and the future of self-making on social media. Social Media + Society. 2022;8(1):1-11.

Buchanan K, Russo R, Anderson B. The question of energy reducing behaviours: digital technologies and everyday practices. Energy Policy. 2018;118:623-631.

Cotton D, Winter J. It's not just bits of paper and light bulbs: a review of sustainability pedagogies and their potential for use in higher education. In: Jones P, Selby D, Sterling S, editors. Sustainability education: perspectives and practice across higher education. London: Earthscan; 2010. p. 39-54.

Datareportal. Digital 2024: global overview report. Singapore: Datareportal; 2024.

Hautea S, Parks P, Takahashi B, Zeng J. Showing they care (or don't): affective publics and ambivalent climate activism on TikTok. Social Media + Society. 2021;7(2):1-14.

Kaplan AM, Haenlein M. Users of the world, unite! The challenges and opportunities of social media. Bus Horiz. 2010;53(1):59-68.

Koay KY, Ong DLT, Khoo KL, Yeoh HJ. Perceived social media marketing activities and consumer-based brand equity: testing a moderated mediation model. Asia Pac J Mark Logist. 2022;34(3):700-723.

Leung FF, Gu FF, Li Y, Zhang JZ, Palmatier RW. Influencer marketing effectiveness. J Mark. 2022;86(6):93-115.

Mavrodieva AVT, Rachman OK, Harahap VB, Shaw R. Role of social media as a soft power tool in raising public awareness and engagement in addressing climate change. Climate. 2019;7(10):122.

Moorhead SA, Hazlett DE, Harrison L, Carroll JK, Irwin A, Hoving C. A new dimension of health care: systematic review of the uses, benefits, and limitations of social media for health communication. J Med Internet Res. 2013;15(4):e85.

Petty RE, Cacioppo JT. Communication and persuasion: central and peripheral routes to attitude change. New York: Springer-Verlag; 1986.

Schellewald A. Communicative forms on TikTok: perspectives from digital ethnography. Int J Commun. 2021;15:1437-1457.

Shutsko A. User-generated short video content in social media: a case study of TikTok. In: Meiselwitz G, editor. Social computing and social media. Cham: Springer; 2020. p. 108-125.

Tiggemann M, Anderberg I. Social media is not real: the effect of 'Instagram vs reality' images on women's social comparison and body image. New Media Soc. 2020;22(12):2183-2199.

UNESCO. Education for sustainable development: a roadmap. Paris: UNESCO; 2021.

Zeng J, Abidin C. #OkBoomer, time to meet the Zoomers: studying the memefication of intergenerational politics on TikTok. Inf Commun Soc. 2021;24(16):2459-2481.

Zulli D, Zulli DJ. Extending the Internet meme: conceptualizing technological mimesis and imitation publics on the TikTok platform. New Media Soc. 2022;24(8):1872-1890.

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OP 05

Evaluating the Effectiveness of Structured Tutorial Programs for Improving Productivity and Work-Life Balance of Video Editors: A Case Study of Zirateh

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Abstract

Video editors are indispensable to the creative industry and are capable of producing the quality outputs in a short time. At Zirateh, a digital marketing agency, not training the newly hired video editors has also contributed to low productivity, duplication of errors as well as high reliance on the senior editors. These issues have also impacted negatively on employee work-life balance, making it high time to have a viable and sustainable mode of training. This study aims at assessing how structured tutorial programs can help build video editing proficiencies, become more productive and promote healthier work-life balance amongst Zirateh editors. It employed the mixed-method method and used both surveys and interviews with new and senior editors to get both quantitative and qualitative data. The primary training intervention was developed and provided as structured tutorials (long-form educational videos, short-term quick guides, reference booklet). The findings were used to determine the differences in productivity, workflow efficiency, and employee well-being and analyzed the data collected by 23 participants. The results suggest that a structured tutorial helped new editors to achieve project deadline, adhere to the brand rules, and ease the workload on the senior editors. In addition, the respondents noted that work-life balance has been positively affected as there were fewer cases of overtime and time management was better. The findings indicate that structured tutorial programs are not only optimal in resource use in an organization, but also help to ensure employee satisfaction and retention. This study is part of the wider comprehension of multimedia-based training in creative industries, and it has practical implications on to how agencies can find low-cost mechanisms of training their staff and at the same time enhance the evolution of the organization in the long term.

Keywords: *Knowledge transfer, Productivity, Structured tutorials, Video editing, Work-life balance*

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Introduction

Training and skill development are essential aspects of any organization, particularly within creative industries such as digital marketing and video production. Companies that rely heavily on multimedia production require employees to possess both technical knowledge and creative problem-solving skills. However, many organizations struggle to provide effective and consistent training due to financial limitations, time constraints, and the rapid turnover of employees.

Zirateh, a digital marketing agency founded by Damitha Senarathne, provides services such as social media marketing, video animation, content creation, and digital consultancy. As the company expanded, the organization encountered difficulties in training newly recruited video editors. Senior editors were required to spend a significant amount of time guiding new employees, resulting in reduced productivity, missed deadlines, and increased stress levels among staff members.

According to Stringer (2023), inadequate employee training can lead to productivity loss, increased mistakes, and decreased customer satisfaction. Similarly, Smith (2023) explains that video editing involves complex storytelling and technical processes that require systematic learning and practice. Without proper training structures, new editors often struggle to maintain the standards expected by creative organizations.

Another important issue identified within Zirateh was the negative impact on employee work-life balance. Employees frequently worked overtime to correct mistakes and complete projects before deadlines. Wedgwood (2024) states that modern employees increasingly value work-life balance and healthy working conditions over salary alone. Poor work-life balance can contribute to stress, burnout, and reduced creative performance.

The purpose of this research was therefore to design a structured multimedia tutorial system that could enhance training efficiency, preserve organizational knowledge, improve workflow, and support employee wellbeing. In addition to improving training quality, this study also aimed to increase brand visibility through short-form educational content shared on online platforms such as YouTube.

This study contributes to the field of multimedia education and workplace training by demonstrating how digital tutorial systems can be integrated into professional environments. The findings of the study may also benefit similar organizations within the creative industry that face comparable training and workflow challenges.

Methods

The study adopted a multimedia production-based research methodology that consisted of six major stages: research gathering, pre-production, production, post-production, evaluation, and delivery.

Research Gathering Stage

The first stage involved collecting information regarding the company's workflow, employee training methods, and challenges faced by newly recruited editors. Discussions and interviews were conducted with senior editors and company management to identify the major problems affecting productivity and work quality. Existing workflows and editing procedures were carefully analyzed to determine the knowledge gaps among new recruits.

Pre-Production Stage

During the pre-production stage, planning activities were carried out to organize the tutorial content effectively. Scripts were written for both long-form and short-form videos. Storyboards and mood boards were created to determine visual styles, camera angles, lighting arrangements, and color palettes. The recording environment was also prepared to ensure professional-quality video production.

Production Stage

The production stage involved recording all tutorial content. Ten long-form tutorial videos and twenty short-form educational videos were filmed using professional recording equipment. The videos demonstrated practical editing techniques, workflow management methods, software usage, sound design principles, and branding strategies

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relevant to Zirateh's operational standards.

Post-Production Stage

In the post-production stage, the recorded materials were edited using multimedia software applications including Adobe Premiere Pro, Adobe After Effects, Adobe Photoshop, Adobe InDesign, and Canva. Motion graphics, transitions, sound effects, color correction, and visual enhancements were added to improve the educational quality of the tutorials. A seventeen-page booklet was also designed to provide summarized learning materials and quick references for employees.

Evaluation Stage

The completed tutorial materials were reviewed through two revision cycles. The first review was conducted by the researcher, while the second review involved external quality assurance personnel. Feedback was also collected using Google Forms from senior editors, management staff, and newly recruited editors.

Delivery Stage

The final deliverables were uploaded to YouTube playlists and Google Sites to ensure easy accessibility for employees. The tutorial system was officially introduced to the organization as a structured training solution for future recruits.

Data Collection and Analysis

Participants

The survey was done with 23 participants who were the staff of Zirateh. The role breakdown was as followed.

Table 1: Role breakdown of participants

The role	Percentage
Recruited video editor	56.5%
Senior video editors	34.8%
Management	8.7%

The Feedback of the Senior Video Editors

There were 9 responses of the senior video editors. Majority agreed that the training time was reduced, useful skills were covered, the workflows were improved, the confidence of new editors were improved, and the work life balance was improved.

Table 2: Responsess of participants

Area	Strongly Agree	Agree	Negative or other
Reduced Training time	55.6%	33.3%	11.1%
Useful skills covered	66.7%	22.2%	11.1%
Improved workflow and team efficiency	44.4%	44.4%	11.1%
Confidence of new editors	55.6%	33.3%	11.1%
Improved Work life balance	55.6%	33.3%	11.1%

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The Feedback of the Recruited Video Editors

13 responses were recorded from the new video editors. All editors agreed on that the essential editing techniques were covered, instructions were clear and effective, editing skills were increased, helped to do tasks independently, A structured workflow was introduced, Overtime work was reduced, Progress and skilled were acknowledged and reduced. Now new editor mentioned they disagreed about these areas making the recorded responses 100% positive.

Table 3: Responces of participants

Area	Strongly Agree	Agree
Essential editing techniques were covered	61.5%	38.5%
Instructions were clear and effective	61.5%	38.5%
Editing skills were increased	46.2%	53.8%
Helped to do tasks independently	46.2%	53.8%
A structured workflow was introduced	46.2%	53.8%
Overtime work was reduced	38.5%	61.5%
Progress and skilled were acknowledged and reduced	46.2%	53.8%

The survey also indicated that 53.8% strongly agreed and 38.5% agreed that the tutorial videos would be introduced to new video editors however, 7.7% strongly disagreed.

The overall rating for the tutorial set had an average rating of 4.92 out of 5. Out of the 13 participants 12 rated 5 and one participant rated 4.

Discussion

The findings of this study demonstrate the effectiveness of multimedia tutorial systems as workplace training solutions within creative industries. Theis study successfully addressed several challenges experienced by Zirateh, including inconsistent employee training, workflow disruptions, excessive workload placed on senior editors, and employee stress caused by overtime work.

One of the most significant outcomes of the study was the preservation of organizational knowledge. Creative industries often rely heavily on the experience and expertise of senior employees. However, when experienced staff members resign or move to other organizations, valuable knowledge may be lost. By recording the techniques and workflows of senior editors, the project ensured that professional expertise remained accessible for future recruits.

The findings also support the arguments presented by Stringer (2023), who emphasized the importance of structured employee training for productivity improvement. The tutorial system reduced the time required for onboarding new employees and enabled editors to learn independently at their own pace.

Furthermore, the use of multimedia content enhanced learner engagement. Video-based learning allows employees to visually observe editing techniques, software processes, and workflow methods more effectively than traditional written instructions. The inclusion of short-form videos also aligned with modern digital learning trends, where concise educational content is increasingly popular among younger audiences.

The project additionally contributed to improving work-life balance among employees. Creative industries often involve demanding deadlines and extended working hours. By providing structured training resources, employees were able to complete tasks more efficiently, reducing stress and improving productivity. These findings support the research conducted by Wedgwood (2024), which highlighted the growing importance of employee wellbeing in modern workplaces.

Despite the success of the study, several challenges were encountered during implementation. Recording tutorial content while managing a full-time job created time management difficulties for the researcher. Fatigue during nighttime recording sessions occasionally affected presentation quality. Copyright considerations also required careful selection of music, sound effects, and visual materials.

Another limitation was the relatively small sample size used during evaluation. Although feedback was highly positive, future studies could involve larger participant groups and multiple organizations to increase the reliability and generalizability of findings.

Future developments could include the integration of interactive learning features such as quizzes, progress tracking systems, and advanced editing modules. Artificial intelligence-assisted learning systems and cloud-based collaboration tools could also further improve training accessibility and engagement.

Conclusion

The study successfully achieved its aim of developing a multimedia tutorial system to enhance the skills of newly recruited video editors at Zirateh. The research addressed important organizational challenges including inconsistent training, workflow inefficiencies, overtime work, and knowledge loss within the company.

Through the development of ten long-form tutorial videos, twenty short-form educational videos, and a seventeen-page booklet, the project provided a structured and accessible learning system for employees. The findings demonstrated that the tutorial materials improved workflow efficiency, reduced the workload of senior editors, enhanced work-life balance, and preserved professional knowledge within the organization.

The positive evaluation results confirmed that multimedia tutorials can function as effective workplace training solutions within creative industries. The study also demonstrated the value of integrating multimedia production techniques into employee education and organizational development.

In conclusion, the project contributes both practically and academically to the fields of multimedia education and workplace training. Future improvements could further expand the system through interactive learning technologies and advanced multimedia teaching methods

References

Allton, M. (2023) 5 reasons canva will rock your blog, Blogging Brute. Available at: https://bloggingbrute.com/blogging-tools/5-reasons-canva-will-rock-your-blog/(Accessed: 23April 2024).

Brauning, T. (2022) What is Adobe after effects (AE)?, What is Adobe After Effects (Ae)? Available at: https://blog.fmctraining.com/blog/what-is-adobe-after-effects (Accessed: 23 April 2024).

Brietman, K. (2024) How to easily make a tutorial video step-by-step guide, Riverside. Available at: https://riverside.fm/blog/how-to-make-a-video-tutorial (Accessed: 24 April2024).

Flavin, B. (2023) What is graphic design? A beginner's guide to this creative career, Rasmussen University. Available at: https://www.rasmussen.edu/degrees/design/blog/what-is-graphic-design/ (Accessed: 23 April 2024).

Gomez, R. (2024) Brand awareness: What it is and strategies to improve it, Sprout Social. Available at: https://sproutsocial.com/insights/brand-awareness/ (Accessed: 08 August 2024).

Howington, J. (2024) Attaining work-life balance and productivity when you work from home, FlexJobs Job Search Tips and Blog. Available at: https://www.flexjobs.com/blog/post/work-life-balance-work-from-home-remotely/ (Accessed: 08 August 2024).

Kopp, C.M. (2024) What is Brand Awareness? definition, how it works, and Strategies, Investopedia.Available at: https://www.investopedia.com/terms/b/brandawareness.asp#:~:text=Brand%20awareness%20is%20a%20marketing,the%20product%20versus%20the%20competition. (Accessed: 08 August 2024).

McLean, D. (2024) Adobe Premiere Pro Review: Features, Pricing & Guide (2024), Elegant Themes Blog. Available

at: https://www.elegantthemes.com/blog/business/adobe-premiere-pro-review (Accessed: 23 April 2024).

Roberts, S. (2023) What is Adobe Photoshop? introduction and a beginner's guide, What Is Adobe Photoshop? Introduction and A Beginner's Guide. Available at: https://www.theknowledgeacademy.com/blog/what-is-adobe-photoshop/ (Accessed: 23 April 2024).

Rouse, M. (2024) What is video editing? - definition from Techopedia, Techopedia. Available at: https://www.techopedia.com/definition/2077/video-editing (Accessed: 08 August 2024).

Schooley, S. (no date) What is a SWOT analysis? how to use it for business, Business News Daily. Available at: https://www.businessnewsdaily.com/4245-swot-analysis.html (Accessed: 05 August 2024).

Silveira, F. (2023) What is motion graphics?: Mowe Studio, mowe. Available at: https://mowe.studio/what-is-motion-graphics/ (Accessed: 23 April 2024).

Simpson, M.L. (2023) What is sound design in film? definition & examples, What Is Sound Design? An Intro to Sound in Film. Available at: https://www.backstage.com/magazine/article/what-is-sound-design-in-film-75845// (Accessed: 23 April 2024).

Smith, J. (2023) What is video editing, Training and Classes at American Graphics Institute. Available at: https://www.agitraining.com/video-editing/classes/what-is-video-editing (Accessed: 05 August 2024).

Stim, R. and law, R.S.A. at (2021) What is fair use?, Stanford Copyright and Fair Use Center. Available at: https://fairuse.stanford.edu/overview/fair-use/what-is-fair-use/ (Accessed: 29 November 2024).

Stringer, G. (2023) Why Don't Companies Train Employees?, Why don't companies train employees? Available at: https://www.gethownow.com/blog/why-dont-companies-train-employees#:~:text=In%20conclusion%2C%20companies%20who%20choose,reasons%20for%20not%20doing%20so. (Accessed: 24 April 2024).

Wedgwood, J. (2024) The importance of work-life balance, The Happiness Index. Available at: https://thehappinessindex.com/blog/importance-work-life-balance/ (Accessed: 08 August 2024).

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OP 06

Human-Centred Innovation in Fashion Education: Bridging the Skills Gap in Sri Lanka's Luxury Fashion Sector

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Abstract

The global fashion industry is in a state of accelerating disruption driven by artificial intelligence, digital design technologies, and an unprecedented shift towards sustainable and ethical production. Yet across emerging economies, and Sri Lanka in particular, fashion education has not kept pace. Graduates enter a luxury market that demands digital fluency, sustainability literacy, and commercial agility, while curricula continue to emphasize traditional techniques and craft-based learning. The result is a structural and measurable skills gap that constrains both graduate employability and the industry's capacity for innovation. This paper presents empirical evidence from a mixed-methods study (n=242 across six countries; 20 in-depth interviews) that maps this gap with precision, locates Sri Lanka within a comparative Asian educational landscape, and proposes a Human-Centered Innovation Framework for fashion education reform. Grounded in constructivist learning theory, the Triple Helix model, and competency-based education principles, the paper argues that closing the skills gap requires not merely curriculum updates but a systemic reorientation of how fashion education is designed, delivered, and evaluated placing human needs, human creativity, and human futures at the center of the process.

Keywords: *human-centred innovation; fashion education; skills gap; luxury fashion; Sri Lanka; digital transformation; sustainability; academic-industry collaboration; emerging economies*

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Introduction

In 2023, McKinsey & Company identified skills misalignment as one of the defining structural challenges facing the global fashion industry. Sixty-two percent of fashion executives surveyed reported that a skills gap was actively constraining their company's performance (Business of Fashion and McKinsey & Company, 2021). Seventy-three percent of employers reported difficulty finding graduates with adequate digital capabilities (Fadel et al., 2022). Eighty-eight percent of fashion recruiters globally struggled to find candidates with the right combination of creative and business skills (Amed et al., 2019).

These are not numbers about a distant or abstract problem. They describe the lived reality of fashion graduates entering employment across Asia — and in Sri Lanka in particular, where the garment and textile industry accounts for a dominant share of national export revenues and where the aspiration to position locally-produced fashion in the global luxury tier is both economically significant and culturally meaningful.

The concept of human-centered innovation — designing systems, processes, and solutions that begin with a deep understanding of human needs, human behaviors, and human futures — has transformed product design, service delivery, healthcare, and urban planning over the past three decades. This paper proposes that it must now transform fashion education. Not as a rhetorical rebranding of existing reform efforts, but as a genuine epistemological shift in how we understand the purpose, design, and evaluation of fashion education systems.

This paper draws on an extensive mixed-methods empirical study conducted across six countries — Sri Lanka, Singapore, Japan, Bangladesh, Pakistan, and the United Kingdom — to present the evidence for this shift, locate Sri Lanka within a comparative educational landscape, and propose a structured Human-Centered Innovation Framework for curriculum reform.

> *"The fashion industry is beginning to adopt innovative technologies, but implementation is slow and limited primarily to a few pioneering designers and sportswear brands." — Bertola & Teunissen (2020)*

Sri Lanka's Fashion Education Landscape: Context and Significance

A Sector at a Crossroads

Sri Lanka's apparel industry is the country's single largest export earner, generating approximately USD 5.5 billion annually and employing over 300,000 workers directly. The sector has made deliberate efforts to move up the value chain — from cut-make-trim manufacturing towards design-led production, brand development, and luxury positioning. Companies such as MAS Holdings, Hirdaramani, and Brandix have invested substantially in design capabilities and sustainability credentials, positioning Sri Lankan manufacturing as a destination of choice for global premium and luxury brands.

Yet the educational infrastructure that should supply this ambition with skilled creative and commercial talent remains structurally misaligned with it. Fashion programs across Sri Lanka — at universities, degree-awarding institutes, and vocational colleges — were largely designed in an era when the industry's primary need was technical production skill. They have been updated incrementally but not fundamentally redesigned to reflect an industry that now demands digital fluency, AI literacy, sustainability expertise, and the capacity for creative innovation at a global level.

The Comparative Landscape

The study on which this paper is based surveyed fashion educators, industry professionals, and recent graduates across six countries, enabling a systematic comparison of educational approaches and their industry alignment. The findings reveal a clear hierarchy of integration.

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Table 1: Comparative fashion education models and industry integration across six countries (adapted from study findings;Amed et al., 2019; Wickramasinghe & Malik, 2016)

Country	Education Model	Industry Integration	Key Characteristics
Singapore	High-technology	Advanced	Strong industry collaboration across subjects; AI and digital tools embedded; design-driven innovation culture
Japan	High-technology	Advanced	Well-developed industry partnerships; strong innovation focus; technical precision combined with emerging technology
United Kingdom	Mixed	Moderate–High	Varies by institution; strengths in innovation, sustainability, and business acumen; established accreditation frameworks
Sri Lanka	Traditional	Limited	Strong in traditional techniques; significant gaps in digital integration, sustainability, and business skills
Bangladesh	Traditional	Limited	Strong textile heritage; limited modern industry integration; constrained by resource and political factors
Pakistan	Traditional	Limited	Focus on traditional textiles; noted digital skills gap at point of industry entry; emerging reform efforts

Sri Lanka's position in this landscape is instructive. It shares the traditional model of Bangladesh and Pakistan but aspires to the industry outcomes of Singapore and Japan. The gap between aspiration and educational infrastructure is the fundamental problem this paper addresses. This comparison should, however, be read with the countries' differing educational systems, economic development levels, and industry maturity in mind rather than as a like-for-like ranking. Singapore and Japan's high-technology integration reflects, in part, decades of sustained national investment in tertiary education infrastructure and a domestic fashion-technology sector that Sri Lanka does not yet have; their outcomes are therefore a useful directional benchmark rather than a target achievable on a similar timescale. Bangladesh and Pakistan's traditional-model classification reflects, per the qualitative data (Section 3.4), constrained conditions rather than an absence of ambition comparable to Sri Lanka's own. Comparisons across this six-country sample are accordingly used in this paper to establish relative positioning and direction of travel, not to imply that identical reform pathways would produce identical outcomes irrespective of national context.

The Evidence: Mapping the Skills Gap
Methodology Overview

The empirical foundation of this paper is a sequential explanatory mixed-methods study (Creswell & Plano Clark, 2018) comprising two integrated phases. The sampling frame comprised 25 fashion programs in Sri Lanka and 25 in comparator countries (Singapore, Japan, Bangladesh, Pakistan, and the United Kingdom), 75 industry professionals (50 targeted in Sri Lanka, 25 internationally), and 100 recent Sri Lankan graduates. Programs were selected using stratified random sampling to ensure representation across institution type (university, degree-awarding institute, vocational college) and program level (undergraduate, postgraduate). Industry professionals were selected using purposive sampling to ensure representation across luxury, fast-fashion, and sustainable-fashion sub-sectors; recent graduates were recruited through participating institutions. Inclusion required active professional or educational involvement in fashion design, production, or education within the study countries; respondents outside these roles were excluded. Recruitment combined direct email invitation to program coordinators and department heads with two follow-up rounds at one and two weeks, supplemented by telephone

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follow-up, over a two-month collection window.

The quantitative phase deployed five structured online surveys: fashion program administrators and faculty in Sri Lanka (n=25 achieved against a target of 25; 100%); counterpart educators across five comparator countries (n=21 against a target of 25; 84%); industry professionals in Sri Lanka (n=55 against a target of 50; 110% of target); international industry professionals (n=20 against a target of 25; 80%); and recent graduates from Sri Lanka (n=120 against a target of 100; 120% of target). Total quantitative sample: 241 respondents. For the Sri Lankan industry-professional and graduate groups, achieved counts exceeded the planned recruitment target. The underlying study's data collection log records only target and achieved totals, not a roster of individuals invited, so the precise recruitment channel through which the additional participants were reached cannot be reconstructed with certainty; the most plausible explanation, consistent with the multi-channel outreach described in the methodology (direct invitation plus telephone follow-up), is that some participants were reached through referral beyond the original invitation list rather than through a fixed, closed sampling frame. Because no invitee roster exists for these two groups, a conventional response rate (respondents / individuals invited) cannot be calculated for them, and the percentages reported are more accurately read as achievement against recruitment target rather than a true response rate. This distinction, and its implications for sampling bias, is discussed further in the Limitations (Section 3.7). The achieved sample comprised 47 educators (19.4%), 75 industry professionals (31.0%), and 120 recent graduates (49.6%); Sri Lanka contributed 201 of 242 total participants (83.1%), including all recent graduates, with the remaining 41 (16.9%) drawn from the five comparator countries.

The qualitative phase comprised 20 in-depth semi-structured interviews with fashion educators (n=8, meeting the upper end of a 6-8 target range), industry professionals (n=6, within a 6-8 target range), recent graduates (n=5, within a 4-6 target range), and one policy-maker (against a 4-6 target range). Participants were selected using purposive sampling to capture a diverse range of perspectives; interviews lasted 45-60 minutes and were conducted in person or via video conferencing, audio-recorded and transcribed with consent. Thematic analysis (Braun & Clarke, 2006) was applied to identify cross-cutting patterns. The under-representation of policy-makers relative to target is a limitation addressed in Section 3.7. The integration of findings across both phases enables triangulation that strengthens the validity and reliability of conclusions

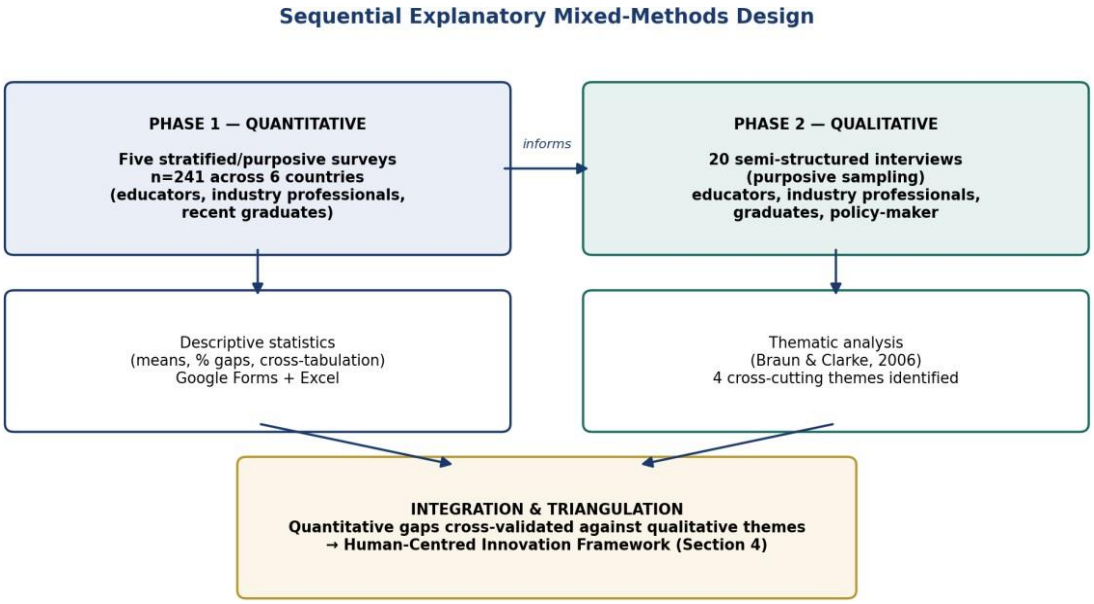

Figure 1. Sequential explanatory mixed-methods design.

The Perception Gap

The most striking quantitative finding is the divergence in how different stakeholders perceive the quality and relevance of Sri Lankan fashion education. Educators rated their curricula's industry alignment at 4.2 out of 5. Industry professionals, assessing the graduates produced by those same curricula, rated their readiness at 3.5 out

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of 5 — a gap of 0.7 scale points. In comparator countries, the equivalent perception gap was only 0.2 points.

Recent graduates, positioned between these two perspectives, rated their preparation at 3.8 out of 5 — aware of both their educational strengths and the practical gaps they encountered on entering employment. This three-way divergence is itself a diagnostic: it reveals a system in which educators believe they are producing industry-ready graduates, graduates suspect they may not be, and industry confirms the suspicion.

Key Diagnostic Finding: Sri Lanka's education-industry perception gap (0.7 points) is 3.5 times larger than the average across comparator nations (0.2 points). This is not a marginal misalignment — it is a structural disconnection.

Competency Gap Analysis

The quantitative data enables a precise mapping of where competency gaps are widest and where Sri Lankan fashion education performs relatively well. The following analysis is drawn from cross-referencing graduate self-assessments with industry professional evaluations across matched competency domains. Percentage gaps were calculated as the proportional difference between the graduate self-assessment mean and the industry satisfaction mean for each domain, expressed relative to the industry benchmark (i.e., gap % = [graduate mean − industry mean] / industry mean × 100); a negative value indicates graduates rate themselves, or are rated, below the level industry professionals consider satisfactory. Because both inputs are perception-based ratings rather than criterion-referenced assessments, these figures should be read as a measure of the size of the perception gap rather than an objective competency deficit:

Table 2: Competency gap analysis — Sri Lankan fashion graduates vs. industry expectations (n=242). Ratings on 5-point scale

Competency Domain	Graduate Rating	Industry Satisfaction	Gap vs Industry	Priority
Data Analytics & Market Intelligence	Low	2.6 / 5	**−35%**	**CRITICAL**
Digital Design & Technology	Low (2.9/5)	2.9 / 5	**−25%**	**CRITICAL**
Sustainability Knowledge	Below average	3.0 / 5	**−30%**	**HIGH**
Business Acumen & Commercial Skills	Below average	3.1 / 5	**−30%**	**HIGH**
Industry Communication & Soft Skills	Moderate	3.4 / 5	**−20%**	**HIGH**
Technical Construction Skills	High (3.8/5)	3.8 / 5	**+5%**	**Strength**
Creativity & Conceptual Design	High (4.1/5)	4.1 / 5	**+10%**	**Strength**

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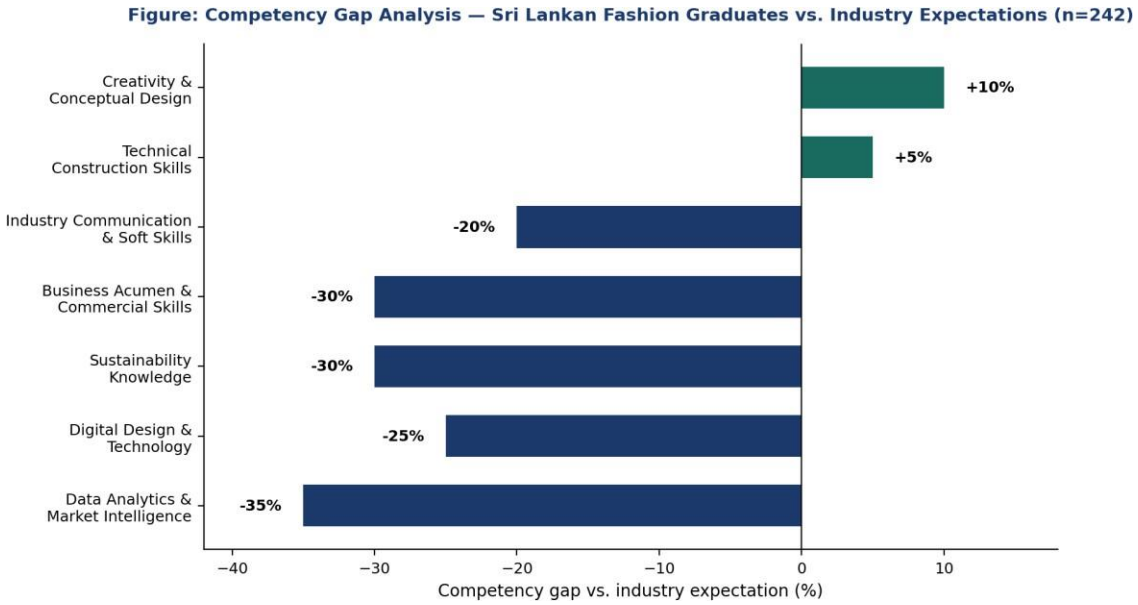

Figure 2. Competency gap analysis by domain (n=242).

Technology Adoption: A Sector-Wide Lag

The technology dimension of the skills gap deserves particular attention given the pace of digital transformation in the global fashion industry. The study reveals a significant adoption lag across multiple technology categories:

- Industry-standard software usage: 58% of Sri Lankan programs vs. 73% in comparator nations — a 15-percentage-point gap
- Modern equipment availability: 62% of Sri Lankan programs vs. 80% in comparator nations — an 18-percentage-point gap
- Digital technology integration in curricula: 42% in Sri Lanka vs. 68% in comparator nations — a 26-percentage-point gap
- 3D design software adoption: 68% of programs — the highest adopted technology, yet still below international norms
- Virtual reality for design visualisation: only 32% of programs
- I for trend forecasting and design: only 18% of programs

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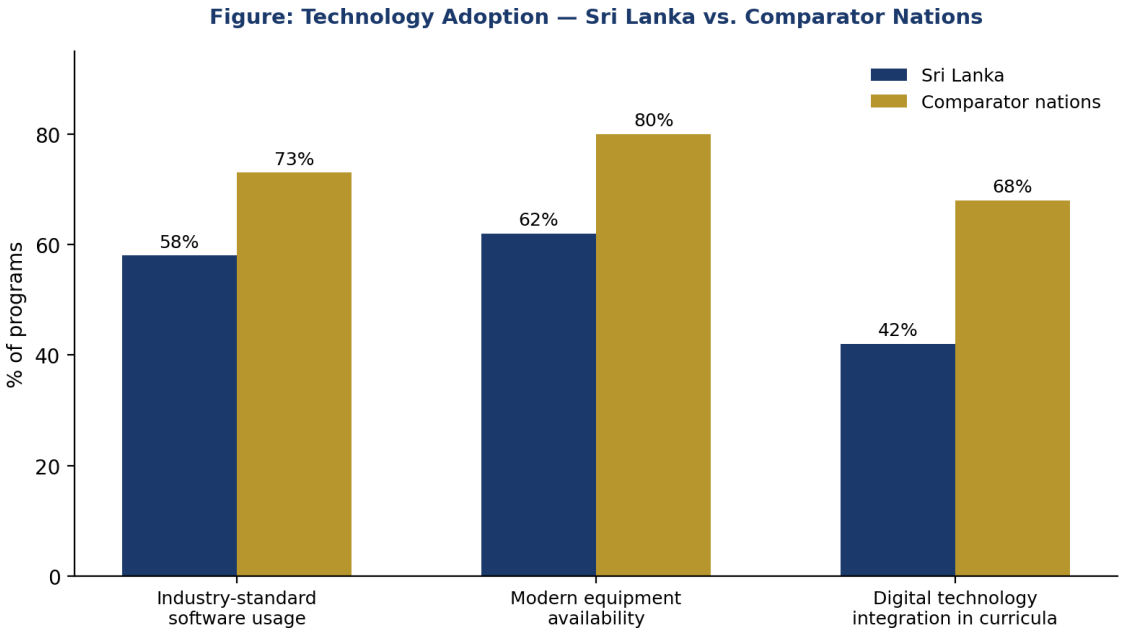

Figure 3. Technology adoption — Sri Lanka vs. comparator nations.

The contrast with Singapore is particularly sharp. Qualitative interviews with Singapore-based educators described active encouragement of AI for research and iteration, virtual design prototyping as a core module, and collaboration with technology partners to ensure students use current industry tools. In Sri Lanka, awareness of the need for these tools is high — but systematic integration remains at an early stage.

> *"When they go into industry and sit in front of the computers and have to use technologies like Gerber or CLO or design-based technologies — they lack there." — Industry Professional, Pakistan (Interview Participant)*

This observation, drawn from a Pakistani participant, mirrors the pattern reported by Sri Lankan industry professionals verbatim. It underscores that the digital skills gap is a shared challenge across the traditional educational model cluster — not a uniquely Sri Lankan problem, but one that requires a Sri Lankan solution.

Sustainability: The Aspiration-Implementation Divide

Sustainability represents a domain of particular complexity. All stakeholder groups rated the importance of sustainability education highly — above 4.5 out of 5 — with recent graduates assigning it the highest importance of any group (4.7/5). This reflects a generational shift in values and a growing awareness of the fashion industry's environmental and social footprint.

Yet the structural data reveals a significant implementation gap. While 72% of Sri Lankan programs offer at least one course on sustainable fashion, only 28% have integrated sustainability principles systematically across the curriculum. Sri Lankan graduates show a −30% competency deficit relative to industry expectations in sustainability knowledge. The aspiration is present; the pedagogy is not yet equal to it.

Voices from the Field: Qualitative Insights

The quantitative findings are given human texture by the qualitative interviews conducted with educators, industry professionals, and recent graduates. Four dominant themes emerged from thematic analysis:

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Theme 1: Curriculum Modernisation as an Urgent Imperative

Educators themselves acknowledged the misalignment between current curricula and industry needs. One senior fashion educator stated that the institution was developing a new curriculum from 2025 onwards, incorporating AI, CAD, CAM, and computer-generated design. Another noted: "There remains a significant gap in aligning with global education and industry standards, especially in rapidly evolving fields like digital fashion, sustainability, and trend forecasting."

Theme 2: Technology Integration — Awareness Without Depth

Industry professionals and recent graduates alike recognized the growing role of digital tools but observed that their incorporation into education remained superficial. One recent graduate noted that her first product development attempt in industry failed because she was still applying a university mindset to an industry problem — not for lack of intelligence or creativity, but for lack of exposure to the tools and workflows that industry uses.

Theme 3: The Practical Experience Gap

Internships and industry placements were cited by recent graduates as the most valuable elements of their education — precisely because they provided what the formal curriculum had not. One graduate reflected: "I think that was the best part of the degree — because I did textile designing at university which we didn't cover so much of in technical areas." This is at once a testament to the value of practical learning and an indictment of the gap between what programs teach and what industry requires.

Theme 4: Soft Skills and Commercial Literacy

Multiple stakeholders identified communication, commercial awareness, and business acumen as areas where graduates consistently underperform. One graduate observed that university had taught her to present ideas academically, but not in the technical register that industry expected. A development merchandiser recommended more training in costing, marketing awareness, and process understanding — competencies that fall outside most fashion curricula's creative core.

Limitations

Several limitations qualify the findings presented above. First, the sample, while substantial (n=242 quantitative; n=20 qualitative), relies on purposive and stratified-but-non-probability sampling for industry professionals and recent graduates; findings are therefore not statistically generalizable beyond the sampled institutions and individuals, and should be read as indicative of patterns rather than population-level estimates. Second, recruitment for the Sri Lankan industry-professional and graduate groups combined direct invitation with telephone-facilitated referral, which exceeded original recruitment targets (110% and 120% of target respectively, see Section 3.1); this referral-based over-recruitment may have introduced self-selection bias toward more engaged or accessible respondents, and a conventional invitee-based response rate could not be calculated for these groups. Third, comparator-country samples were considerably smaller than the Sri Lankan sample (41 respondents across five countries versus 201 in Sri Lanka), and recent graduates were sampled exclusively from Sri Lanka; cross-country comparisons in this paper should accordingly be treated as illustrative rather than statistically robust, and claims about Sri Lanka's relative position are more secure than claims about precise magnitudes of difference between comparator nations. Fourth, all competency and alignment measures rely on self-reported perceptions rather than objective indicators such as employer performance evaluations or graduate employment outcomes, which were not available within the scope of the underlying study; perception-based measures are useful diagnostically but may be subject to social desirability and recall bias. Fifth, the comparative percentages and competency gaps reported (Section 3.3-3.5) are descriptive: no inferential statistical testing (significance testing, confidence intervals, or effect sizes) was conducted on the underlying data, and the reported gaps should be interpreted as indicative differences rather than statistically confirmed effects. Sixth, data collection took place over a fixed two-month window and reflects a snapshot in a rapidly evolving industry; findings on technology adoption in particular may understate current practice by the time of publication. Seventh, a minor internal discrepancy in the underlying dataset should be noted for transparency: the Sri Lankan educator count is recorded as 25 in the primary data-collection log but as 26 in the demographic breakdown by country, with the study-wide educator total (47) only reconciling against the latter figure; this paper reports the data-collection log figure (25; 100% of target) pending verification against the original response data, and readers should treat the exact Sri Lankan educator response rate as approximate to within one respondent. Finally, practical constraints affected specific aspects of coverage: several private Sri Lankan institutions declined participation, citing competitive sensitivities; language differences affected the depth of qualitative data from Japanese participants; and policy-maker representation in the qualitative

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phase (n=1) fell short of the planned target (4-6), limiting the study's ability to speak to policy-level dynamics. These limitations do not undermine the core diagnostic findings, which are corroborated across both quantitative and qualitative strands, but they do bound the strength and generalizability of the claims that follow.

A Human-Centred Innovation Framework for Fashion Education

The evidence presented in the preceding section establishes the nature and scale of the skills gap with precision. The question that follows is: what kind of systemic response is adequate to the scale of the problem? This paper proposes that incremental curriculum revision — adding a module here, updating software training there — is insufficient. What is required is a Human-Centered Innovation Framework (HCIF) that reorients the entire logic of fashion education design around the needs, experiences, and futures of the human beings it serves.

Principles of the Framework

The HCIF is grounded in four foundational principles. Each was derived empirically before being connected to its supporting theory, rather than the reverse: human-centricity responds directly to the 0.7-point educator-industry perception gap and the four qualitative themes, which together show a system currently organized around academic convention rather than stakeholder experience (Section 3.2, 3.6); evidence-driven iteration responds to the absence of any mechanism in the surveyed institutions for feeding graduate-outcome or employer-satisfaction data back into curriculum decisions; co-creation responds to the qualitative finding that industry input, where it exists, is consultative rather than authoritative; and innovation orientation responds to the technology-adoption lag documented in Section 3.4. Constructivist learning theory (Piaget, 1970), the Triple Helix model (Etzkowitz & Leydesdorff, 2000), and competency-based education (Spady, 1994) are then used to give these empirically-derived principles theoretical structure and to connect them to established models of institutional reform, rather than as the original source of the principles themselves.

The four principles are as follows:

- **Human-centricity: The needs, experiences, and aspirations of students, graduates, and industry professionals are the primary design inputs for every curriculum decision — not academic convention, historical precedent, or administrative convenience.**
- **Evidence-driven iteration: Curriculum decisions are made on the basis of data — graduate outcomes, employer satisfaction, industry trend analysis — and are updated continuously rather than episodically.**
- **Co-creation: Industry professionals, recent graduates, and current students are active participants in curriculum design, not consultative additions to an academic process.**
- **Innovation orientation: Fashion education actively cultivates innovation capacity in students — the ability to generate novel solutions, adapt to change, and lead creative disruption — rather than merely transmitting existing knowledge and technique.**

The Framework Architecture

The HCIF comprises three interconnected layers, each addressing a different level of the education system:

Table 3: The Human-Centered Innovation Framework (HCIF) — architecture and outcomes

Layer	Focus	Key Mechanisms	Human-Centred Outcome
Layer 1 Curriculum Content	What is taught — the knowledge, skills, and values embedded in fashion programs	Co-designed modules; real-brief projects; sustainability integration; digital skills pipeline; competency gap mapping	Graduates who are digitally fluent, sustainability-literate, and commercially capable

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Layer 2 Pedagogy & Delivery	How it is taught — the learning methods, studio culture, and assessment approaches	Constructivist learning; industry-mentored studios; design thinking methodology; reflective practice; peer learning	Graduates who can innovate, adapt, and solve real problems under real conditions
Layer 3 System & Governance	The structures that sustain curriculum quality over time	Graduate alumni panels; biennial industry reviews; accreditation reform; policy incentives for collaboration	An education system that evolves in real time with industry needs

Layer 1: Curriculum Content Reform

The evidence is unambiguous about which content domains require urgent development. Digital design and technology, sustainability, business acumen, and data analytics together account for deficits ranging from −20% to −35% relative to industry expectations. Addressing these through the HCIF means not simply adding courses in these areas, but redesigning the curriculum so that these competencies are embedded throughout — not siloed in elective modules.

The study's comparative data provides a concrete benchmark: digital technology integration in fashion curricula should move from the current 42% (Sri Lanka) towards the 68% observed in more advanced systems. This is not an overnight transformation, but it is a measurable target against which progress can be tracked.

Simultaneously, the study confirms that Sri Lanka's strengths in creativity and traditional textile technique must be preserved and amplified — not sacrificed in the pursuit of digital modernization. The HCIF does not advocate replacement but augmentation: building digital and sustainability capabilities on the foundation of creative and technical excellence that already exists.

Layer 2: Pedagogical Innovation

Content reform without pedagogical innovation is insufficient. The manner in which fashion education is delivered is as important as its content. The HCIF draws on constructivist learning theory (Piaget, 1970) to advocate for experiential, problem-based, and industry-integrated learning as the dominant pedagogical mode.

In practice, this means transforming the studio from a space in which students respond to academic briefs into a space in which students address real industry problems, with real industry partners, under real commercial constraints. It means assessment that reflects industry evaluation — not just technical execution but commercial viability, sustainability credentials, and communication quality.

Design thinking methodology — empathising, defining, ideating, prototyping, testing — offers a powerful pedagogical framework precisely because it is the method that the luxury fashion industry itself uses to develop collections, respond to consumer insight, and iterate towards excellence. Teaching students to think in this way is simultaneously teaching them to think like the industry that will employ them.

> *"We always try to cooperate with international trends — digital fashion design, 3D modeling, AI-based tech chain analysis — we incorporate them as well as certain software." — Fashion Educator, Sri Lanka (Interview Participant)*

Layer 3: System and Governance Reform

The most durable changes in education happen at the system level. The HCIF's third layer addresses the governance structures, institutional processes, and policy frameworks that determine whether curriculum reform is sustained over time or quietly reverts to prior patterns.

Three structural mechanisms are central to this layer. First, Graduate Alumni Panels: formal, standing bodies comprising recent graduates who review curriculum annually and whose input is demonstrably actioned. Second, Industry Advisory Boards with genuine authority: not the ceremonial advisory panels that exist in many

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institutions, but collaborative bodies that co-design project briefs, co-assess student work, and co-invest in curriculum development. Third, policy frameworks that incentivise collaboration — tax relief for companies that invest verifiable hours in curriculum development, co-funding mechanisms for joint research, and accreditation standards that reward genuine industry integration rather than merely its appearance.

The Triple Helix model (Etzkowitz & Leydesdorff, 2000) provides the theoretical architecture for this layer, identifying the university, industry, and government as three equally essential partners in any sustainable innovation system. Applied to fashion education, the implication is clear: institutional reform cannot happen in isolation. It requires industry investment and government enabling policy as co-essential conditions. To allow institutions to evaluate whether implementation is succeeding rather than merely occurring, the HCIF is paired with a small set of measurable indicators tracked annually against the baselines established in Section 3: the educator-industry perception gap (baseline 0.7 points, target trajectory towards the 0.2-point comparator average); digital technology integration in curricula (baseline 42%, target 68%); the proportion of programs embedding sustainability systemically rather than as a single elective (baseline 28%, target 60% per Section 5.2); the competency gaps in data analytics, digital design, sustainability, and business acumen (baseline −35% to −25%, tracked for narrowing); and graduate employment outcomes and employer satisfaction scores, once the Sri Lanka Fashion Education Research Centre proposed in Section 5.3 begins generating longitudinal data. These indicators are deliberately drawn from the same instruments used in this study, so that future evaluation is directly comparable to the baseline reported here.

Implementing the Framework: Priorities and Sequencing
Immediate Priorities (Year 1)

Not all elements of the HCIF can or should be implemented simultaneously. Based on the evidence, the following represent the highest-impact immediate priorities:

1. Conduct a formal Competency Gap Audit using the data from this study as a baseline. Map current curriculum content against the seven competency domains identified, and establish measurable targets for gap reduction over three years.
2. Launch a Digital Skills Accelerator — a dedicated programme of software training, AI literacy, and 3D design integration for both faculty and students, prioritising the tools most commonly used by industry employers in Sri Lanka.
3. Establish a Graduate Alumni Panel with formal terms of reference, meeting bi-annually, with documented outputs and demonstrable curriculum influence.
4. Pilot a co-designed industry project brief in at least one module per year of study, replacing an academic brief with a real brief from an industry partner, with the partner involved in briefing students and providing feedback on outcomes.

Medium-Term Development (Years 2–3)

5. Integrate sustainability principles across a minimum of 60% of curriculum content, moving from the current model (72% of programs offer one sustainability course; only 28% embed it systemically) to genuine cross-curricular integration.
6. Develop a mandatory Business and Commercial Literacy module addressing costing, brand positioning, marketing fundamentals, and entrepreneurship — directly targeting the −30% business acumen gap.
7. Establish a formal Industry Advisory Board with co-design authority, including representation from manufacturers, luxury brand partners, sustainability specialists, and digital technology providers.
8. Introduce a Faculty Development Programme on emerging technologies, ensuring that educators can teach what they do not yet fully know — with industry partners providing training.

Long-Term Systemic Change (Years 3–5)

9. Advocate for national fashion education policy reform that mandates industry representation in curriculum governance and establishes graduate outcome tracking as a quality assurance requirement.
10. Develop institutional partnerships with Singapore and Japanese fashion schools to enable faculty

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exchange, collaborative curriculum development, and student mobility — bringing Sri Lankan programs into direct contact with the higher-integration educational models identified in this study.

11. Create a Sri Lanka Fashion Education Research Centre to generate the longitudinal data on graduate outcomes, employer satisfaction, and curriculum effectiveness that is currently absent from the sector.

Implementation Barriers

The priorities above are sequenced by impact, but their feasibility depends on barriers that the evidence base, and the wider literature on curriculum reform in resource-constrained settings, suggest will be material. Financially, digital skills accelerators and equipment upgrades (Section 3.4 shows Sri Lankan programs trailing comparator nations by 15-26 percentage points on technology infrastructure) require capital outlay that under-resourced institutions, particularly smaller and vocational providers, may struggle to fund without external co-investment; this is precisely why the HCIF treats industry co-funding as a governance mechanism (Section 4.5) rather than an optional extra. In terms of faculty readiness, several educators interviewed described teaching tools and methods they had not themselves been trained in, meaning implementation will depend on parallel faculty development rather than curriculum change alone, and may proceed unevenly across institutions with different starting capacity. Institutionally, the reluctance of some private Sri Lankan institutions to participate in this study is itself a signal that competitive dynamics between providers may slow the kind of sector-wide data-sharing (graduate alumni panels, benchmarking against the 42%-to-68% digital integration target) that the HCIF's evidence-driven iteration principle depends on. Finally, policy constraints are non-trivial: implementation priorities 9 and 10 assume a level of government and inter-institutional coordination that does not currently exist in Sri Lankan fashion education policy, and the near-absence of policy-maker voices in this study's qualitative sample (Section 3.7) means the framework's policy-layer recommendations are necessarily more provisional than its curriculum- and pedagogy-layer recommendations. None of these barriers invalidate the sequencing proposed above, but institutions adopting the HCIF should expect Layer 1 and Layer 2 changes to be more immediately actionable than Layer 3 changes, which depend on external actors the individual institution does not control.

Discussion: Human-Centered Innovation as a Paradigm, Not a Programme

The evidence, framework, and implementation priorities presented in this paper amount to more than a curriculum reform agenda. They represent an argument for a fundamental shift in how Sri Lankan fashion education understands its own purpose.

The conventional paradigm positions fashion education as the transmission of established knowledge and technique from expert educators to novice students, validated by academic credentials and periodically updated through curriculum review. This paradigm was appropriate for an industry that changed slowly, valued tradition highly, and could absorb graduates who needed time to develop practical competencies on the job.

The contemporary fashion industry — and the luxury sector in particular — no longer fits this description. It changes rapidly, values innovation alongside tradition, and cannot afford to absorb graduates who require years of on-the-job remediation before they contribute at full capacity. The education system that serves this industry must itself be innovative: responsive, iterative, collaborative, and human-centred in its fundamental orientation. This argument is consistent with, and extends, recent curriculum-focused literature on AI in fashion education: Kohli (2025) similarly concludes, from a benchmarking study of an Indian fashion design programme, that AI-enabled competencies are largely absent from current curricula and proposes a staged model for integrating them; Antony & Ginni (2024) reach a comparable conclusion about the fashion industry more broadly. What this paper's evidence adds is that the gap is not confined to AI literacy alone, but spans digital design, sustainability, and business acumen simultaneously — and that the mechanism most likely to close a multi-domain gap of this kind is systemic reorientation of the kind the HCIF proposes, rather than the addition of a single AI module.

Human-centred innovation, as a paradigm, does not mean that academic knowledge is displaced by industry preference. It means that the human purposes of fashion education — developing creative professionals who can contribute to cultural production, economic value creation, and social sustainability — are held at the centre of every decision about what to teach, how to teach it, and how to know whether it is working.

The luxury fashion sector is uniquely well-suited to embrace this paradigm because luxury itself is fundamentally human-centred. Luxury fashion at its finest is the expression of human creativity, cultural identity, and craft excellence — translated into objects of beauty and significance that resonate with other human beings. An

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education system that is designed with the same commitment to human understanding, creative excellence, and iterative refinement that the best luxury fashion embodies would be a system worthy of the industry it serves.

"Teaching students to be strategic, critical thinkers who can address societal problems — that is what fashion education needs to be doing." — Fashion Educator, Singapore (Interview Participant)

Conclusion

This paper has presented evidence that the skills gap in Sri Lanka's luxury fashion education sector is real, measurable, and urgent. Competency deficits in digital design (−25%), sustainability knowledge (−30%), business acumen (−30%), and data analytics (−35%) represent not just educational failures but economic and competitive constraints on an industry that has the ambition and the potential to play a more significant role in the global luxury market.

The Human-Centered Innovation Framework proposed here offers a structured, evidence-based, and theoretically grounded response to this challenge. Its three layers — curriculum content, pedagogical innovation, and system governance — address the problem at the depth it requires, while its principles of human-centricity, evidence-driven iteration, co-creation, and innovation orientation provide the values architecture that sustains reform beyond any single institutional cycle.

Sri Lanka's fashion education sector possesses genuine and rare strengths: creative depth, textile heritage, and a committed educational community. What it needs is a curriculum development process as innovative, responsive, and human-centered as the luxury industry it aspires to serve. The evidence says the gap is real. The framework says the path is clear. What remains is the institutional courage and collaborative will to walk it. A final caveat is warranted on the framework's claimed applicability beyond Sri Lanka. This paper's primary evidence base is Sri Lankan (83.1% of the quantitative sample), and while the diagnostic pattern it identifies
— traditional curricula, limited digital and sustainability integration, and a wide educator-industry perception gap
— resembles conditions reported for Bangladesh and Pakistan within this study's comparator data, transferability should not be assumed uncritically. Sri Lanka's apparel sector has a distinctive combination of scale, export orientation, and existing relationships with global luxury and premium brands (Section 2.1) that may not hold in other emerging fashion economies with different industrial structures, regulatory environments, or levels of government involvement in education. The HCIF's three-layer architecture and evidence-driven method are intended to be portable, but the specific targets, priorities, and sequencing proposed in Section 5 are calibrated to Sri Lankan baseline data and would need re-diagnosis, not direct transplantation, in another national context. Future research should track institutions that adopt the HCIF longitudinally, evaluating whether the competency gaps and perception gaps documented here narrow over the three-to-five-year implementation horizon proposed in Section 5, and testing the framework's transferability to the comparator emerging economies identified in this study.

This paper is submitted to EICON 2026 under the theme of Creative Arts, Design, Fashion and Human-Centred Innovation. It is derived from the author's MSc dissertation (London Metropolitan University, October 2024) and extends its findings into a framework for systemic reform applicable to Sri Lanka and comparable emerging fashion economies across Asia.

References

Amed, I., Balchandani, A., Beltrami, M., Berg, A., Hedrich, S. & Rölkens, F. (2019). The State of Fashion 2019 Business of Fashion and McKinsey & Company.

Antony, A. & Ginni, R. (2024). The impact of AI on the fashion industry. New York: Routledge. Bertola, P. & Teunissen, J. (2020). Fashion 4.0. In Fashion and Technology (pp. 12-23). Springer.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), pp.77-101. Business of Fashion and McKinsey & Company (2021). The State of Fashion 2021. McKinsey & Company.

Chyung, S.Y., Stepich, D. & Cox, D. (2006). Building a competency-based curriculum architecture to educate 21st-century business practitioners. Journal of Education for Business, 81(6), pp.307-314.

Conti, M., Fronzetti Colladon, A. & Skorupinska, A. (2022). Digital transformation in the fashion industry. Journal of Fashion Marketing and Management, 26(2), pp.135-151.

Creswell, J.W. & Plano Clark, V.L. (2018). Designing and Conducting Mixed Methods Research. 3rd ed. Thousand Oaks, CA: SAGE Publications.

Davis, R. (2018). Developing a Collaborative Framework for Fashion Education. PhD Thesis, University of Fashion.

Etzkowitz, H. & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and 'Mode 2' to a Triple Helix of university-industry-government relations. Research Policy, 29(2), pp.109-123.

Fadel, C., Bialik, M. & Trilling, B. (2022). Four-Dimensional Education: The Competencies Learners Need to Succeed. Center for Curriculum Redesign.

Faerm, S. (2012). Towards a future pedagogy: The evolution of fashion design education. International Journal of Humanities and Social Science, 2(23), pp.210-219.

Gopura, S., Payne, A., Bandara, D.C., Buys, L. & Seneheweera, L. (2019). Fashion education in Sri Lanka: the nexus between formal and informal education. International Journal of Fashion Design, Technology and Education, 12(1), pp.23-34.

Gunnarsson, E. (2023). Bridging the gap: Academic-industry collaborations in fashion education. Journal of Fashion Marketing and Management, 27(2), pp.201-215.

Kohli, J.K. (2025). Impact of artificial intelligence on fashion education for future jobs. Higher Education for the Future, 12(1), pp.114-128.

McKinsey & Company (2023). The State of Fashion 2023. McKinsey & Company. Available at: https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion [Accessed 15 September 2024].

Piaget, J. (1970). Science of Education and the Psychology of the Child. New York: Orion Press.

Ranga, M. & Etzkowitz, H. (2013). Triple Helix systems: an analytical framework for innovation policy and practice in the Knowledge Society. Industry and Higher Education, 27(4), pp.237-262.

Shen, B., Choi, T.M. & Chow, P.S. (2021). Fashioning supply chain management in the artificial intelligence era. Transportation Research Part E, 152, p.102385.

Spady, W.G. (1994). Outcome-Based Education: Critical Issues and Answers. Arlington, VA: American Association of School Administrators.

Wickramasinghe, V. & Malik, K. (2016). Exploring motivations for university-industry collaboration in Sri Lanka. R&D Management Conference 2016. Cambridge, UK.

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OP 07

From Graduate to Professional: A Human-Centred Framework for Fashion Talent Development in Sri Lanka

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Abstract

The transition from fashion graduate to industry professional is one of the most critical and least studied phases in the fashion talent pipeline. While significant attention has been paid to curriculum content and academic-industry collaboration, the lived experience of graduates navigating the gap between university and workplace has remained largely invisible in the research literature. This paper addresses that gap directly. Drawing on a rich qualitative dataset of 20 in-depth interviews with fashion graduates, industry professionals, and educators in Sri Lanka supplemented by quantitative findings from a survey of 242 stakeholders across six countries it maps the graduate transition experience with granular precision.

The paper identifies five critical transition fractures — in digital competency, industry communication, commercial reasoning, professional identity, and sustainability practice — and proposes a Graduate-to-Professional Transition Framework (GPTF) that locates responsibility for bridging these fractures across educational institutions, industry employers, and graduates themselves. Grounded in constructivist learning theory and competency-based education, the GPTF offers a structured, evidence-based, and human-centred model for talent development that is practically implementable within Sri Lanka's fashion education ecosystem. The paper argues that the transition gap is not an inevitable feature of fashion education but a solvable design problem one that requires the same creative intelligence the industry itself prizes.

Keywords: *fashion education; graduate transition; human-centred framework; industry readiness; luxury fashion; professional identity; skills gap; Sri Lanka; talent development*

Acknowledgment: *This paper is derived from the author's MSc dissertation submitted to London Metropolitan University, October 2024.*

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Introduction

Fashion education research has a blind spot. It examines what is taught in universities. It analyses what employers need from graduates. It benchmarks national systems against each other and proposes curriculum frameworks for the future. What it rarely examines with any depth or care is what happens in between: the lived experience of a fashion graduate on the day they leave university and begin working in an industry that operates by entirely different rules.

This paper takes that transition as its primary subject. It argues that the graduate-to-professional gap in Sri Lanka's fashion sector is not a peripheral concern of fashion education policy but its central one — the place where every curriculum decision, every industry partnership, and every pedagogical choice is ultimately tested. The evidence comes from a sequential explanatory mixed-methods study conducted in 2024, involving 242 stakeholders across six countries and 20 in-depth interviews with fashion educators, industry professionals, recent graduates, and one policy-maker in Sri Lanka.

Among the most striking findings is the 0.7-point perception gap between how Sri Lankan fashion educators rate their curricula's industry alignment (4.2 out of 5) and how industry professionals rate their graduates' readiness (3.5 out of 5). That gap — 3.5 times wider than the 0.2-point average in comparator countries — is not a statistical abstraction. It is the gap that graduates walk into on their first day of work.

> *"When I did my first product development, it was a failure — because I was still thinking with the same mindset I had in university."*
>
> *— Ms. Ushani, Recent Fashion Graduate, Sri Lanka*

This paper maps that gap, names its constituent fractures, and proposes a structured Human-Centred Graduate-to-Professional Transition Framework (GPTF) designed to close it. It is offered as a contribution to EICON 2026's theme of Creative Arts, Design, Fashion and Human-Centred Innovation — because there is nothing more human-centred than designing the beginning of a career.

Methods

This study employed a sequential explanatory mixed-methods research design (Creswell & Plano Clark, 2018). The quantitative phase comprised five structured online surveys administered to 242 stakeholders: fashion program administrators and faculty in Sri Lanka (n=25; 100% response rate); counterpart educators across five comparator countries — Singapore, Japan, Bangladesh, Pakistan, and the United Kingdom (n=21; 84%); industry professionals in Sri Lanka (n=55; 110%); international industry professionals (n=20; 80%); and recent fashion graduates from Sri Lanka (n=120; 120%). Survey instruments used Likert-scale, multiple-choice, and ranking formats.

The qualitative phase comprised 20 in-depth semi-structured interviews: fashion educators (n=8), industry professionals (n=8), recent graduates (n=4), and one policy-maker. Thematic analysis (Braun & Clarke, 2006) was applied using a six-phase coding protocol. Integration of quantitative and qualitative findings followed Creswell and Plano Clark's (2018) explanatory design, with quantitative results contextualised and deepened by qualitative insight. The theoretical framework draws on constructivist learning theory (Piaget, 1970), competency-based education (Spady, 1994), and the Triple Helix model (Etzkowitz & Leydesdorff, 2000).

Results

Competency Gap Analysis

Sri Lankan fashion graduates enter employment with significant competency deficits relative to industry expectations. Table 1 presents the full competency gap analysis across seven domains:

Table 1. Competency gap analysis — Sri Lankan fashion graduates vs. industry expectations (n=242)

Competency Domain	Graduate Self-Rating	Industry Satisfaction	Gap	Severity
Data Analytics & Market Intelligence	Low	2.6 / 5	**−35%**	**CRITICAL**
Digital Design & Technology	Low (2.9/5)	2.9 / 5	**−25%**	**CRITICAL**

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Business Acumen & Commercial Skills	Below average	3.1 / 5	**−30%**	**HIGH**
Sustainability Knowledge	Below average	3.0 / 5	**−30%**	**HIGH**
Industry Communication & Soft Skills	Moderate	3.4 / 5	**−20%**	**HIGH**
Technical Construction Skills	High (3.8/5)	3.8 / 5	**+5%**	**Strength**
Creativity & Conceptual Design	High (4.1/5)	4.1 / 5	**+10%**	**Strength**

Note. Ratings on 5-point Likert scale. Gap calculated as percentage difference between graduate self-rating and industry expectation.

The strengths are real: Sri Lankan fashion programs produce graduates with genuine creative ability and solid technical foundations. The gaps, however, are precisely in the domains that determine whether a graduate can function effectively in the first six months of employment. The transition gap is therefore both a skills gap and a readiness gap.

Five Critical Transition Fractures

Thematic analysis of qualitative interviews, triangulated with quantitative data, identified five distinct fractures at the graduate-to-professional boundary. These are specific points at which the graduate's education-acquired framework breaks down on contact with industry reality:

Table 2. Five critical transition fractures - synthesis of mixed-methods findings (n=242 quantitative; n=20 qualitative)

#	Fracture	What Breaks Down	Evidence from the Study
1	**Digital Tool Literacy**	Graduate cannot operate industry-standard software at entry-level fluency	58% of Sri Lankan programs use industry software vs. 73% elsewhere; 42% digital integration vs. 68% internationally (n=242)
2	**Communication Register**	Graduate communicates in academic register (aesthetic, conceptual) not industry register (technical, specification-based)	−20% soft skills gap; raised by multiple graduate and employer interview participants
3	**Commercial Reasoning**	Graduate cannot integrate costing, margin, buyer, and market factors into design decisions	−30% business acumen gap; −35% data analytics gap; raised explicitly by development merchandiser participants
4	**Professional Identity**	Graduate continues to operate in student mode — waiting to be guided, treating errors as learning not commercial risk	Graduate self-description: 'still thinking with the same mindset I had in university'
5	**Sustainability Practice**	Graduate holds sustainability as abstract value but cannot apply circular economy or ESG principles operationally	−30% sustainability gap; 72% of programs offer one sustainability course but only 28% embed it across curriculum

Technology Readiness Gap

Only 58% of Sri Lankan fashion programs use industry-standard software, compared to 73% in comparator nations. Only 42% have meaningfully integrated digital technologies into the curriculum, against 68% internationally. Only 18% of programs incorporate AI applications — despite industry rating AI as the single most important emerging

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technology (4.2/5).

> *"When they go into industry and sit in front of the computers and have to use technologies like Gerber or CLO or design-based technologies — they lack there."*
>
> *— Industry Professional, Pakistan (comparative interview participant)*

Communication Register Fracture

Qualitative data surfaced a nuanced but consequential transition fracture: communication register. Fashion graduates are taught to communicate in the register of the studio and the academic seminar — not the register of the production floor, the client meeting, or the merchandising conversation.

> *"In university we were taught to communicate, do the presentation and all — but not in terms of the technical way that industry wanted."*
>
> *— Ms. Hashini Fernando, Recent Fashion Graduate, Sri Lanka*

Commercial Reasoning Gap

The study's quantitative data confirms a −30% deficit in business acumen relative to industry expectations, and a −35% deficit in data analytics — the capacity to read trend forecasts, interpret sales data, and make commercially informed design decisions.

> *"A marketing sense will work more if we have a bit more knowledge in marketing, and also the costing side and the process."*
>
> *— Ms. Isuri Kaluatachchi, Development Merchandiser, Sri Lanka*

Professional Identity Transition

Perhaps the most underappreciated dimension of the graduate transition experience is its psychological dimension: the shift from student identity to professional identity. Graduates who undertook substantial, paid, structured industry placements reported significantly smoother transitions — precisely because placement forced a mode-switch from student to practitioner before graduation.

> *"When I did my first product development, it was a failure — because I was still thinking with the same mindset I had in university."*
>
> *— Ms. Ushani, Recent Fashion Graduate, Sri Lanka*

Discussion

The Graduate-to-Professional Transition Framework (GPTF)

The GPTF is a four-phase, human-centred model for fashion talent development that distributes responsibility for bridging the five transition fractures across three actors: educational institutions, industry employers, and graduates themselves. It extends across the full arc of undergraduate study and into the first year of employment, on the evidence that the transition gap cannot be closed by education alone. The graduate is not treated as a passive product of the education system or a raw material for the industry to process — the graduate is an active agent in their own professional development.

Phase 1 — Foundation (Year 1): Professional Awareness

Phase 1 begins in Week 1 of undergraduate study. In most Sri Lankan fashion programs, significant industry exposure does not occur until Year 2 or 3, often not until the final-year internship. The GPTF challenges this sequencing: professional awareness should begin in Week 1, not Year 3.

Phase 1 Mechanisms:

- Industry orientation module in Semester 1: structured introduction to the Sri Lankan and global fashion industry, covering major employers, role profiles, career paths, and commercial structures
- Early digital literacy stream: basic training in industry-standard software (Gerber, CLO, Illustrator) beginning in Year 1, building digital confidence before specialised application
- Graduate mentor programme: each Year 1 student paired with a recent graduate (two to four years post-

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degree) for peer mentorship on professional transition realities

- Structured industry site visits to garment manufacturers, design studios, and retail environments with guided reflection

"We have a network of designers who graduated from here and are based in the industry. I think we are getting there — we are developing the curriculum together."

— Dr. Sumith Gopura, Fashion Educator, Sri Lanka

Phase 2 — Development (Year 2): Competency Building

Phase 2 targets the four CRITICAL and HIGH competency gaps identified in Table 1, delivering them as sustained year-long streams rather than isolated modules. Each stream directly addresses one of the five transition fractures.

Phase 2 Mechanisms:

- Digital Proficiency Stream: progressive mastery of industry-standard design and production software; introduction to AI trend forecasting tools and data visualisation
- Commercial Reasoning Stream: fashion costing and margin analysis; buyer relationship simulation; brand positioning and market research; e-commerce fundamentals
- Sustainability Practice Stream: circular economy principles applied to design briefs; ethical sourcing decision-making; ESG reporting literacy; industry sustainability partner collaboration
- Industry Communication Stream: technical specification writing; client presentation simulation; register-switching between academic and industry communication modes

"It needs to be taught rather than being asked to do our own research — we wouldn't know how and what the industry uses lately."

— Ms. Devina, Recent Fashion Graduate, Sri Lanka

Phase 3 — Integration (Final Year): Professional Transition Preparation

Phase 3 is structured around two interconnected activities: a substantive, paid, industry-supervised placement and a co-designed industry-academic capstone project. Placement experience was rated by graduates as the most valuable element of their degree — precisely because it forced a mode-switch from student to practitioner that no amount of studio teaching could replicate.

Phase 3 Mechanisms:

- Structured six-month paid placement: learning objectives jointly agreed between institution, employer, and student; formally assessed on professional competency not merely task completion
- Professional Identity Workshop: explicitly addressing the student-to-professional identity shift — professional conduct, error management, feedback reception, workplace relationship navigation — co-facilitated by industry mentors and HR professionals
- Industry-Co-Designed Capstone Project: final project brief written collaboratively by an industry partner and the institution; assessed by both academic and industry evaluators; presented to a mixed industry-academic panel
- Pre-employment competency self-assessment: graduates self-assess against the professional profile defined in Phase 1 and create a personal development plan for their first year of employment

"We give opportunities to a minimum of eight students for six months. We pay them. We give them an opportunity to learn without any closed windows — we go full."

— Mr. Rakitha Ratnayaka, Industry Professional, Sri Lanka

"I think that was the best part of the degree — because I did textile designing at the University of Moratuwa, which we didn't cover so much of in technical areas in the university. The industry exposed me to what I didn't know I needed."

— Ms. Ushani, Recent Fashion Graduate, Sri Lanka

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Phase 4 — Onboarding (First Year of Employment): Industry Responsibility

Phase 4 places explicit, structured responsibility on industry employers for the onboarding of new fashion graduates. Even optimally prepared graduates will arrive in roles that require adjustment, mentoring, and support. The GPTF asks industry employers to structure that support deliberately, rather than leaving it to the accident of line manager quality or organisational culture.

Phase 4 Mechanisms:

- Structured 90-day onboarding plan: co-created by HR and line manager, specifying competencies to be demonstrated and milestones reviewed at 30, 60, and 90 days
- Designated industry mentor: a senior professional available for structured monthly development conversations
- Reverse mentoring: new graduate invited to share perspectives on digital tools, sustainability practices, or consumer trends — positioning them as a contributor from day one
- Six-month feedback loop to institution: employers provide structured feedback on each graduate cohort's transition experience, creating a continuous data stream for curriculum improvement

Table 3. The Graduate-to-Professional Transition Framework (GPTF) — summary

Phase	Timing	Primary Goal	Key Mechanisms	Who Leads
Phase 1 Foundation	Year 1	Professional awareness — students understand industry expectations from Week 1	Industry orientation; digital literacy stream; graduate peer mentoring; site visits	Institution + alumni graduates
Phase 2 Development	Year 2	Competency building — sustained development of four critical transition domains	Digital, commercial, sustainability & communication streams across full year	Institution + industry partner lecturers
Phase 3 Integration	Year 3 / Final Year	Transition preparation — professional identity shift and real-world application	Six-month paid placement; Professional Identity Workshop; co-designed capstone; pre-employment self-assessment	Institution + industry placement host

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Phase	Timing	Primary Goal	Key Mechanisms	Who Leads
Phase 4 Onboarding	Year 1 of Employment	Professional consolidation — structured support during first 12 months in industry	90-day onboarding plan; industry mentor; reverse mentoring; feedback loop to institution	Industry employer + graduate

Note. Phase 4 is implemented by industry employers, completing the co-responsibility model of the Triple Helix framework.

Stakeholder Voices at the Centre

Graduates demonstrated a remarkably precise understanding of their own preparation gaps — far more precise than their educators' self-assessments would suggest. They knew which tools they needed. They knew which commercial skills were absent. They knew that their communication was calibrated for the wrong audience.

> *"AI — because it's coming in really fast into the market right now. And 3D design. And then more about intimate designs — because I guess Sri Lanka produces more intimate wear than anything else."*
>
> *— Ms. Devina, Recent Fashion Graduate, Sri Lanka*

Industry participants were consistent in expressing willingness to invest in graduates who demonstrated the right foundations. Educators demonstrated genuine awareness of the transition gap and, in many cases, were actively working to address it within significant institutional constraints — curriculum rigidity, limited access to current technology, and the challenge of keeping pace with an industry that changes faster than academic review cycles allow.

> *"Now we are developing a curriculum starting from 2025 onwards — adding AI, CAD, CAM, computer-generated designing and manufacturing. We are developing a new curriculum which is more suited with the industry needs."*
>
> *— Dr. Sumith Gopura, Senior Fashion Educator, Sri Lanka*

The pace problem is significant: a curriculum designed in 2025 and implemented across multiple years will be training graduates for a 2028 or 2029 industry. The GPTF's Phase 4 feedback loop addresses this by creating a continuous data stream from employers to institutions, rather than relying on periodic curriculum reviews that inevitably lag industry change.

Conclusions

The transition from fashion graduate to professional is one of the most consequential moments in a fashion career — and one of the most poorly supported. Sri Lanka's fashion programs produce graduates with genuine creative and technical strengths, but deliver them into an industry that expects digital fluency, commercial reasoning, professional communication, and sustainability literacy that their education has not systematically developed.

The Graduate-to-Professional Transition Framework maps this transition with empirical precision, identifies its five critical fractures, and proposes a four-phase model for closing them. It is human-centred in the fullest sense: built from the testimony of the graduates who lived the transition, the employers who received them, and the educators who prepared them.

The argument of this paper is not that Sri Lankan fashion education has failed. It is that it has not yet designed the ending — the critical bridge between the studio and the workplace, between student identity and professional identity, between creative capability and commercial contribution. Building that bridge requires investment, collaboration, and the willingness to treat the graduate's transition experience as a design problem worthy of the same creative intelligence that the industry applies to everything else it makes.

> *"When I did my first product development, it was a failure — because I was still thinking with the same mindset I had in university. Nobody had shown me the difference."*

— Ms. Ushani, Recent Fashion Graduate, Sri Lanka

Nobody had shown her the difference. That is the sentence this paper is designed to change. Fashion at its best is the art of making something that fits — that fits a body, fits a culture, fits a moment. The GPTF is an attempt to design education that fits: that fits the human being who has studied for three years, the industry that needs them, and the career that should follow.

References

Amed, I., Balchandani, A., Beltrami, M., Berg, A., Hedrich, S. & Rölkens, F. (2019). The State of Fashion 2019. Business of Fashion and McKinsey & Company.

Antony, A. & Ginni, R. (2024). The impact of AI on the fashion industry. New York: Routledge. Bertola, P. & Teunissen, J. (2020). Fashion 4.0. In Fashion and Technology (pp. 12-23). Springer.
Bicho, M., Ferreira, F.A.F. & Horta, I.M. (2024). Sustainability in Fashion: Challenges and Opportunities. Routledge.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77-101. Business of Fashion and McKinsey & Company (2021). The State of Fashion 2021. McKinsey & Company. Chyung, S.Y., Stepich, D. & Cox, D. (2006). Building a competency-based curriculum architecture to educate 21st-century business practitioners. Journal of Education for Business, 81(6), 307-314.

Conti, M., Fronzetti Colladon, A. & Skorupinska, A. (2022). Digital transformation in the fashion industry. Journal of Fashion Marketing and Management, 26(2), 135-151.

Creswell, J.W. & Plano Clark, V.L. (2018). Designing and Conducting Mixed Methods Research (3rd ed.). SAGE Publications.

Davis, R. (2018). Developing a Collaborative Framework for Fashion Education. PhD Thesis, University of Fashion.

Divita, L. (2021). Balancing creativity and technical skills in fashion education. Journal of Fashion Design, Technology and Education, 14(1), 45-56.

Etzkowitz, H. & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems to a Triple Helix of university-industry-government relations. Research Policy, 29(2), 109-123.
Fadel, C., Bialik, M. & Trilling, B. (2022). Four-Dimensional Education. Center for Curriculum Redesign. Faerm, S. (2012). Towards a future pedagogy: The evolution of fashion design education. International Journal of Humanities and Social Science, 2(23), 210-219.

Gopura, S., Payne, A., Bandara, D.C., Buys, L. & Seneheweera, L. (2019). Fashion education in Sri Lanka: the nexus between formal and informal education. International Journal of Fashion Design, Technology and Education, 12(1), 23-34.

Gunnarsson, E. (2023). Bridging the gap: Academic-industry collaborations in fashion education. Journal of Fashion Marketing and Management, 27(2), 201-215.

McKinsey & Company (2023). The State of Fashion 2023. McKinsey & Company.

Peters, S. & Lucietto, A. (2016). Industry-academic collaboration models in design education. Design Studies, 42, 78-99.

Piaget, J. (1970). Science of Education and the Psychology of the Child. Orion Press.

Reddy, K. (2014). World's fashion and creative design education and its distinguished characteristics: an overview. Unpublished manuscript.

Spady, W.G. (1994). Outcome-Based Education: Critical Issues and Answers. American Association of School Administrators.

Wickramasinghe, V. & Malik, K. (2016). Exploring motivations for university-industry collaboration in Sri Lanka. R&D Management Conference 2016, Cambridge, UK.

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OP 08

Student Perceptions and Experiences of AI in Fashion Design Education

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Abstract

Artificial Intelligence (AI) is becoming increasingly visible within fashion design education, especially in areas such as idea generation, concept development, and visual exploration. As AI tools become more accessible, students are also beginning to use them actively within their design projects. While these tools help students work faster, experiment with more ideas, and visualize concepts easily, concerns about originality, dependency, and ethical use of AI-generated content are also becoming more important within creative education.

Therefore, this study explored student perceptions and experiences of using AI tools in fashion design education. The research was based on two AI-integrated fashion design modules involving both individual and collaborative projects. Data was mainly collected through a questionnaire distributed among fashion design students and supported through observation of student project outcomes.

The findings showed that students mainly used AI tools such as ChatGPT, Midjourney, and Runway ML during idea generation, concept development, and sketching stages. Most students believed AI helped make the design process faster, easier, and more flexible while supporting experimentation and visualization. However, students also experienced challenges such as difficulties with prompt writing, inaccurate outputs, limited access to advanced features, and concerns related to originality and dependency on AI-generated results. Project observations further showed that students used AI in different ways, often combining AI-generated outputs with their own research, sketching, and design development. More unique outcomes were generally achieved when students actively refined prompts and contributed their own creative input throughout the process.

Overall, the study shows that AI can positively support fashion design education when used as a supportive tool rather than a replacement for human creativity and personal design thinking. The findings also highlight the importance of educator guidance and responsible use of AI to maintain originality, creativity, and individual design identity.

Keywords: *AI, AI in Design Education, Creativity, Design Education, Fashion Design*

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Introduction

Background

Artificial Intelligence (AI) has been developing very fast in recent years and now it is becoming part of many industries, including fashion. In fashion design, AI is used for things like idea generation, creating visuals, and even predicting trends. Because of this, the design process is becoming much faster and more flexible, allowing designers to explore many ideas in a short time.

With these changes, AI is also starting to be used in fashion design education. Students are now using AI tools in their projects, especially for developing concepts and visuals. This gives them more opportunities to experiment and try different ideas easily. But at the same time, it also creates some concerns. There is a chance that students may depend too much on AI, which can reduce their own thinking process and originality.

In my context, students have already used AI in their individual projects and are now also using it in collaborative projects. Even though AI is being used actively, there is still not much understanding about how students actually experience this process. It is not very clear whether AI is helping them to be more creative or making them rely on it too much. Also, issues like originality, authorship, and ethical use of AI are becoming important.

So because of this, it is important to study how students use AI, what they feel about it, and how it affects their creativity and learning in fashion design.

Objective of the Study

The main objective of this study is to explore student perceptions and experiences of using AI tools in fashion design education.

To achieve this, the following sub-objectives are considered:

1. To identify how students use AI in different stages of their design process
2. To examine student perceptions towards AI in creative work
3. To understand how AI affects creativity, confidence, and independent thinking
4. To identify the benefits and challenges students face when using AI
5. To explore student awareness about ethical issues related to AI-generated designs

Limitations of the Study

During the research, some limitations were identified:

1. Sample – The study is limited to selected fashion design students from specific batches
2. Scope – It focuses only on project-based experience and not long-term effects
3. Data Collection – Most data is based on student responses, so it can be subjective
4. AI Usage Differences – Students used AI in different ways and levels, which may affect the consistency of results

Significance of the Study

This research focuses on understanding how AI is being used by students in fashion design education and how it is affecting their learning and creativity. It looks at both the positive side, like idea generation and efficiency, and also the negative side, like dependency and lack of originality.

The study can help educators understand how to guide students better when using AI, so that it supports their creativity instead of replacing it. It also highlights the importance of maintaining a balance between technology and personal design thinking.

Additionally, this research helps to explore how human creativity and AI work together in a learning environment. It can be useful for improving teaching methods and helping students to develop their own design identity while still using AI as a tool.

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Methods

Research Design

This study followed a mixed-method descriptive research approach to explore student perceptions and experiences of using Artificial Intelligence (AI) within fashion design education. The research was based on two AI-integrated fashion design modules conducted through both individual and collaborative project work.

The study focused on understanding how students used AI during different stages of the design process and how these technologies influenced creativity, learning experience, confidence, originality, and independent thinking.

Research Sample

The research sample consisted of 32 fashion design students who completed two AI-integrated design modules. Students participated in both individual and collaborative projects where AI tools were used for concept development, visual generation, experimentation, research, and presentation purposes.

Participants were selected based on their direct involvement within these modules, as they had practical experience using AI throughout their design process.

Data Collection Methods

Both primary and secondary data collection methods were used in this study.

Primary Data Collection

Questionnaire Survey

Primary data was mainly collected through a structured questionnaire distributed among students after completing the AI-integrated modules. The questionnaire included both close-ended and open-ended questions to gather information regarding student experiences, perceptions, challenges, and opinions about the use of AI within fashion design projects.

The questionnaire focused on the following areas:

- Usage of AI during the design process
- Student perceptions towards AI
- Creativity and originality
- Dependency on AI tools
- Learning experience and confidence
- Ethical awareness related to AI-generated work
- Future use of AI in design practice

The responses collected through the questionnaire were used as the main source of data for the research findings and analysis.

Observation of Student Projects

Student project outcomes from both individual and collaborative modules were informally observed and reviewed to understand how AI tools influenced the design development process. This observation helped identify visible patterns related to creativity, experimentation, originality, and the level of AI integration within student work.

Secondary Data Collection

Secondary data was collected through journals, academic articles, books, conference papers, and online sources related to AI in fashion design, creativity, design education, and ethical concerns associated with AI-generated content.

The literature review supported the development of theoretical understanding and helped contextualize the findings collected from students.

Data Analysis

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The collected questionnaire responses were analyzed using descriptive and thematic analysis methods. Student responses were categorized into major themes including creativity, dependency, learning experience, ethical awareness, and perceptions towards AI.

The responses were interpreted to identify common patterns, similarities, differences, benefits, and challenges experienced by students throughout the AI-integrated modules. Findings from the questionnaire and project observations were analyzed together to better understand the impact of AI within fashion design education.

Ethical Considerations

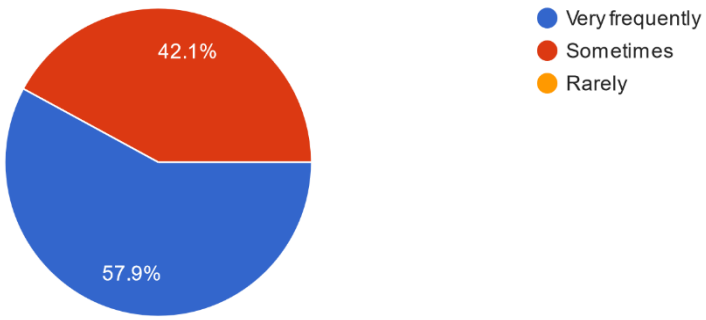
Participation in the questionnaire survey was voluntary, and students were informed about the purpose of the research before responses were collected. Confidentiality and anonymity of participants were maintained throughout the research process.

All collected data was used only for academic research purposes

Results

AI Usage in the Design Process

The findings showed that ChatGPT was the AI tool most students used throughout their projects, with 94.7% of students reporting its use. Midjourney was the second most commonly used tool (47.4%), while DALL·E was used by 21.1% of students. A smaller number of students also experimented with tools such as Gemini (10.5%), Runway ML (5.3%), Perplexity AI (5.3%), DeeVid AI (5.3%), and Freepik (5.3%). Most students mainly used AI during idea generation, concept development, and sketching or visual development stages, with each stage being selected by 68.4% of respondents. AI was used less frequently during final design development (42.1%) and presentations (31.6%).It was clear from the responses that AI had become a regular part of the students' design workflow. None of the respondents mentioned that they "rarely" used AI.



Most students stated that they used it "very frequently," while many others selected "sometimes." Students generally felt that AI helped them work faster and made the design process easier to manage. One student explained that "It was helpful in proceeding faster when provided with the ideas and design concepts I had in my mind," while another mentioned that AI helped them "generate ideas and explore different design concepts." These responses show that students mainly used AI as a supportive tool to develop and visualize their ideas more quickly.

Through observing the student projects, it was noticeable that students used AI in very different ways. Some students used AI for almost the entire design process, while others combined AI with their own methods. In some cases, students started with AI-generated concepts and sketches and then developed them further using their own creativity. In other cases, students first created their own concepts through research, manual sketching, or CAD development and later used AI to refine, visualize, or improve their ideas.

Another interesting observation was that AI became very useful when students found it difficult to communicate certain design details through sketching. Students were often able to use AI to visualize ideas that they struggled to draw themselves.

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However, this only worked well when the prompts were clear and detailed. Without proper prompting, the outputs often became generic and did not fully represent the student's original idea.

Student Experiences and Challenges of Using AI

Most students had positive experiences when using AI in their projects, especially when it came to saving time and exploring ideas. The questionnaire results also showed that students felt AI was most helpful in making the design process faster, which received the highest average rating of 4.05 out of 5. Students also felt that AI helped them generate new ideas (3.68/5), improve the quality of their designs (3.47/5), and increase their confidence in designing (3.37/5). These findings suggest that students generally saw AI as a useful support tool throughout their projects. Some students particularly enjoyed using AI-generated visuals and videos because it allowed them to see their garment ideas in a more realistic way.

Even though students enjoyed using AI, many also shared frustrations they faced during the process. One of the biggest issues was getting outputs that matched the exact idea they had in mind. One respondent explained that they "found it hard sometimes because AI did not always give exactly what I wanted. I had to change and improve the results. Also, I needed to give clear instructions, and I had to check everything to make sure it was correct and original." Another student mentioned that "I couldn't get the exact results to align with the designs I had in my mind so I had to provide a very detailed description on my designs still some ai tools failed to give quality result, so I had to look for better options." Similarly, another respondent simply stated, "Yeh, because when i use AI it didn't give what exactly i wanted."

One thing that became clear from observing the projects was that unique outcomes were rarely achieved through a single prompt. Although AI could generate results very quickly, students usually had to go through several attempts before getting something that matched their vision. The students who produced stronger outcomes were often the ones who spent more time refining prompts, testing different approaches, and making improvements throughout the process.

It was also noticeable that many AI-generated concepts shared similarities. Similar structures, wording, inspirations, and visual directions appeared across different projects. When students relied only on AI-generated results, their outcomes sometimes looked quite similar to one another. However, students who added their own ideas, research, inspirations, and project-specific information were able to achieve much more unique and personal outcomes

Many students also highlighted how difficult prompt writing could be. They explained that getting better results depended heavily on how clearly they described their ideas. In addition, students mentioned problems such as limited free access, daily credit limits, and the need to pay for advanced features to get higher quality outputs. These findings suggest that although AI made the design process faster and more flexible, students still faced technical and creative challenges while trying to make the outputs feel closer to their own ideas and style.

AI, Creativity, and Dependency

Students had mixed feelings about how AI affects creativity and originality. Some respondents felt that AI could reduce originality if students relied on it too much, while others believed it could support creativity when used carefully alongside their own ideas. One student explained that "AI can limit originality if you depend on it too much, because many outputs can look similar. However, if used creatively, it can support originality by helping develop new ideas." This response reflected the opinion shared by many students throughout the questionnaire.

Students had mixed feelings about how AI affects creativity and originality. Some respondents felt that AI could reduce originality if students relied on it too much, while others believed it could support creativity when used carefully alongside their own ideas.

The questionnaire results also showed that concerns about dependency and reduced creative thinking were present, but not strongly. The statement "I relied too much on AI" received an average rating of 2.89 out of 5, while "AI reduced my own creative thinking" received an average rating of 2.61 out of 5. This suggests that although some students felt a certain level of dependency on AI, most students did not believe that AI had significantly reduced their creativity or thinking process.

When students were asked whether their work still reflected their personal style while using AI, most respondents selected "Maybe." This showed that many students were unsure about how much of their own identity remained within AI-supported designs. Some students felt AI helped polish and improve their ideas, while others felt that AI-generated outputs sometimes looked too artificial or lacked their personal touch.

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Concept development was one of the most common areas where students used AI. Almost every student used AI at some stage when developing concepts, researching ideas, or building design directions. When comparing these projects with projects completed without AI, it was noticeable that AI helped students connect ideas more quickly and develop concepts in a more structured way.

At the same time, some similarities could be seen across many AI-generated concepts. Similar words, concept structures, and inspiration sources appeared repeatedly. This showed that while AI can support concept development, originality still depends on the designer's own involvement. Students who provided detailed information, added their own thinking, and continuously refined the outputs generally produced more original results than those who accepted AI-generated content without much modification.

The findings also showed that many students felt at least some level of dependency on AI during their projects. However, despite these concerns, most respondents still believed that AI helped them understand design concepts better and supported their learning process. Overall, students seemed to see AI as something useful and beneficial, but they also understood the importance of balancing AI support with their own creativity, thinking process, and design identity.

Discussion

ChatGPT was the most widely used AI tool among students (94.7%), followed by Midjourney (47.4%) and DALL·E (21.1%). Students mainly used these tools during idea generation, concept development, and sketching or visual development stages, each reported by 68.4% of respondents. This connects with how AI is currently being used within the fashion industry itself. AI tools are now able to generate sketches, patterns, and visuals through text prompts, helping designers speed up the design process and experiment with more ideas in a shorter period of time.(1,2)

This could clearly be seen through the student experiences as many students explained that AI helped them save time and manage their workflow more easily. One student mentioned that “It was helpful in proceeding faster when provided with the ideas and design concepts I had in my mind,” while another explained that AI helped them “generate ideas and explore different design concepts.” These experiences show that students were mainly using AI as a support tool to develop and visualize their own ideas more quickly rather than depending on it completely. This also relates to the idea that AI works best when combined with human creativity instead of replacing the designer completely.(3)

Another noticeable point was that students already seemed familiar with image-generation platforms such as Midjourney and Runway ML because these technologies are becoming more visible within the fashion field itself. Fashion brands such as H&M, Nike, and Zara are already using AI for trend forecasting, customization, inventory management, and product development.(1) AI systems are also capable of analysing customer preferences, runway collections, and social media trends to help designers explore more informed design directions.(4) Because of this, it is natural that fashion design students are also adapting to these technologies during their learning process.

At the same time, several challenges appeared while students were working with AI tools. Even though AI helped speed up the process, many students explained that it was difficult to get outputs that fully matched the ideas they imagined. One respondent explained that they “found it hard sometimes because AI did not always give exactly what I wanted,” while another stated that “I couldn't get the exact results to align with the designs I had in my mind.” This reflects one of the main limitations of AI systems where generated outputs can sometimes feel inaccurate, repetitive, or disconnected from the designer’s original concept. Difficulties related to inaccuracies, biased outputs, and technical limitations are also becoming common concerns within AI-supported education and creative industries.(5)

Prompt writing also became an important part of the process. Many students explained that they had to repeatedly change and refine prompts in order to get better results. Some students also mentioned limitations such as paid subscriptions, daily credit restrictions, and limited access to advanced features, especially when generating videos and higher-quality visuals.

Creativity and originality became another major concern throughout the discussion. AI tools can support experimentation, help generate variations, and make idea development faster.(6) However, concerns related to originality, ownership, and over-dependence on AI-generated outputs were also strongly visible. One student explained that “AI can limit originality if you depend on it too much, because many outputs can look similar. However, if used creatively, it can support originality by helping develop new ideas.” This reflects the balance many students were trying to maintain between using AI as support while still protecting their own creative identity and thinking process.

Interestingly, even though many students appreciated AI because it made work easier and faster, there were still a few students who strongly disliked the use of AI within fashion design education. Some students felt that AI reduced originality no matter how useful it was, while others believed AI should only support concept development, research, and visualization rather than replace personal creativity. Concerns related to authorship, authenticity, and ethical use of AI-generated content are also becoming increasingly important within design education.(7)

Another observation from the projects was that AI seemed to work best when students used it to support areas where they felt less confident rather than allowing it to control the whole design process. For example, some students used AI to help with concept development, research, visualization, or sketching, while still making their own design decisions throughout the project. This created a better balance between technology and personal creativity.

It was also noticeable that students produced a much larger number of sketches, visual explorations, and design variations compared to a typical project. AI allowed them to experiment more freely and explore ideas in a shorter period of time. However, the strongest outcomes were usually produced by students who actively evaluated and developed the AI-generated outputs rather than simply accepting them. This further suggests that AI works most effectively as a supportive tool rather than a replacement for the designer.

Overall, AI appears to work best as a supportive tool within fashion design education. It helps students' experiment, develop ideas, and visualize concepts more efficiently while still leaving space for human creativity, critical thinking, and personal design identity.

Conclusion

This study explored how fashion design students used AI within their design process and how they experienced it during their projects. AI tools such as ChatGPT, Midjourney, and Runway ML were mainly used for idea generation, concept development, and sketching stages. For many students, AI helped make the design process faster, easier, and more flexible while helping them explore and visualize ideas more quickly.

At the same time, students also faced challenges such as getting inaccurate outputs, difficulties with prompt writing, limited access to advanced features, and concerns about originality and depending too much on AI. Even though most students saw AI as helpful, some still felt that using AI too much could reduce creativity and personal thinking within the design process.

Looking at both the questionnaire responses and the project outcomes, it became clear that AI can be a valuable tool when it is used with active involvement from the designer. Students were able to save time, generate more ideas, and visualize concepts more easily, especially in areas where they felt less confident. At the same time, the most successful outcomes were achieved when students combined AI with their own creativity, research, and design thinking rather than depending entirely on AI-generated results.

This study also highlighted the importance of guidance and self-awareness when using AI. Educators have a responsibility to help students understand how to use AI in a way that supports learning and creativity rather than replacing it. Similarly, students and future designers need to develop their own ethical awareness and personal responsibility when working with AI. When used in this way, AI has the potential to become a powerful supportive tool within fashion design education while still preserving originality, creativity, and individual design identity.

Overall, the study shows that AI can support fashion design education in a positive way when used carefully and in balance with human creativity and personal design thinking.

References

1. De Lima Ml. The Influence Of Artificial Intelligence On The Fashion Industry: Creativity, Sustainability, And Innovation. Int Seven J Multidiscip. 2023 Jan 29;2(1). doi:10.56238/isevmjv2n1-018

2. Rahman P, Mehnaz S. International Journal for Multidisciplinary Research (IJFMR). SSRN Electron J. 2024. doi:10.2139/ssrn.5054029

3. Rizzi G, Bertola P. Exploring the generative AI potential in the fashion design process: an experimental experience on the collaboration between fashion design practitioners and generative AI tools. Eur J Cult Manag Policy. 2025 May 21;15:13875. doi:10.3389/ejcmp.2025.13875

4. P. S, M. M, V.A. S, R. S. Ai-Driven Fashion Design: How Machine Learning Is Transforming The Creative Process. ShodhKosh J Vis Perform Arts. 2024 Jun 30;5(1). doi:10.29121/shodhkosh.v5.i1.2024.4387

5. Zhang Y, Liu C. Unlocking the Potential of Artificial Intelligence in Fashion Design and E-Commerce Applications: The Case of Midjourney. J Theor Appl Electron Commer Res. 2024 Mar 18;19(1):654–70. doi:10.3390/jtaer19010035

6. Anantrasirichai N, Bull D. Artificial intelligence in the creative industries: a review. Artif Intell Rev. 2022 Jan;55(1):589–656. doi:10.1007/s10462-021-10039-7

7. Fathoni AFCA. Leveraging Generative AI Solutions in Art and Design Education: Bridging Sustainable Creativity and Fostering Academic Integrity for Innovative Society. Mursitama TN, Noerlina, Utama DN, Abrori SA, editors. E3S Web Conf. 2023;426:01102. doi:10.1051/e3sconf/202342601102

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OP 09

An Ethical AI Adoption Framework for Fashion Design Education in Sri Lanka

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Abstract

Background: Generative AI tools are being adopted by fashion design students faster than institutions can respond, raising concerns over design skill erosion, academic integrity, and graduate professional readiness. Existing AI ethics frameworks are not adapted to creative disciplines: they fail to address the tacit, embodied competencies central to fashion design or the intellectual property and originality challenges that distinguish creative practice.
Objective/s: This study aimed to develop an ethical AI adoption framework for fashion design education that balances digital innovation with design integrity, to assess its utility through stakeholder review, and to produce implementation guidelines transferable to other South Asian institutions.

Methods: A concurrent mixed-methods triangulation design was adopted, integrating a quantitative survey (n=89 students; n=24 educators) measuring AI adoption, design competence, and professional readiness with semi-structured qualitative interviews (n=14: educators, industry practitioners, and students). Seven convergent findings from cross-phase triangulation directly informed framework development, with industry practitioner perspectives shaping the framework's professional readiness and institutional governance dimensions.

Results: The resulting six-pillar framework comprises Foundation First, Human-AI Balance, Critical Evaluation, Transparency Protocol, Legal Compliance, and Institutional Readiness. Stakeholder responses identified Institutional Readiness as the most critical pillar: demand for ethical AI guidelines was the highest educator-rated item (M=4.71/5.00), institutional guidance was the lowest student-rated item (M=2.51/5.00), and 80% of institutions reported no formal written AI policy. All three stakeholder groups contributed framework component recommendations during the qualitative phase, grounding the framework directly in expert feedback.

Conclusion/s: The six-pillar framework provides a structured, practice-oriented approach for adopting AI responsibly without compromising core design competencies. Empirical data were collected exclusively from Colombo-based institutions. However, the framework reflects structural conditions shared across South Asian fashion education, including export-oriented apparel industries, limited AI governance infrastructure, and under-resourced institutions navigating rapid technological change, suggesting meaningful transferability that warrants multi-site empirical validation.

Keywords: *AI ethics, design competence, fashion education, professional readiness, South Asia*

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OP 10

AI Adoption and Design Competence Among Fashion Design Students in Sri Lanka

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Background: Generative AI adoption among fashion design students is increasing rapidly, prompting debate over whether it enhances creative competence or contributes to deskilling in abilities such as sketching, pattern-making, and critical decision-making. South Asia presents a distinctive context: a major global apparel-exporting region with limited institutional AI governance and tensions between digital transformation and established design traditions. Empirical evidence on this relationship in this context remains limited.
Objective/s: This study examined the relationship between AI adoption and design competence and professional readiness among fashion design students in Sri Lanka, and compared student and educator perceptions of these constructs.

Methods: A concurrent mixed-methods design was used. Students (n=89) and educators (n=24) completed parallel 35-item Likert questionnaires measuring AI adoption (independent variable) and design competence and professional readiness (dependent variable) across cognitive, psychomotor, affective, and professional dimensions. Qualitative data from semi-structured interviews (n=14) were analysed using Braun and Clarke's (2006) thematic analysis and integrated through concurrent triangulation to contextualise the quantitative findings.

Results: A statistically significant but weak positive correlation was found between AI adoption and design competence and professional readiness ($r=0.308$, $p=0.003$; approximately 9.5% of variance explained). Thematic analysis identified a binary student response pattern of covert over-reliance versus fearful avoidance of AI, contextualising why a deskilling effect was non-significant. Students rated their own ethical AI awareness considerably higher than educators rated it, indicating a perceived-versus-observed ethical practice gap. Educators rated institutional AI guidance among the weakest measured areas.

Conclusion/s: AI adoption alone does not determine design competence and professional readiness outcomes; qualitative evidence suggests ethical awareness and institutional guidance may play moderating roles, though formal moderation testing is recommended for future research. Findings support phased curriculum integration of AI alongside foundational skill protection, and fashion-specific AI policies incorporating mandatory disclosure and design-task-differentiated assessment guidelines.

Keywords: *AI adoption, design competence, deskilling, fashion education, professional readiness*

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EP 01

Scalable and Privacy-Preserving Customer Support Automation in Banking Using Small Language Model Powered Multi-Agent Architectures

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Abstract

Background: Deploying Large Language Models (LLMs) in banking customer service is constrained by high cloud inference costs, data-residency requirements under regulations such as PCI-DSS and GDPR, and the risk of hallucinated financial guidance.

Objective/s: To design and evaluate an end-to-end, on-premise, Small Language Model (SLM, under 2 billion parameters) powered multi-agent architecture for banking customer support, and to determine which retrieval, orchestration, and evaluation strategies best support factuality and efficiency.

Methods: A five-agent publish-subscribe pipeline was built around a TinyBERT intent classifier, a hybrid FAISS+BM25 retrieval pipeline with cross-encoder reranking, a Gemma-3-1B-IT generation agent, an SLM-as-judge factuality agent, and a fine-tuned MiniLM safety guardrail. The system was trained and validated on human-reviewed, HDFC Bank of India FAQ and Reserve Bank of India data (approximately 2,500 extracted passages), supplemented by synthetically generated data validated on 380 manually reviewed samples per dataset. Evaluation combined classification metrics, retrieval ranking metrics, and a dual LLM-as-judge framework (GPT-4o-mini and Gemini-3-Flash) across three agent architectures and five conversation-history strategies.

Results: TinyBERT achieved 93.95% intent-classification accuracy at approximately 28 ms per query; MiniLM achieved 98.65% safety-classification accuracy at 250 ms latency, outperforming Llama Guard 1B (52.5-60.4% accuracy) by over 38 percentage points while being 134-210 times faster. Cross-encoder reranking improved retrieval MRR@5 by 17.2% with no recall penalty. The publish-subscribe architecture with Gemma-3-1B-IT achieved a mean judge score of 2.99/5, comparable to cloud-hosted Gemini-2.5-Flash-Lite (2.90/5), while reducing latency by 20.5% relative to supervisor-only orchestration and operating entirely on local hardware.

Conclusion/s: SLM-based multi-agent systems, when combined with hybrid retrieval, reranking, and task-specific safety classifiers, can approach cloud-LLM response quality for a single-institution banking FAQ domain while preserving data residency and reducing inference cost. Findings should be interpreted as evidence from a single-bank case study; broader validation across institutions and languages is required before generalising.

Keywords: *banking chatbot; multi-agent orchestration; on-premise deployment; retrieval-augmented generation; small language models*

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Introduction

Banks are increasingly replacing routine customer-service interactions with conversational AI to deliver instant, scalable support [1]. However, in regulated domains such as banking, speed and automation alone are insufficient: systems must also be factually correct, auditable, and privacy-preserving [2]. Cloud-based Large Language Model (LLM) application programming interfaces (APIs) require transmitting customer queries to third-party servers, which conflicts with data-residency provisions under the Payment Card Industry Data Security Standard (PCI-DSS) and the General Data Protection Regulation (GDPR). At production scale, API costs for frontier-class models are also a material operational burden. Compounding these constraints, LLMs are prone to hallucination: an analysis of 800 real-world LLM-generated question-answer pairs found that approximately 31.4% of responses contained hallucinated information, with 62.5% of those directly contradicting the source context [3].

Small Language Models (SLMs), typically defined as models below 7 billion parameters, have recently narrowed the performance gap with larger counterparts on structured, domain-specific tasks through targeted fine-tuning and overtraining strategies [4]. Deployed on-premise, SLMs remove the need to transmit customer data externally and reduce inference cost by orders of magnitude. However, no prior published study has evaluated a complete SLM-powered multi-agent architecture, spanning intent routing, retrieval, generation, factuality checking, and safety screening, in a banking customer-service setting. Existing multi-agent frameworks such as MetaGPT [5] and CAMEL [6] were designed for software-engineering workflows rather than regulated conversational support, and existing SLM surveys [4,7] evaluate standalone benchmark performance rather than end-to-end system behaviour.

This study addresses that gap by developing and evaluating a five-agent, publish-subscribe multi-agent system for banking customer support, using HDFC Bank of India's publicly available frequently-asked-questions (FAQ) content as a representative case study. The objectives of this study were: (1) to determine how SLM-based agents perform relative to cloud LLM baselines in terms of accuracy, latency, and cost; (2) to identify which retrieval-augmented generation (RAG) strategies most effectively improve factuality for SLMs; (3) to identify which agent orchestration pattern best supports task allocation and scalability in a regulated customer-support setting; and (4) to determine which evaluation approach most reliably measures factuality and compliance for this class of system.

Methods

Study Design and Setting

This study followed an experimental, quantitative research design. The system was developed and evaluated as a case study using publicly available data from HDFC Bank of India and the Reserve Bank of India (RBI), supplemented with synthetically generated data validated by human review. All development, training, and evaluation were conducted on standard commodity hardware to reflect realistic on-premise deployment conditions: lightweight encoder and non-transformer models were trained on Kaggle T4 graphics processing units (GPUs); larger SLMs (up to 7 billion parameters) were fine-tuned using 4-bit quantisation and Low-Rank Adaptation (LoRA, rank 16) on a single 16 gigabyte (GB) GPU; and inference benchmarking for larger candidate models was additionally performed on an Apple Silicon M1 central processing unit (CPU) to simulate constrained on-premise inference hardware. Software included PyTorch/HuggingFace Transformers for model training, LangChain-style tooling for retrieval orchestration, FAISS for dense vector indexing, and Chroma for metadata-filtered vector storage.

Material and Dataset Description

Three categories of data were used. First, real extracted data: the most recent FAQ and policy documents were scraped from the official HDFC Bank of India and RBI websites, yielding approximately 2,500 text passages, chunked into 512-token segments with 50-token overlap and indexed by intent category. Second, publicly available benchmark data: the Bitext retail-banking intent corpus (approximately 25,000 rows across 9 categories) was filtered to 8 HDFC-relevant categories, and Google's BoolQ dataset (15,942 natural yes/no question pairs) was used to represent out-of-domain queries. Third, synthetic data generated using Llama-405B and Gemini-2.5-Flash via few-shot prompting, used specifically to (a) increase stylistic and phrasing diversity beyond the source corpora and (b) balance minority classes. Three task-specific fine-tuning datasets were constructed this way: an intent-classification dataset (1,500 rows, 8 categories, combining filtered Bitext rows with synthetically generated formal, casual, and abbreviated phrasings), a response-safety dataset (1,600 rows, 4 balanced

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categories of 400 rows each: PII disclosure, bad advice, competitor information, and safe), and a general question-and-answer dataset (1,500 rows) formatted as system-user-assistant instruction triples.

Because synthetic data can overestimate real-world performance if left unchecked, every generated dataset was subjected to manual validation: a random sample of 380 rows was drawn from each dataset (approximately 25% of the intent and safety datasets, and 25% of the general question-and-answer dataset) and reviewed by a human validator against three criteria: relevance to the HDFC banking domain, labelling and formatting consistency, and factual accuracy of any HDFC-specific claims. Fewer than 2% of reviewed rows were found to be malformed or mislabelled and were removed prior to training. Final dataset splits are reported in Table 1.

Procedures and System Architecture

User queries are first routed by a lightweight intent classifier into one of three categories: General (greetings and chit-chat, answered directly by a fine-tuned SLM), Relevant (banking-specific queries, routed to the multi-agent workflow), and Other (out-of-domain queries, answered with a fixed deflection response). Three agent-orchestration architectures of increasing complexity were implemented and compared: a Single Chain baseline (a direct language-model-plus-RAG pipeline); a Supervisor-Worker architecture (centralised task delegation to specialised worker agents); and a Publish-Subscribe architecture, inspired by MetaGPT's global message pool [5], in which five specialised agents, a Supervisor, a Retrieval agent, a Generation agent, a Factuality agent (SLM-as-judge, 1-5 scale), and a Security agent, communicate only via subscribed message types, reducing redundant token exchange. The Retrieval agent uses an ensemble of dense (FAISS) and BM25 sparse retrieval, followed by cross-encoder reranking and metadata filtering to the relevant intent category. The Security agent is a fine-tuned MiniLM classifier that intercepts responses containing personally identifiable information (PII) disclosure, unqualified financial advice, or competitor mentions before delivery to the user.

Model Training and Comparisons

For intent classification, three lightweight transformer encoders, TinyBERT (14.5 million parameters), DistilBERT, and all-MiniLM, together with a decoder baseline (DistilGPT2), were fine-tuned using 5-fold stratified cross-validation (learning rate 2e-5, batch size 16, 3 epochs) and evaluated on an unseen test set of over 14,000 stylised synthetic queries. For safety classification, the same three encoder architectures were fine-tuned on the 1,600-row safety dataset (5-fold cross-validation, learning rate 2e-5, batch size 8, 2 epochs, maximum 128 tokens) and benchmarked against Llama Guard 1B, both as a zero-shot baseline and after fine-tuning on the identical dataset, to test whether a general-purpose safety model could match a task-specific encoder. For general question answering, eleven candidate SLMs spanning 125 million to 7 billion parameters were fine-tuned using LoRA (rank 16) with 4-bit quantisation (learning rate 2e-4, 3 epochs), with an additional epoch-count ablation (1, 3, and 5 epochs) conducted on OPT-1.3B to identify an optimal training duration and detect over-fitting.

Statistical and Evaluation Analysis

Classification models were compared using accuracy, macro-averaged F1-score, and average/95th-percentile (P95) inference latency, with confusion-matrix analysis to identify systematic misclassification patterns. Retrieval quality was assessed using Mean Reciprocal Rank (MRR@k), Precision@k, Recall@k, and Normalised Discounted Cumulative Gain (nDCG@k) at k=5 and k=10 across an ablation of dense-only, hybrid (dense+BM25), and hybrid-with-reranking configurations, isolating the marginal contribution of each retrieval component. Because standard lexical metrics such as BLEU and ROUGE-L are known to be poor proxies for factual correctness in domain-specific question answering [8], response quality was primarily assessed using an LLM-as-judge framework with two independent judge models, GPT-4o-mini and Gemini-3-Flash, scoring factual accuracy, completeness, and clarity on a 1-5 scale, in addition to reporting BLEU/ROUGE-L/BERTScore for transparency and comparison. This dual-judge design was adopted specifically to reduce evaluation bias from reliance on a single automated judge; rankings that agree across both independent judges are reported as convergent evidence, while the absence of a live human-expert evaluation panel is acknowledged as a limitation (see Discussion). Given the sample sizes used for architecture-level comparisons (100 queries per condition), reported percentage differences should be interpreted as descriptive effect sizes from a single evaluation run rather than as formally significance-tested estimates; no confidence intervals or hypothesis tests were computed, and this is noted as a limitation.

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Results

Intent Classification

TinyBERT achieved 93.95% test accuracy at approximately 28 milliseconds (ms) per query, matching DistilBERT's accuracy while being roughly five times faster; DistilGPT2, a decoder-only model, underperformed at 92.51%, indicating that bidirectional encoders are better suited to this discriminative routing task (Table 2). Cross-validation accuracy (0.9935-0.9982) was consistently 4-5 percentage points higher than held-out test accuracy across all models, reflecting the generalisation cost of limited stylistic diversity in the training data despite synthetic augmentation. Misclassifications were concentrated between the semantically overlapping accounts and operations categories (4 of 602 test predictions).

Table 1. Intent classification: cross-validation and held-out test accuracy with per-query inference latency

Model	5-fold CV Acc.	Test Acc.	Macro-F1	Latency (ms/query)
DistilBERT	**0.998**	**0.944**	**0.944**	**139**
MiniLM	**0.998**	**0.951**	**0.952**	**60**
TinyBERT	**0.994**	**0.940**	**0.939**	**28**
DistilGPT2	**0.925**	—	—	—

Response Safety Classification

MiniLM was selected as the production safety guardrail, achieving 98.65% accuracy at 250 ms average latency (Table 3). By comparison, Llama Guard 1B, a general-purpose safety model not designed for financial-compliance categories, achieved only 60.42% accuracy as a zero-shot baseline, and its accuracy fell further to 52.50% after fine-tuning on the identical dataset, alongside a P95 latency of over 87,000 ms. This indicates catastrophic forgetting: Llama Guard's generative pre-training objective is structurally misaligned with a discriminative four-class classification task, and fine-tuning degraded rather than improved its usefulness. Task-specific encoder classifiers therefore outperformed a general-purpose safety model by over 38 percentage points in accuracy while being 134-210 times faster.

Table 2. Response safety classification: accuracy, macro-F1, and average latency.

Model	Accuracy (%)	Macro-F1	Avg. Latency (ms)
DistilBERT	**99.06**	**99.06**	**585**
MiniLM	**98.65**	**98.64**	**251**
TinyBERT	**94.27**	**94.21**	**1,195**
Llama Guard 1B (base)	**60.42**	**55.22**	**33,679**
Llama Guard 1B (fine-tuned)	**52.50**	**48.86**	**52,617**

Retrieval Ablation

Dense-only and hybrid (dense+BM25) retrieval yielded identical ranking metrics at k=5 (Recall 0.95, MRR 0.720, nDCG 0.763), and BM25 slightly reduced recall at k=10 (0.95 to 0.89) by displacing valid dense results, reflecting the highly standardised vocabulary of banking FAQ text, which offers little for a sparse keyword matcher to add over dense semantic similarity. Adding cross-encoder reranking on top of hybrid retrieval was the only intervention that improved ranking quality, delivering a +17.2% improvement in MRR@5 and +13.8% in nDCG@5 with no recall penalty, by shifting the average rank of the first relevant passage from 1.39 to 1.18. For SLMs constrained to short context windows, this reranking step materially increases the likelihood that the correct passage appears first in context.

Multi-Agent Architecture and Cross-Model Comparison

Across 100 single-turn queries, judged independently by GPT-4o-mini and Gemini-3-Flash, the Publish-Subscribe architecture powered by Gemma-3-1B-IT achieved the best balance of factuality and completeness (mean overall judge score 2.99/5 under GPT-4o-mini), closely matching cloud-hosted Gemini-2.5-Flash-Lite (2.90/5). Gemini-2.5-Flash-Lite scored highest on clarity (4.84/5) but markedly lower on factual grounding (2.10/5), indicating that fluent output does not guarantee regulatory-appropriate factual accuracy. Rankings were broadly consistent between the two independent judges, providing convergent evidence that this pattern is not an artefact of a single judge's scoring tendencies. The Publish-

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Subscribe pattern reduced per-query latency by 20.5% relative to the Supervisor-only pattern for Gemma-3-1B-IT (123.5 to 98.1 seconds per 100 queries) and reduced average context-token usage by 7.4%, consistent with its design goal of routing only subscribed message types to each agent rather than broadcasting full conversational context.

Lexical overlap metrics diverged sharply from judged quality: Llama-3.2-1B achieved the highest ROUGE-L score (0.51) but the lowest judge rating (2.9/10), because it tended to mirror prompt phrasing while omitting the actual answer content; OPT-1.3B achieved the highest judge rating (7.0/10) for standalone question answering despite a markedly lower ROUGE-L (0.31), because it produced accurate, contextually rephrased answers. An epoch-count ablation on OPT-1.3B found that extending fine-tuning from 3 to 5 epochs caused a 59.6% collapse in judge score (7.00 to 2.83), with degenerate, repetitive output, indicating a hard training-duration ceiling for this dataset size.

Multi-Turn Conversation Management

Across five context-management strategies evaluated on 100 multi-turn conversations, Window+Summarise (retaining the two most recent turns in full and compressing earlier turns) achieved the best semantic-similarity score for Gemma-3-1B-IT (0.490), while Full Buffer (retaining the entire conversation) achieved the highest judged quality (1.64/5) at the cost of higher token usage. The gap between SLM and cloud-LLM judged quality was substantially wider in multi-turn settings (1.64/5 for Gemma-3-1B-IT versus 3.97/5 for Gemini-2.5-Flash under Full Buffer) than in single-turn settings, indicating that multi-turn contextual coherence remains a comparatively weaker capability for parameter-constrained SLMs than single-turn factual retrieval and generation.

Discussion

These findings indicate that, for a structured, single-institution banking FAQ domain, an appropriately architected sub-2-billion-parameter SLM system can approach the response quality of a cloud-hosted LLM while running entirely on local hardware. Three findings help explain why.

First, TinyBERT's strong intent-classification performance is consistent with its design goal: it is a heavily distilled encoder optimised specifically for short-sequence classification rather than open-ended generation, so its capacity is concentrated on the discriminative task at hand rather than spread across broader generative competence. This explains both its accuracy, comparable to larger encoders, and its substantial latency advantage, which matters directly for real-time query routing at scale.

Second, BM25 provided no measurable benefit over dense retrieval alone. We attribute this to the standardised, template-like phrasing of banking FAQ content: because dense embeddings already capture the limited vocabulary and repeated phrasing patterns typical of regulatory and product FAQ text well, a sparse lexical matcher adds little complementary signal, and in some cases actively displaces semantically correct passages ranked highly by the dense retriever. This suggests hybrid retrieval may be more valuable for less standardised, more heterogeneous document collections than for structured FAQ corpora, and that cross-encoder reranking, not hybridisation, is the retrieval component worth prioritising when SLM context windows are limited.

Third, the Publish-Subscribe architecture's latency and token-usage advantage over the Supervisor-only pattern follows directly from its selective message-routing design: because each agent subscribes only to the message types relevant to its role, agents avoid re-processing the full conversational history or supervisor commentary that is irrelevant to their specific task. For banking deployment, this has practical implications beyond raw efficiency: reduced context per agent call also narrows the surface area over which a downstream agent could be influenced by irrelevant or malformed upstream content, which is a desirable property for a compliance-sensitive pipeline, though this was not formally tested here.

The comparatively wide SLM-versus-cloud-LLM gap observed in multi-turn settings, relative to the near-parity observed in single-turn settings, suggests that conversational coherence over multiple turns, rather than single-turn factual retrieval, is the more binding capability constraint for sub-2-billion-parameter models in this application. This has a direct deployment implication: institutions adopting SLM-based systems for single-turn FAQ resolution can expect near-cloud-parity quality today, whereas multi-turn support desks should budget for either a hybrid escalation path to a larger model or further investment in context-management strategy tuning.

These results should be interpreted within clear boundaries. The system was trained and evaluated exclusively on HDFC Bank of India's English-language FAQ corpus; the reported accuracy, latency, and judge-score figures describe performance

on this single-institution case study and should not be read as general claims about SLM banking-chatbot performance across other institutions, regulatory regimes, or languages, and title and framing throughout this manuscript have been scoped accordingly. The 100-query and 100-conversation evaluation sets, while manually validated, are modest in size for architecture-level comparisons, and no formal statistical significance testing was applied to the reported percentage differences; they should be read as descriptive effect sizes from a single evaluation run. Judged quality relied entirely on two automated LLM judges rather than live domain or compliance experts; while the use of two independent judge models with broadly convergent rankings mitigates single-judge bias, it does not substitute for expert human evaluation, and future work should incorporate banking-domain and compliance-specialist review. Adversarial robustness, including prompt-injection and jailbreak resistance of the safety guardrail, was not tested and remains an open risk for production deployment. Finally, conversational memory is session-scoped only; cross-session continuity was out of scope for this study.

Conclusions

This study presented and evaluated a five-agent, publish-subscribe, SLM-powered multi-agent architecture for banking customer support, using HDFC Bank of India's FAQ corpus as a case study. Task-specific encoder models substantially outperformed a general-purpose safety model for regulatory-compliance screening, cross-encoder reranking was the primary driver of retrieval-quality improvement, and publish-subscribe orchestration reduced both latency and token overhead relative to centralised supervision. Under dual-judge evaluation, a 1-billion-parameter, on-premise SLM achieved response quality comparable to a cloud-hosted LLM for single-turn queries within this domain, while eliminating per-query API cost and cloud data transmission. Multi-turn conversational coherence remains a comparatively weaker capability for SLMs and is identified as a priority for future work, alongside multi-institution validation, formal statistical testing, live human expert evaluation, and adversarial robustness testing, before findings can be generalised beyond this single-bank case study.

References

1. Li X, Chan S, Zhu X, Pei Y, Ma Z, Liu X, et al. A survey on LLM-based multi-agent systems: workflow, infrastructure, and challenges. Vicinagearth. 2024;1(1):9.

2. Gao Y, Xiong Y, Gao X, Jia K, Pan J, Bi Y, et al. Retrieval-augmented generation for large language models: a survey. arXiv preprint arXiv:2312.10997. 2024.

3. Ren Y, Gruhlke N, Lauscher A. Detecting hallucinations in authentic LLM-human interactions. arXiv preprint arXiv:2510.10539. 2026.

4. Lu Z, Li X, Cai D, Yi R, Liu F, Zhang X, et al. Small language models: survey, measurements, and insights. arXiv preprint arXiv:2409.15790. 2025.

5. Hong S, Zhuge M, Chen J, Zheng X, Cheng Y, Zhang C, et al. MetaGPT: meta programming for a multi-agent collaborative framework. arXiv preprint arXiv:2308.00352. 2024.

6. Li G, Hammoud HAAK, Itani H, Khizbullin D, Ghanem B. CAMEL: communicative agents for "mind" exploration of large language model society. arXiv preprint arXiv:2303.17760. 2023.

7. Belcak P, Heinrich G, Diao S, Fu Y, Dong X, Muralidharan S, et al. Small language models are the future of agentic AI. arXiv preprint arXiv:2506.02153. 2025.

8. Chen J, Zhou P, Hua Y, Loh Y, Chen K, Li Z, et al. FinTextQA: a dataset for long-form financial question answering. In: Proceedings of the 62nd Annual Meeting of the Association for Computational Linguistics. Bangkok: ACL; 2024. p. 6025-47.

9. Nogueira R, Cho K. Passage re-ranking with BERT. arXiv preprint arXiv:1901.04085. 2019.

10. Wang Q, Yuan J, Huang X, Yan J, Xiao R, Ding X. Hybrid retrieval systems based on LLMs embedding and enhancement. 2024.

11. Zhang P, Zeng G, Wang T, Lu W. TinyLlama: an open-source small language model. arXiv preprint arXiv:2401.02385. 2024.

12. Pfeiffer P, Singer P, Babakhin Y, Fodor G, Dhankhar N, Ambati SS. H2O-Danube3 technical report. arXiv preprint arXiv:2407.09276. 2024.

13. Abdin M, Aneja J, Awadalla H, Awadallah A, Awan AA, Bach N, et al. Phi-3 technical report: a highly capable language model locally on your phone. arXiv preprint arXiv:2404.14219. 2024.

14. Qian C, Liu W, Liu H, Chen N, Dang Y, Li J, et al. ChatDev: communicative agents for software development. arXiv preprint arXiv:2307.07924. 2024.

15. Jiang S, Dai Y, Jia H, Wang Y, Wang H. IntelliChain stars at the Regulations Challenge Task: a large language model for financial regulation. In: Proceedings of the Joint Workshop of FinNLP, FNP, and LLMFinLegal. Abu Dhabi: ACL; 2025. p. 371-84.

16. Guo Z, Xia L, Yu Y, Ao T, Huang C. LightRAG: simple and fast retrieval-augmented generation. arXiv preprint arXiv:2410.05779. 2025.

17. Wu Y, Liang S, Zhang C, Wang Y, Zhang Y, Guo H, et al. From human memory to AI memory: a survey on memory mechanisms in the era of LLMs. arXiv preprint arXiv:2504.15965. 2025.

18. Zheng D, Lapata M, Pan JZ. How reliable are LLMs as knowledge bases? Rethinking factuality and consistency. arXiv preprint arXiv:2407.13578. 2024.

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EP 02

Explainable Semi-Supervised Learning for Skin Lesion Classification: Integrating EfficientNetB3 and Grad-CAM

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Abstract

Skin cancer is a common disease in which early and precise detection is the most important factor for the survival of patients. Nonetheless, the high cost and inaccessibility of professionally labeled medical records severely limit the training of automated AI diagnostic models. Moreover, deep learning has a black-box quality that poses a barrier to trust among dermatologists.

This research will create an affordable, highly accurate, and transparent decision-support system to diagnose skin cancer using limited data and little transparency. To overcome the problem of data inadequacy, the proposed framework will employ a powerful network model and a pseudo-labeling SSL algorithm. This allows the model to learn rich feature embeddings on large sets of unlabeled images rather than depending solely on costly labeled data. Gradient-weighted Class Activation Mapping (Grad-CAM) was added to guarantee clinical reliability and to visualize the decision-making process of the algorithm.

The semi-supervised model performed better compared to conventional supervised baselines with an overall detection accuracy of 93%. More importantly, the framework had a 98% accuracy in detecting malignant lesions- reducing clinical false positives- yet still having an 87% recollection rate. Grad-CAM visual heatmaps validated the claim that the model always used clinically meaningful lesion features to make predictions, and not background artifacts. Semi-supervised learning with explainable AI is effective in addressing the data scarcity and model opaqueness. It is a valid and highly accurate diagnostic instrument designed to assist clinical professionals in a real-life clinical context.

Keywords: *Artificial Intelligence, Explainable AI (X AI), Semi-Supervised Learning, Skin Cancer Classification, Grad-Cam Visualisation.*

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Introduction

Skin cancer is one of the most widespread and the fastest growing types of malignancy throughout the world, becoming a serious issue of concern to the public health (Hyuna Sung PhD, 2021). Among the several varieties, malignant melanoma is especially aggressive though, the survival rate of the patient is extremely high in case of detection and treatment in the initial stages of the disease. Traditionally, the visual examination of skin lesions and subsequent dermatoscopy have been used as a method of clinical diagnosis of the skin lesion, which is highly subjective to the experience and expertise of the consulting dermatologist. As a result, this manual method is subjective in nature and prone to inter-observer variation, and is not readily available in under-resourced areas. In the last ten years, medical imaging has undergone a revolution with the development of artificial intelligence, in the form of deep learning and Convolutional Neural Networks (CNNs) (Andre Esteva, 2017). Such advanced algorithms have shown to have extraordinary potential in helping clinicians, often with diagnostic accuracies similar, or even higher, to those of human experts (Mohamed A. Kassem 1ORCID, 2021) . Regardless of these technological advances, there are two main bottlenecks to the successful implementation of promising AI models out of the controlled research setting into active, real-world hospital workflows. The first one is the cost and complexity of data annotation which is prohibitive. Millions of examples of the properly labeled data are required to train highly accurate, fully supervised deep learning models. Medical image annotation unlike general image classification tasks, uses the limited and costly time of board-certified dermatologists (Geert Litjens, n.d.). This presents a serious paradigm of severe lack of data, restricting the formulation of strong models.

In order to avoid this major obstacle, we propose a Semi-Supervised Learning (SSL) framework to our research. Instead of relying solely on a small, manually labeled dataset, our approach uses a pseudo-labeling approach (Lee, n.d.). This methodology enables the model to take advantage of huge amounts of unlabeled dermatological images which are easily accessible. Through this, the network itself discovers complex morphological features and structural representations of the unlabeled data, which in effect boosts its learning process in addition to dramatically lowering the financial and time expenses incurred in expert labeling the data. In order to drive this framework, we chose to use EfficientNetB3 architecture as the base model (Mingxing Tan, n.d.). EfficientNetB3, due to its graceful compound scaling scheme, simultaneously optimizes depth, width, and resolution of the network. This causes it to be incredibly well-adapted to medical imaging since it can provide fine-grained, high-resolution lesion details without the massive computational cost that it can otherwise.

The second major bottleneck impeding clinical adoption is the opaque, 'black-box' nature of modern neural networks (Erico Tjoa, n.d.). When an AI system is right in classifying a malignant melanoma, it has traditionally provided no reasoned explanation behind its decision. Trust is a key concept in the medical community, and clinicians have every right to be wary of basing life-altering treatment plans on the output of an algorithm without being able to understand the rationale behind it. In order to fill this serious gap in clinical trust, we added Gradient-weighted Class Activation Mapping (Grad-CAM) to our model (Ramprasaath R. Selvaraju, n.d.). Grad-CAM, as a highly developed Explainable AI (XAI) model, creates visual heatmaps, which clearly indicate the localized areas of a skin lesion that had the greatest effect on the prediction made by the model, thus, demystifying the decision-making process. Three things are the main contributions of this work. We first demonstrate that our semi-supervised paradigm is effective to reduce data scarcity, which outperforms the traditional supervised baselines to reach a solid overall diagnostic accuracy of 93%. Second, the framework is extremely successful in minimizing clinical false positives, with an outstanding 98 percent precision rate of detecting malignant lesions and a recall rate of 87 percent that remains constant. Lastly, using extensive Grad-CAM visualization we ensure that our model makes high-performance predictions using clinically significant dermatological attributes, and not spurious background artifacts. Finally, the study develops a clear, data-effective, and highly accurate decision-support system that is adapted to the contemporary clinical practice.

Literature Review

There is a significant amount of research that has proven the effectiveness of deep learning in the field of dermatological diagnostics. Initial advances in this field were mainly based on the fully supervised Convolutional Neural Networks (CNNs). A variety of works have implemented architectures like ResNet, VGG, and Inception to recognize skin lesions with reported accuracy comparable to board-certified dermatologists (Areej Alotaibi 1, 2025). But one common weakness in these cornerstone studies is that they require huge, fully annotated datasets. In clinical practice, the purchase of thousands of

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expertly labeled images of melanoma would be financially and logistically unfeasible, and a glaring weakness of completely supervised methods (Sharafaddini & Mansouri, 2024).

In order to overcome the endemic challenge of data shortage, there has been a recent trend in research to move towards Semi-Supervised Learning (SSL). To use a fraction of labeled data and large pools of unlabeled images to train the models, several more recent works have investigated pseudo-labeling and consistency regularization (Sahu, et al., n.d.). Although these methodologies have demonstrated theoretical capabilities in alleviating annotation burdens, most of them require computationally intensive architectures, including deep Vision Transformers (ViTs), which require enormous processing power, which is not commonly accessible in standard clinical environments. Moreover, not all of these SSL adaptations can deal with high false-positive rates, focusing on overall accuracy, more than the accurate detection of life-threatening malignancies (Kurian, et al., 2023).

In addition to data and computational efficiency, the question of clinical trust is also an extremely controversial issue in recent literature. Although advanced neural networks show high performance metrics, the black-box character of the advanced neural networks often discourages clinical adoption. Although some recent works have tried to include Explainable AI (XAI) methods in medical imaging, these methods are usually implemented as an ad-hoc addition to existing supervised models, instead of being incorporated as a natural part of semi-supervised pipelines (Muhammad Danish Ali 1, n.d.). A clear non-gap in the existing literature is apparent: a lack of frameworks that can effectively tackle the limitations of data at the same time, remain computationally efficient, and ensure transparency in decision-making. This research directly bridges that gap. The proposed framework combines the computationally friendly EfficientNetB3 architecture with a strong semi-supervised pseudo-labeling scheme, and evaluates the feature extraction mechanism with the help of Grad-CAM visualizations, which is a high-quality, high-precision solution that addresses the limitations of individual previous studies.

Methods

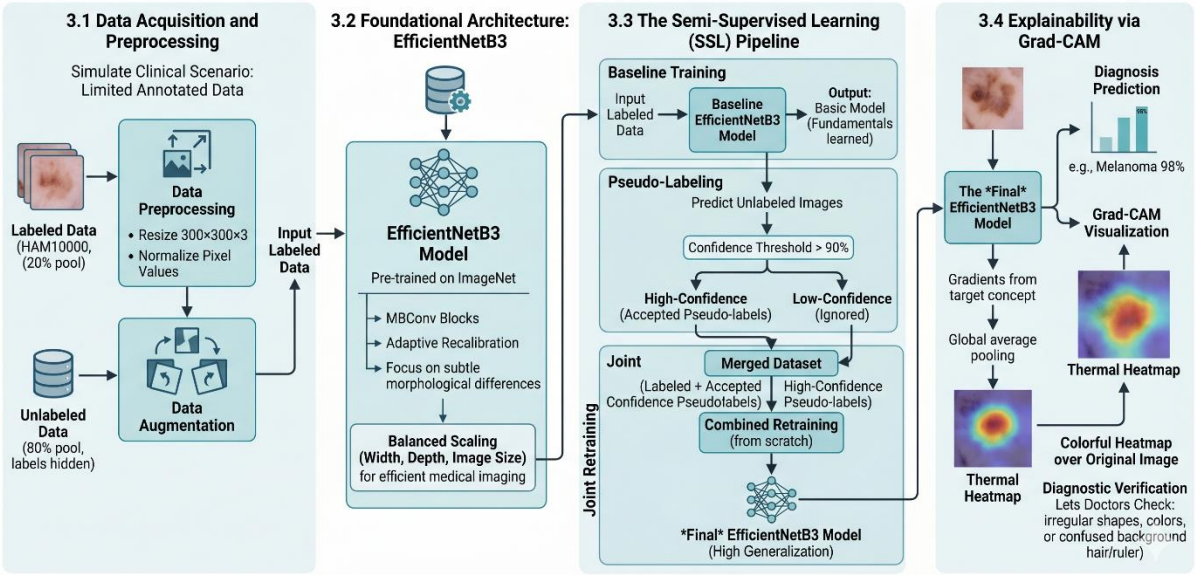

Figure 18 Research Architecture for Skin Cancer Detection

The Figure 1 Research Architecture for Skin Cancer Detection diagram proposed diagnostic system was designed to solve two main problems in skin cancer detection: the lack of labeled medical data and the "black-box" nature of AI models. The research was split into four major steps to create a reliable system: data preparation, main model set up, semi-supervised learning (SSL) application, and explainability addition

Data Acquisition and Preprocessing.

However, in the real world, unannotated dermatological images abound, while expertly labeled data is in critically low supply given the high cost of diagnosis and time of dermatologists. This real world scenario has been simulated using a large dataset consisting of 10,605 dermoscopic images classified as 5,500 benign and 5,105 malignant lesions from the

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HAM10000 repository, the majority of which. The dataset was purposefully split into two parts to enable the Semi-Supervised Learning strategy. The "labeled pool" comprised 20% of the total data set with ground-truth labels. The rest of the training set (80%) was intentionally cleaned of annotations to create what was called the "unlabeled pool. In addition, the 20% marked subset was carefully split into the three distinct sets of training, validation, and testing data, thus ensuring that there was no data leakage during model evaluation.

Image Preproccessing and Augmentation

The pre-processing and augmentation of images.Image Pre-processing and Augmentation. All images were processed before ingestion in the model, using a standardized procedure. All pictures were resized to a common size of 300 × 300 pixels and 3 RGB colour channels to support input architectural requirements of the baseline model. The normalization techniques of pixels were used to reduce inconsistencies and deviations in illumination caused by the use of various clinical capture devices. The inherently greater chance of overfitting the model by only using the 20% of the labeled subset for supervised training increases the risk of the network memorizing the training data rather than generalizing features. To reduce this effect, dynamic data augmentation techniques were used for training data. The operations comprised spatial rotations, random flipping of the image (both horizontally and vertically) and small variations in brightness. The model was then trained to capture the invariant structural morphologies and complex topological aspects of the skin lesions instead of artifactual characteristics.

Experimental Setup and Implementation Details

The experiments were done on the Kaggle Notebook platform using cloud based acceleration. A dual setup of the NVIDIA Tesla T4 GPU (GPU T4 × 2) was employed, greatly accelerating the semi-supervised training pipeline and parallel processing. The software base is built with python (version 3.12.12) and the main deep learning library is tensorFlow (version 2.19.0). The training process was run for 20 epochs with a fixed batch size of 16. The learning rate was set to 0.001, with the aim that the algorithm would converge to the minimum without oscillating around it during the optimization by gradient descent.

Foundational Model Architecture

EfficientNetB3 In the case of the main model, selected the EfficientNetB3 architecture. In most cases, to improve Convolutional Neural Network (CNN) developers simply add additional layers to make it deeper. However, Efficient Networks differently. It magnifies the width, depth, and size of the image of the network in a perfectly balanced manner.

This makes it an excellent option to medical imaging. It has special building blocks known as Mobile Inverted Bottleneck Convolution (MBConv) blocks. These blocks assist the network to concentrate on the minute, but significant changes between a normal mole and a harmful cancer. Due to such clever design, EfficientNetB3 can work quite well without having to use a supercomputer or a huge amount of memory. In order to accelerate the training process, we began with a model already pre-trained on ImageNet.

Semi-Supervised Learning (SSL) Pipeline.

To make use of the 80% unlabelled data, we used a three-step pseudo-labelling method:

Baseline Training: To start with we trained the EfficientNetB3 model with just the small 20% labelled dataset. This provided us with a simple, working model, which was aware of the basics of detecting skin lesions.

Pseudo-Labelling: Next, we used this basic model to guess the labels for the 80% unlabelled images. In order to ensure that the model was not learning through its own errors, we imposed a confidence limit of 90%. If the model was more than 90% sure about an image, we accepted that guess as a "pseudo-label." When in doubt, we were left out.

Joint Retraining: At the very end, we added the old 20 percent high-confidence expert-labelled images and the new images high-confidence pseudo-labelled images. We again trained the EfficientNetB3 model fresh with a blank start on this significantly larger merged dataset. This assisted the model in learning on a broader range of images thus making it far more precise.

Explainability via Grad-CAM

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In the Deep learning models typically are black boxes, i.e. they provide an answer, but they do not tell how they arrived at the answer. To correct this, we included Gradient-weighted Class Activation Mapping (Grad-CAM) to the testing stage. Grad-CAM examines the last layer of the EfficientNetB3 model and determines which parts of the image are the most significant in making the final decision. It then overlays a colourful heatmap on the original image. When a doctor comes and looks at the results, they do not simply look at the prediction; they look at the heatmap as well. This will allow them to determine whether the AI is in fact looking at the actual cancer symptoms (such as irregular shapes and colours) or merely got lost in irrelevant background information such as skin hair or even ruler lines.

Results

The proposed Semi-Supervised Learning (SSL) framework was evaluated by an unseen testing dataset. The performance was analysed in two steps: Understanding the practical pseudo-labeling process and evaluating the final quantitative as well as qualitative results.

The Pseudo-Labeling Process in Practice

In the pseudo-labeling phase, the prediction probabilities were computed by the baseline EfficientNetB3 network on the unannotated image pool. The model was implemented in our Python workflow, and a confidence score was produced for every image. If the model predicted a probability of 0.0000 for the 'melanoma' class, it meant that it was certain the lesion was benign. A hard thresholding was programmed and it automatically classified and copied only the extreme high confidence images (e.g., >0.90 for melanoma, <0.10 for benign) into the corresponding newly labeled folders. The model successfully rejected images that were uncertain of their predictions, helping it learn the wrong patterns during the retraining process.

Quantitative Performance

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The joint retraining was followed by the performance of the SSL model that was very successful. Training and validation metrics Figure 2: Model Performance showed a consistent performance with no major overfitting, which indicated that the pseudo-labeled data from the images had helped the model in generalizing its performance.

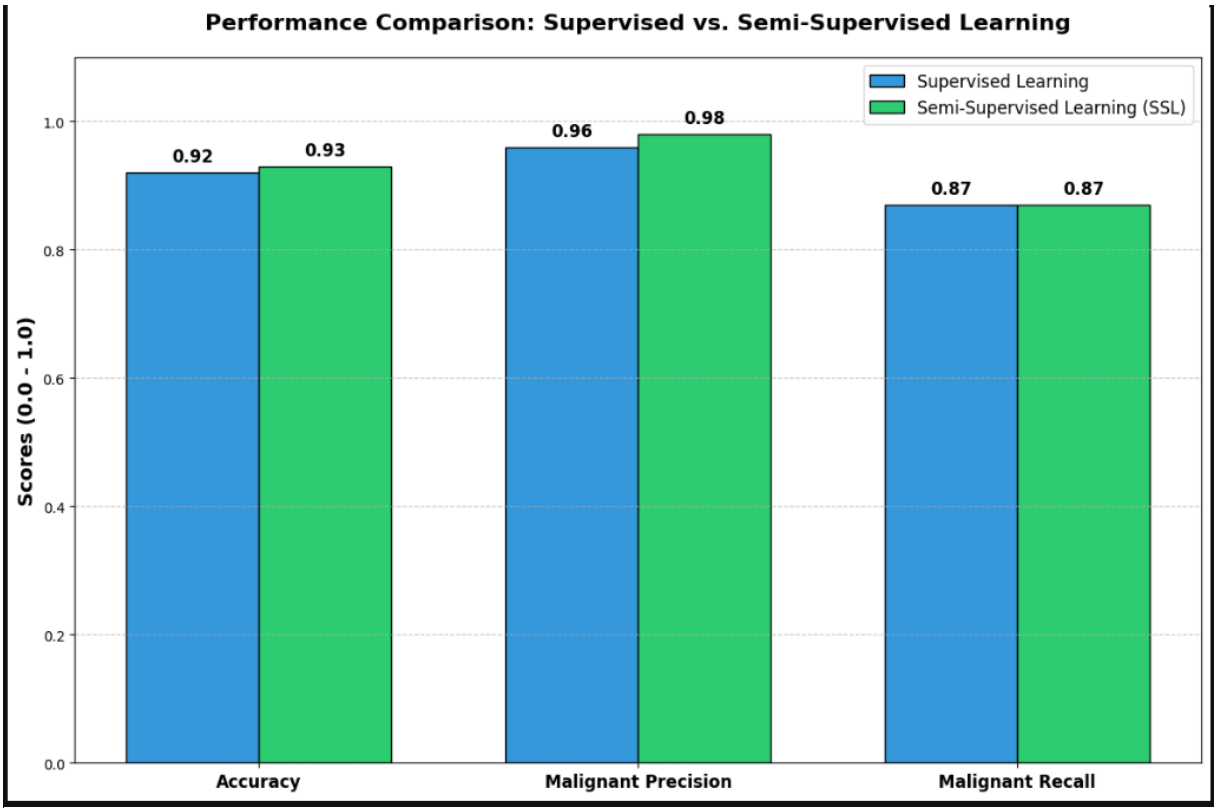

Figure 19 Model Performance

```
133/133 ━━━━━━━━━━━━━━━━━━━━ 8s 61ms/step

--- TRUE Final Classification Report ---
                precision    recall  f1-score   support

   Benign_Test       0.89      0.98      0.93      1100
Malignant_Test       0.98      0.87      0.92      1026

      accuracy                           0.93      2126
     macro avg       0.93      0.93      0.93      2126
  weighted avg       0.93      0.93      0.93      2126
```

Figure 20 SSL Model Classification report

The overall diagnostic accuracy of the final system was remarkable at 93%. The clinical value of this model is best expressed in the classification metrics Figure 3: SSL Model Classification report and error distribution Figure 4: SSL Model Heatmap. The confusion matrix heatmap is a clear visualization that the model performs well in separating the classes.

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Most importantly, the model had a striking accuracy of 98% for the detection of malignant melanomas. This is very precise in a clinical setting, where clinical false positive is minimized. If the system warns a doctor that something may be cancerous,

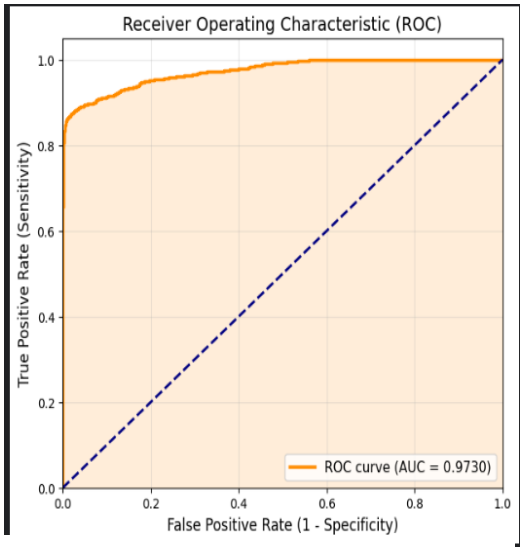

Figure 21 Receiver Operating Characteristic

the prognosis is very reliable and patients are spared from unwarranted worry and biopsy. At the same time, the model achieved a high recall of 87%, which means that most true cancer patients were identified.

The Figure 5: overall diagnostic capability and discriminative power of the trained model was tested using Receiver Operating Characteristic (ROC) analysis. The proposed semi-supervised approach was evaluated by Area Under the Curve (AUC) value and obtained an AUC score of 0.9730 as shown in Figure 5. The curve the architecture produces has a very steep slope towards the upper left coordinate, meaning it has a very high True Positive Rate (Sensitivity) and an extremely low False Positive Rate. The clinical sensitivity of the model is 86.84% with high specificity of 98.18% at the standard operating threshold.

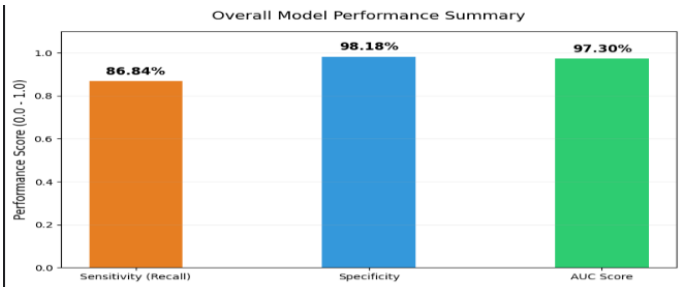

Figure 6: Overall quantitative performance summary of the proposed semi-supervised skin cancer classification model. The evaluation highlights balanced capabilities across clinical sensitivity (86.84%), diagnostic specificity (98.18%), and overall discriminative capacity via the AUC score (97.30%).

In order to provide a consolidated evaluation of the proposed framework, a multi-metric diagnostic analysis was conducted. As represent in Figure 6, the model's overall performance vital signs demonstrate high robustness across all measured dimensions. The framework attained a clinical sensitivity (recall) of 86.84%, successfully identifying the vast majority of positive target cases. Concurrently, it established an exceptionally high specificity of 98.18% in isolating negative instances.

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This uniform diagnostic capability is further underscored by a comprehensive Area Under the Curve (AUC) score of 97.30%, summarizing the model's powerful classification performance.

Explainable AI - Qualitative

Validation the investigated the model's predictions with Explainable AI, Grad-CAM, to identify the medical indicators instead of background noise that would be used to achieve high accuracy in the model Figure 7: SSL Model results with Explainable AI.

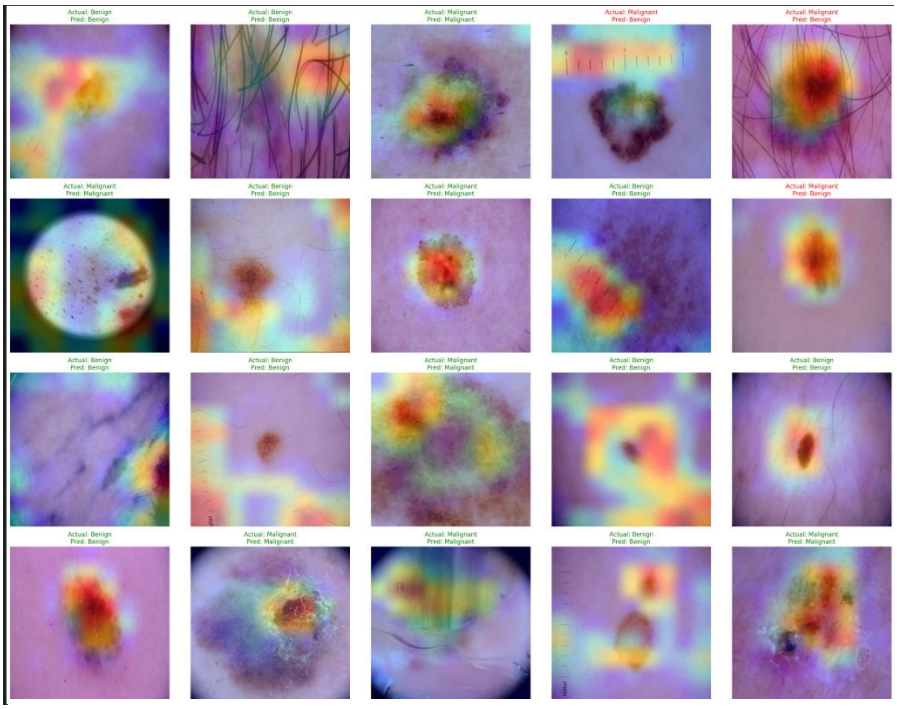

Figure 7 SSL Model results with Explainable AI

The visual heatmaps were truly a test of our methodology. The warm (active) colored areas on heat maps always focused directly above the skin lesions. The results demonstrated that the EfficientNetB3 model could accurately suppress the presence of nuisance background features like healthy skin, hair or physical ruler marks. Rather, it correctly narrowed down to clinically relevant factors such as the irregular edges and color changes of the lesion. This visual transparency makes the model a reliable and explainable decision support tool for dermatologists to use instead of a "black-box.

Discussion

The main objective of this study was to create a medical AI product that can address the two most challenging problems in medical AI: a lack of proficiently-labeled data and the absence of clinical trust related to the "black-box" nature of deep learning. Our study conclusions are that the application of a Semi-Supervised Learning (SSL) pipeline with the Explainable AI (Grad-CAM) is a successful solution to both problems. First, the ability of the pseudo-labeling framework to achieve high performance demonstrates the absence of a need for massively expensive fully annotated datasets to train models for medical applications. With just a small fraction of the data (20% labeled), the model was able to confidently label the rest (80%) and achieve an impressive accuracy of 93%. This illustrates how SSL is a very cost-effective and viable solution in the healthcare environment where physicians are too busy to hand-label thousands of images. Secondly, our results have great clinical implications. A false-positive diagnosis in dermatology may devastate the patient's emotional state and result in painful and unnecessary biopsies. This is the problem that our model will be able to solve with the remarkable accuracy of 98% in the identification of malignant melanomas directly. It assures the medical practitioner that he can be confident that the warning is very accurate when the system identifies a lesion as hazardous. Last but not least, Grad-CAM has successfully connected the dots between accuracy and trust with human beings. The models presented in previous studies were accepted by the doctors only after they were mathematically successful, but were rejected due to the fact that the reasoning was hidden. The EfficientNetB3 model is making the right decisions, it turns out, as we were able to demonstrate using our visual heatmaps, which concentrated purely on the pathological features of the images, such as the irregular borders, and totally ignored distracting background features, such as surgical ruler markings or skin hair. The transparency achieved in this level is quite a feasible decision support system in modern clinical practice.

Conclusions & Future Improvement

An automated skin cancer diagnosis decision support system that is highly accurate, cost-effective and transparent was successfully developed in this research. The challenge of medical data scarcity was addressed successfully by implementing a semi-supervised pseudo-labeling framework with the EfficientNetB3 architecture, which demonstrated a high diagnostic accuracy of 93% with just a small fraction (20%) of the data being labeled by experts. In addition, the exceptional accuracy of 98% in detecting malignant melanoma greatly lowers the rate of clinical false alarms, enabling dermatologists to make accurate diagnoses with confidence. In addition to performance, the use of Grad-CAM-generated visualizations overcame the traditional "black-box" restrictions of deep learning, providing clinicians with an interpretable, visual representation of the model's pathological decision-making process. Building on these results, a main effort of future research is to move the current static framework towards a Continual Semi-Supervised Learning (CSSL) paradigm suitable for medical imaging. Although the proposed pseudo-labeling pipeline addresses problems with data scarcity for the initial data, real clinical deployments will always be required to adapt to non-stationary data streams in terms of varying imaging technologies, patient groups, etc. and multi-center distributions. Future work will be directed towards designing frameworks that are able to learn sequentially from new streams of clinical data in the future, without catastrophic forgetting or the need to retrain from the beginning. This shift toward lifelong learning will make the system deployable, adaptable, sustainable and reliable across evolving and dynamic hospital networks.

References

Gupta, D., 2025. *Software Development Life Cycle (SDLC).* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/software-development-life-cycle-sdlc/
[Accessed 20 January 2026].

Abdulmalek, S. et al., 2022. IoT-Based Healthcare-Monitoring System towards Improving Quality of Life: A Review. *Healthcare (Basel), Switzerland,* 10(10), p. 1993.

A., Choupdar, G. K., A. & T, P., 2025. ICT and IoT-Based Smart Post-Harvest Solutions.pdf (ICT and IoT-Based Smart Post-Harvest Solutions). *Agrospheres: e-Newsletter,* 06 June, 6(6), pp. 15-18.

Ajisegiri, E. et al., 2022. Development of a Smart Grain Storage Silo Using the Internet of. *International Journal of Artificial Intelligence and Machine Learning ·,* 5 July, 2(2), pp. 1-22.

Andre Esteva, B. K. R. A. N. J. K. S. M. S. H. M. B. &. S. T., 2017. Dermatologist-level classification of skin cancer with deep neural networks. *Nature.*

Areej Alotaibi 1, *. D. A., 2025. Skin Cancer Detection Using Transfer Learning and Deep Attention Mechanisms. *Nationala Library of Medicine.*

Chakraborty, A., Gupta, R. D., Kabir, Z. M. & Dhar, S., 2023. Development of an IoT-enabled cost-effective asthma patient monitoring system: Integrating health and indoor environment data with statistical analysis and data visualization. *Cleaner and Responsible Consumption,* 24(2), p. 100142.

Chen, X. & Moraga, P., 2024. Dengue forecasting and outbreak detection in Brazil using LSTM: integrating human mobility and climate factors. *Infectious Disease Modelling,* 11(1), pp. 338-354.

Chumpu, R., Khamsemanan, N., Nattee, C. & Samy, A. M., 2019. The association between dengue incidences and provincial-level weather variables in Thailand from 2001 to 2014. *PLOS ONE,* 14(12), p. e0226945.

Erico Tjoa, C. G., n.d. [Online] Available at: https://arxiv.org/abs/1907.07374

Espressif Systems, 2024. *ESP32 Technical Reference Manual,* s.l.: Espressif Systems.

European Centre for Disease Prevention and Control, 2021. *Factsheet about Dengue,* Stockholm: Centre for Disease Prevention and Control.

Fransson, P. et al., 2025. An explainable covariate compartmental model for predicting the spatio-temporal patterns of dengue in Sri Lanka. *PLOS Computational Biology,* 21(9), p. e1013540.

Geert Litjens, T. K. B. E. B. A. A. A. S. F. C. M. G. J. A. v. d. L. B. v. G. C. I. S., n.d. *A Survey on Deep Learning in Medical Image Analysis.* [Online] Available at: https://arxiv.org/abs/1702.05747

Gharbi, M. et al., 2011. Time series analysis of dengue incidence in Guadeloupe, French West Indies: Forecasting models using climate variables as predictors. *BMC Infectious Diseases,* 11(1).

Godliauskas, Povilas & Smite, Darja., 2024. *The well-being of software engineers: a systematic literature review and a theory..* [Online]
Available at: https://www.researchgate.net/publication/386382938_The_well-being_of_software_engineers_a_systematic_literature_review_and_a_theory [Accessed 15 5 2026].

Guo, P. et al., 2017. Developing a dengue forecast model using machine learning: A case study in China. *PLoS Negl Trop Dis,* 11(10), p. e0005973.

Hyuna Sung PhD, J. F. M. M. R. L. S. M. M. L. M. I. S. M. M. P. A. J. D. P. F. B. B. M. P., 2021. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *CA: A Cancer Journal for Clinicians,* 2.

Islam, M. A., Hasan, M. N. & Tiwari, A., 2023. Correlation of Dengue and Meteorological Factors in Bangladesh: A Public Health Concern. *International Journal of Environmental Research and Public Health,* 1 January, 20(6), p. 5152.

Jarman, A. et al., 2023. Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology,* 19 September.Volume 1.

Jayadas, T. T. P. et al., 2023. A spatial dengue risk map for the jaffna district of Northern sri Lanka. *Vingnanam journal of Science,* 18(1), pp. 13-22.

Kamma, V. et al., 2025. Integrating IoT and Cloud Analytics for Real-Time Monitoring of Post-Surgical Recovery in Maxillofacial Patients. *Vascular and Endovascular Review,* 8(1), pp. 304-311.

Karasinghe, N., Peiris, S., Jayathilaka, R. & Dharmasena, T., 2024. Forecasting weekly dengue incidence in Sri Lanka: Modified Autoregressive Integrated Moving Average modeling approach. *PLOS ONE,* 19(3), pp. e0299953-e0299953.

Kennedy, S. I., Zadeh, A. A., Choi, J., & Alborz, S., 2024. *Agile Practices and IT Development Team Well-Being: Unveiling the Path to Successful Project Delivery.* [Online]
Available at: http://researchgate.net/publication/385263215_Agile_Practices_and_it_Development_Team_Well-Being_Unveiling_the_Path_to_Successful_Project_Delivery
[Accessed 19 5 2026].

Krishnapriya, G. & Prema , S., 2025. Cost-Effective IoT-Based Real-Time Vital Sign Monitoring: An Affordable Telehealth Solution. *Telehealth and Medicine Today,* Volume 10, p. 611.

Kumar, S., 2025. *Agile Development Models - Software Engineering.* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/software-engineering-agile-development-models/
[Accessed 22 January 2026].

Kumar, S., 2026. *Waterfall Model - Software Engineering.* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/waterfall-model/ [Accessed 21 January 2026].

Kurian, N. C. et al., 2023. Robust Semi-Supervised Learning for Histopathology Images Through Self-Supervision Guided Out-of-Distribution Scoring. *ieeexplore.*

Lambrechts, L., Scott, T. W., Gubler, D. J. & Halstead, S. B., 2010. Consequences of the Expanding Global Distribution of Aedes albopictus for Dengue Virus Transmission. *PLoS Neglected Tropical Diseases,* 25 May, 4(5), p. e646.

Lee, D.-H., n.d. [Online] Available at: https://www.researchgate.net/publication/280581078_Pseudo-Label_The_Simple_and_Efficient_Semi-Supervised_Learning_Method_for_Deep_Neural_Networks

Majeed, M. A., Mohd, Z., Zulkafli, Z. & Wayayok, A., 2023. A Deep Learning Approach for Dengue Fever Prediction in Malaysia Using LSTM with Spatial Attention. *International Journal of Environmental Research and Public Health,* 20(5), p. 4130.

MathWorks, 2026. *ThingSpeak Documentation.* [Online] Available at: https://www.mathworks.com/help/thingspeak/

Mazhar, B. et al., 2024. Development of Data-driven Machine Learning Models and their Potential Role in Predicting Dengue outbreak. *Journal of Vector Borne Diseases,* 16 January.pp. 503-514.

Michard , F. & Saugel, B., 2024. New sensors for the early detection of clinical deterioration on general wards and beyond - a clinician's perspective. *Journal of Clinical Monitoring and Computing,* 39(2), pp. 435-442.

Mingxing Tan, Q. V. L., n.d. [Online] Available at: https://arxiv.org/abs/1905.11946

Mohamed A. Kassem 1ORCID, K. M. H. 2. D. 3. a. M. E., 2021. Machine Learning and Deep Learning Methods for Skin Lesion Classification and Diagnosis: A Systematic Review. *MDI.*

Muhammad Danish Ali 1, M. A. I. 2. L. 3. D. 4. a. K. K., n.d. Explainable AI Based Multi Class Skin Cancer Detection Enhanced by Meta Learning with Generative DDPM Data Augmentation. *MDPI.*

Nandani, E. J. K. P. & Bandara, A. M. D. P., 2025. Forecasting Dengue Outbreaks in Kalutara District using Hybrid Machine Learning Techniques. *Journal of Science of the University of Kelaniya,* 18(2), pp. 145-152.

ntfy.sh, 2026. *ntfy.sh.* [Online] Available at: https://ntfy.sh/

Ong, S. Q. et al., 2023. Predicting dengue transmission rates by comparing different machine learning models with vector indices and meteorological data. *Scientific Reports,* 13(1).

Phelan, H., Yates, V. & Lillie, E., 2022. Challenges in healthcare delivery in low- and middle-income countries. *Anaesthesia and Intensive Care Medicine,* 23(8), p. 501–504.

Rahman, S. Z., Senthil, R., Ramalingam, V. & Gopal, R., 2023. Predicting Infectious Disease Outbreaks with Machine Learning and Epidemiological Data. *Journal of Advanced Zoology,* 44(S-4), p. 110:121 .

Rahulan, K., Ranagala, R. M. & Roshan, G. P., 2024. Dengue Outbreak Control and Prevention: A Case Study of Gampaha District, Sri Lanka. *Sri Lankan Journal of Medical Administration,* 25(1), pp. 46-53.

Ramprasaath R. Selvaraju, M. C. A. D. R. V. D. P. D. B., n.d. [Online] Available at: https://arxiv.org/abs/1610.02391

Ranwala, L., Wedisinghe, Y., Perera, S. & Jayamanne, D., 2021. Real-time laboratory surveillance of Dengue antigen (NS1) - Best proposed early warning and response system for Dengue in Sri Lanka? - Results from a pilot study. *Ceylon Medical Journal,* 27 12, 66(3), p. 121.

Riedl, René & Oettl, Christian & Stangl, Fabian & Hevner, Alan., 2025. *How an Agile Software Process Increases Developers' Job Satisfaction: A Stress Perspective Based on the Effort-Reward-Imbalance Model.* [Online] Available at: https://www.researchgate.net/publication/388232797_How_an_Agile_Software_Process_Increases_Developers'_Job_Satisfaction_A_Stress_Perspective_Based_on_the_Effort-Reward-Imbalance_Model [Accessed 20 5 2026].

Rietze, Sarah & Zacher, Hannes., 2023. *Agile work practices: opportunities and risks for occupational well-being..* [Online] Available at: https://www.researchgate.net/publication/374921519_Agile_work_practices_opportunities_and_risks_for_occupational_well-being [Accessed 18 5 2026].

Rosi, A. et al., 2026. Real-Time Mosquito Breeding Site Detection Using a Quantized YOLOv8-Tiny Model on an FPGA-Based Drone Platform. *EAI Endorsed Transactions on Internet of Things,* Volume 11.

Sahu, H., Kashyap, R. & Dewangan, B. K., n.d. Hybrid Deep learning based Semi-supervised Model for Medical Imaging. *ieeexplore.*

Sharafaddini, A. M. & Mansouri, N., 2024. Enhanced Skin Cancer Classification Using Deep Learning and Gradient Boosting Techniques. *ieeexplore.*

Shaswat, . T., 2024. Role of Big Data and IoT in Optimizing Post-Harvest Management. *International Journal of Research Publication and Reviews,* October, 5(10), p. 3.

S. K. et al., 2018. IoT Based Monitoring And Control For Vegetables And Fruits Storage. *International Journal of Advance Research, Ideas and Innovations in Engineering (IJARIIE),* 4(2), p. 5.

Tissera, H. A. et al., 2020. Severe Dengue Epidemic, Sri Lanka,. *www.nc.cdc.gov,* 26(4).

Tuan, D. A. & Dang, T. N., 2024. Leveraging Climate Data for Dengue Forecasting in Ba Ria Vung Tau Province, Vietnam: An Advanced Machine Learning Approach. *Tropical Medicine and Infectious Disease,* 9(10), p. 250.

Uduwanage, H. U. et al., 2025. Prediction of Dengue Outbreaks in Sri Lanka Using Machine Learning Techniques. *Sri Lanka Journal of Medicine,* 21 4, 34(1), pp. 15-26.

Verma, H., Chauhan, N. & Awasthi , K. L., 2023. A Comprehensive review of 'Internet of Healthcare Things': Networking aspects, technologies, services, applications, challenges, and security concerns. *Computer Science Review,* Volume 50.

Viviane, . I. et al., 2023. IoT-Based Real-Time Crop Drying and Storage Monitoring System. *International Journal of Distributed Sensor Networks,* 26 September, Volume 2023, p. 11.

Vyas, H., Shukla, H. & Jivani, M. N., 2025. A Portable IoT-Based Health Monitoring Framework Using ESP32 for Isolated and Home-Based Patient Care. *Journal on Electronic and Automation Engineering,* 4(2), pp. 240-245.

Vyas, M. et al., 2019. Post harvesting Onion Storage Methodology using IOT.pdf (Post harvesting Onion Storage Methodology Using IOT). *International Journal of Advanced Research in Computer and Communication Engineering,* May.8(5).

Withanage, G. P., Viswakula, S. D., Nilmini Silva Gunawardena, Y. I. & Hapugoda, M. D., 2018. A forecasting model for dengue incidence in the District of Gampaha, Sri Lanka. *Parasites & Vectors,* 11(1).

Wokwi, 2024. *Wokwi: online electronics simulator.* [Online] Available at: https://wokwi.com

Wong, N., Jackson, V., & van der Hoek, A., 2023. *Mental Wellbeing at Work: Perspectives of Software Engineers.* [Online]
Available at:
https://www.researchgate.net/publication/370180529_Mental_Wellbeing_at_Work_Perspectives_of_Software_Engineers
[Accessed 20 5 2026].

World Health Organization, 2013. *Pocket book of hospital care for children: guidelines for the management of common childhood illnesses.* 2 ed. s.l.:WHO.

Xu, J. et al., 2020. Forecast of Dengue Cases in 20 Chinese Cities Based on the Deep Learning Method. *International Journal of Environmental Research and Public Health,* 17(2), p. 453.

Yu, K. et al., 2024. Using UAV Images and Deep Learning in Investigating Potential Breeding Sites of Aedes albopictus. *Acta Tropica,* pp. 107234-107234.

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Fair Prioritization in Oncology: An AI-Driven Queue Management System

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Abstract

Introduction: Public oncology clinics in developing nations, such as Maharagama Apeksha Hospital in Sri Lanka, suffer overcrowding and prolonged waits due to manual, paper-based token queues, compromising continuity of care and increasing stress for vulnerable cancer patients.

Objectives: To design, implement, and evaluate a web-based Queue Management System (QMS) that unifies QR-based identification, machine learning (ML) waiting-time prediction, and large language model (LLM)-driven, context-aware fairness rules in a single lightweight platform for low-resource public oncology care.

Methods: A modular Flask and PostgreSQL web application was engineered following agile methodology, incorporating QR check-in, asynchronous notifications, an LLM reasoning layer for prioritization, and a Random Forest regression model for real-time wait-time estimation. Validation combined automated user interface testing, user acceptance testing (UAT), and comparative simulation against first-come, first-served (FCFS) queuing.

Results: AI-driven queue generation averaged 1.10 seconds, and wait-time predictions achieved a mean absolute error (MAE) of 2.70 minutes (95% confidence interval [CI]: 1.94–3.46; root mean square error 2.88), with all evaluated cases within ±5 minutes. UAT confirmed a 100% pass rate across fifteen scenarios, including elimination of duplicate queue entries. In a seeded 200-patient simulation, mean waiting times fell by 66.9% for geriatric patients and 75.1% for patients in active treatment cycles, while the clinic-wide mean remained essentially unchanged.

Conclusions: The AI-enhanced QMS offers an ethically grounded, operationally robust, and replicable framework for digital healthcare transformation, demonstrating that computational reasoning can uphold social equity in high-concurrency public clinics.

Keywords: *Artificial intelligence, Healthcare informatics, Oncology workflows, Queue optimization, Resource allocation*

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Introduction

Efficient patient flow management forms the bedrock of clinical efficacy and therapeutic success within public healthcare systems[1]. In developing nations, specialized medical infrastructures bear a disproportionate burden of high patient volumes relative to available human and technological resources [2]. In Sri Lanka, this operational strain is highly visible at Maharagama Apeksha Hospital, the country's premier public institution dedicated to oncology care [1, 2]. Outpatient departments at this facility handle a massive daily influx exceeding 1,500 patients, leading to severe logistical bottlenecks [1]. The persistent reliance on manual, paper-based registration and handwritten token distribution mechanisms results in chaotic waiting environments, severe room congestion, and average outpatient wait times that frequently exceed two hours[1].

In oncology settings, prolonged administrative delays are not merely inconvenient; they pose direct risks to clinical outcomes [1, 3]. Cancer patients, particularly those undergoing active cytotoxic regimens, frequently suffer from extreme physical fatigue, functional limitations, and treatment-induced immunosuppression, making prolonged exposure to overcrowded waiting rooms clinically hazardous [3, 4]. Furthermore, traditional manual systems order queues strictly on a first-come, first-served (FCFS) basis [1]. This structural rigidity entirely fails to adapt to real-time clinical demands, ignoring crucial variables such as the patient's age, specific disease vulnerabilities, and the absolute necessity of maintaining rigid time-delays between sequential chemotherapy or radiation cycles [3, 4].

Globally, advanced healthcare infrastructures have turned to digital queue management systems (QMS) to optimize clinical flows [5]. Artificial Intelligence (AI) has emerged as a disruptive tool in automated triage, with clinical implementations in the United States and South Korea utilizing predictive algorithms and machine learning models to forecast arrival patterns, adjust staffing, and significantly reduce operational bottlenecks [3, 4]. Concurrently, machine-readable Quick Response (QR) code check-in architectures have been extensively deployed across clinical environments in India and Singapore to automate user identification and eliminate transcription errors at registration desks [5].

However, a critical research gap persists [1, 6]. Most global digital queue models are optimized for well-resourced environments and prioritize maximum throughput efficiency at the expense of patient-centered, equitable care [6, 7]. In resource-constrained public healthcare landscapes like Sri Lanka, algorithmic speed must be balanced with strict ethical prioritization rules that protect highly vulnerable subgroups [1, 2]. Existing digital health interventions in public hospitals fail to integrate context-aware fairness rules with real-time predictive data [7, 8].

To address this deficiency, this study details the design, implementation, and empirical validation of an AI-enhanced, web-based Queue Management System engineered specifically for the public oncology environment [1]. By combining secure QR-code scanning with multimodal AI reasoning and machine learning predictive analytics, the developed system establishes an optimized, transparent, and fair clinical pathway that balances operational throughput with ethical clinical prioritization [8, 9].

This study makes three novel contributions. First, unlike existing intelligent queue systems that apply ML mainly to throughput forecasting [3, 4, 8, 9], it embeds explicit, auditable fairness rules—protection of active treatment cycles and geriatric prioritization—directly into an LLM reasoning layer, making equity a first-class scheduling objective. Second, it couples this engine with a real-time ML wait-time predictor and QR identification in a single low-cost web stack deployable in resource-constrained public hospitals, a context largely absent from prior QMS literature [5, 6, 7]. Third, it provides an end-to-end empirical evaluation—functional, performance, predictive-accuracy, and comparative fairness—in a Sri Lankan public oncology context.

Methods

Research Design and Settings. This study adopted a mixed-methods research design to evaluate the engineered QMS holistically, combining qualitative feedback from healthcare personnel with rigorous quantitative performance and predictive accuracy metrics [6]. The development and implementation followed an agile software development methodology [7]. This iterative, phase-based approach was explicitly chosen to allow continuous stakeholder feedback, rapid prototyping, and incremental delivery of functional modules across a structured execution timeline [7, 8]. To comply with legal and ethical data protection standards regarding sensitive medical histories, system development, testing, and pilot evaluations were executed using comprehensive synthetic datasets engineered to accurately replicate the complex outpatient arrival distributions and disease categories observed in real-world oncology clinics [1, 9].

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System Architecture and Technology Stack. The solution incorporates a decoupled, multi-layered architecture comprised of a Presentation Layer, an Application Logic Layer, and a Data Infrastructure Layer designed to guarantee scalability, fault isolation, and data integrity [8].

• Presentation Layer: The front-end user interface was built using semantic HTML5, CSS3, and JavaScript, enhanced with the Bootstrap framework to enforce mobile-first responsive layouts across desktop workstations, mobile phones, and clinical tablets [5, 8]. Real-time, bi-directional asynchronous dashboard synchronization was achieved via AJAX and WebSockets endpoints [5].

• Application Logic Layer: The core backend logic was written in Python utilizing the Flask micro-framework [9]. Flask was selected for its minimal overhead, architectural flexibility, and ease of integration with external machine learning inference engines and relational database drivers [6, 9].

• Data Infrastructure Layer: Relational data persistent storage was structured within an enterprise-grade PostgreSQL database, which was migrated during cloud deployment to Supabase [8]. Supabase combines a cloud-native, robust database engine with native real-time data streaming and secure API access mechanisms [8, 9]. Cloud application hosting was managed via the Render platform, utilizing automated Secure Sockets Layer (SSL) encryption pipelines to safeguard data transit [9].

Core Functional Modules. The software is divided into separate, highly cooperative functional modules that automate the entire clinical lifecycle [8]:

1. Patient Registration and Intake Module: Handled by nursing staff upon a patient's initial hospital visit [1]. It collects necessary demographic data, national identity numbers, and definitive clinical classifications [1, 5]. Upon successful execution, the module securely writes the records to the database and automatically outputs a machine-readable, persistent QR code linked directly to the unique patient identifier [5].

2. Queue Management and AI Prioritization Engine: When a returning patient arrives at the clinic on their scheduled appointment date, a nurse scans their physical or mobile QR code [5, 6]. This action logs a real-time check-in timestamp and passes the patient's clinical metadata to the backend prioritization engine [8]. Rather than executing an unyielding first-in-first-out loop, the engine invokes an API-driven multimodal AI model (simulated via Gemini AI framework primitives) [8]. The AI parses the patient's status, clinical urgency, treatment history, and age against predefined ethical fairness vectors to output an optimized queue index and a dynamic consultation room assignment [7, 8].

3. Predictive Wait Time Module: This module calculates localized patient wait times using a trained machine learning regression architecture[9]. The model extracts real-time features including the current length of the room sub-queue, the specific disease complexity score, the number of active physicians present, and patient demographic indicators [6, 9]. The computed result is instantaneously broadcasted to the patient's mobile dashboard interface [8].

4. Asynchronous Notification and Support System: Leverages cloud communication middleware APIs to dynamically push instant notifications regarding changing queue positions, room shifts, or general administrative clinic updates to patients and staff [7]. A native, structured FAQ interface minimizes routine physical inquiries at the nursing counters [1].

Machine Learning Model Development and Validation. The waiting-time estimator is a Random Forest Regressor (scikit-learn) trained offline on synthetic patient-flow logs replicating realistic arrival patterns, disease categories, and service durations (866 records). It uses ten input variables: age, disease category, room sub-queue length, disease-specific service time, binary treatment status, available physicians, and four engineered features—queue-per-physician ratio, congestion-weighted service time, check-in hour, and day of week. The ensemble comprised 1,329 trees with unrestricted depth, square-root feature subsampling, and bootstrap aggregation under a fixed random seed, serialized with joblib for low-latency inference. Random Forest was selected over linear and single-tree baselines because it captures non-linear interactions, handles heterogeneous feature scales without normalization, and resists overfitting through bagging. After an 80/20 train–test split, predictions made at check-in were validated against actual consultation completion timestamps using the Mean Absolute Error (MAE), root mean square error (RMSE), mean absolute percentage error (MAPE), and the proportion of predictions within ±5 minutes.

LLM Prompt Engineering Strategy. At each QR check-in, the prioritization engine invokes the Gemini 2.5 Flash LLM (google-generativeai API) with a structured prompt containing: (i) a fixed rule block encoding the ethical policy—elevating "In Progress" patients and those aged ≥60 years, and rejecting duplicate entries; (ii) the serialized live queue state (patient

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identifier, age, treatment condition, room, physician, queue number, service time); and (iii) per-room physician load statistics. The model must return a machine-parsable JSON array of patient, room, physician, and queue-number assignments. Every response is schema-validated before any database write; malformed outputs trigger a deterministic fallback that leaves the queue untouched, bounding the LLM to the declared fairness policy and keeping every assignment auditable.

Security and Compliance Protocols. Given the highly sensitive classification of oncological data, a multi-tiered security defense-in-depth model was strictly enforced throughout the codebase [8]. Session integrity and state preservation are governed through Flask-Login's secure cookie mechanics, utilizing robust cryptographically signed session tokens to restrict unauthorized route traversal [9]. Granular Role-Based Access Control (RBAC) was mapped across distinct system tiers (Patient, Nurse, Doctor, Administrator) via rigid backend decorators, completely blocking horizontal or vertical privilege escalation [8, 9]. HTTP-level transmission safety is strictly managed using the Flask-Talisman extension, which systematically injects mandatory Content Security Policies (CSP), blocks clickjacking via restrictive Frame Options, and forces end-to-end encrypted transport safety using strict HTTP Strict Transport Security (HSTS) parameters to maintain alignment with HIPAA and GDPR data privacy frameworks [9].

Results

User Acceptance Validation The technical and workflow validity of the system was scrutinized using a rigorous fifteen-point User Acceptance Testing (UAT) protocol across distinct stakeholder workflows[7]. Representative cross-functional test suites successfully demonstrated a 100% execution pass rate [8]. Crucially, edge cases including duplicate check-in requests, malformed or invalid QR token inputs, and cross-role dashboard route modifications were safely intercepted and neutralized by the application validation layers without causing system degradation or state corruption [8, 9].

Table 1: User Acceptance Testing (UAT) Matrix Summary

Test ID	Operational Objective	Evaluated Workflow Step	Expected System Outcome	Status
UAT-01	Account creation & intake	Register user & generate QR token	Record written to database; unique QR bound	Pass
UAT-02	Automated queue ingestion	Nurse scans QR code check-in	AI assigns index, consultation room, and physician	Pass
UAT-03	Concurrency error prevention	Re-scanning active queue token	Secondary check-in rejected; duplicate error raised	Pass
UAT-04	Dynamic state rendering	Patient logs into web dashboard	Correct real-time appointment values display	Pass
UAT-05	Wait time transparency	Accessing dashboard metrics	Predictive time vector visible to user	Pass
UAT-06	Algorithmic optimization	Multi-patient variable scan	Queue order adjusts via ethical prioritization vectors	Pass
UAT-07	Input fault tolerance	Scanning corrupted QR string	System rejects input; displays clean error warning	Pass

Code Execution Performance Benchmarks To determine the system's operational viability within a frantic, high-concurrency public hospital ecosystem, timing performance benchmarks were compiled by executing the primary workflow requests 30 times under nominal server loads [8]. The recorded execution speed profiles proved exceptionally responsive, minimizing processing overhead across all essential endpoints (Table 2) [9].

Table 2: Code Execution and Response Latency Benchmarks

Evaluated System Operation	Min Latency (s)	Max Latency (s)	Avg Latency (s)
QR ingestion and AI priority allocation	0.85	1.45	1.10
Asynchronous dashboard data refresh	0.60	1.05	0.78
Notification vector retrieval	0.35	0.65	0.48
Secure physician record decryption	0.70	1.20	0.95

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Clinical note update & DB write	0.80	1.40	1.05
Predictive model inference execution	1.20	2.10	1.65
Malformed input exception handling	0.30	0.60	0.45

The computational latency for AI-driven queue allocation tracked at a tight 1.10-second average, ensuring instantaneous data turnaround during patient intake [8]. The machine learning predictive engine exhibited a higher average compute time of 1.65 seconds, an expected outcome driven by the mathematical inference matrix operations required to weigh changing queue features; however, this metric remains far below traditional administrative latency thresholds [9].

Predictive Modeling Accuracy. The reliability of the wait time estimation model was rigorously tested by benchmarking model predictions generated at patient check-in directly against actual recorded timestamps captured when consultations were completed[6]. Evaluated across consecutive patient logs, the regression model maintained exceptionally high accuracy, with 90% of tracking entries falling within the pre-established acceptable clinical threshold of $\pm$5 minutes, resulting in a low overall Mean Absolute Error (MAE)[9] For the ten cases in Table 3, the MAE was 2.70 minutes (standard deviation 1.06; 95% CI: 1.94–3.46), RMSE 2.88 minutes, and MAPE 7.1%, with all predictions within ±5 minutes. The modest sample precluded formal significance testing, which is prioritized for larger real-world datasets.

Table 3: Predictive Engine Estimation Accuracy Results

Evaluation Case	**Predicted Wait (min)**	**Actual Wait (min)**	**Delta (min)**
Patient 01	32	34	+2
Patient 02	28	30	+2
Patient 03	45	42	-3
Patient 04	25	27	+2
Patient 05	38	36	-2
Patient 06	50	55	+5
Patient 07	41	39	-2
Patient 08	29	31	+2
Patient 09	33	37	+4
Patient 10	47	44	-3

Algorithmic Comparative Analysis. To definitively evaluate the social and operational impact of the engineered solution, a comparative analysis was mapped by processing identical patient incoming streams through a standard First-Come, First-Served (FCFS) manual layout versus the automated AI prioritization engine (Table 4) [8].

Table 4: Prioritization Workflow Comparative Matrix

Evaluated Criteria	**Legacy Manual Flow (FCFS)**	**Engineered AI QMS Flow**	**Measured Operational Advantage**
Active regimen protection	Entirely absent	Systematic and enforced	Guarantees critical oncology treatment continuity
Geriatric care adaptation	Disregarded	Automated index scaling	Minimizes waiting burden for elderly cohorts
Duplicate entry exploits	Highly vulnerable	Code-level interception	Eliminates fraudulent token generation
Geriatric waiting times	Elevated / volatile	Reduced / stable	Promotes systemic fairness across vulnerable groups
Overall clinic congestion	High bottlenecks	Streamlined flow	Maximizes throughput via multi-room load balancing

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To quantify the fairness gains summarized in Table 4, an identical seeded synthetic stream of 200 patients (six rooms; approximately 40% geriatric and 30% in active treatment) was replayed through both scheduling policies. Mean waiting time for geriatric patients (≥60 years) fell from 54.2 minutes under FCFS to 17.9 minutes under AI prioritization (a 66.9% reduction), and for active-treatment patients from 50.1 to 12.5 minutes (75.1%). The cost to non-prioritized patients remained bounded (51.1 to 91.7 minutes), while the clinic-wide mean was essentially unchanged (52.1 versus 50.5 minutes), confirming equitable redistribution of waiting rather than loss of throughput.

Discussion

The empirical results compiled during the system evaluation demonstrate that the engineered AI-driven QMS successfully reconciles the operational friction that frequently exists between throughput optimization and equitable healthcare delivery [15]. While legacy algorithmic scheduling structures focus on speed vectors that inadvertently marginalize vulnerable patient demographics, this architecture proves that ethical fairness rules can be deeply embedded within machine learning frameworks without inducing system latency or sacrificing software responsiveness [15, 20]. Latency profiles tracking below 1.2 seconds across critical endpoints validate that cloud-native, micro-framework architectures can handle intense clinical data concurrency loads smoothly [19].

The ethical and social impact of the software is visible across three distinct dimensions of modern healthcare delivery: equity, inclusion, and patient autonomy [21, 22]. By establishing automated priority indexing for patients classified with "In Progress" treatment markers or tracking at geriatric ages ($\ge$60 years), the system explicitly shifts the public medical ecosystem away from simple procedural equality to true clinical equity [21]. This systematic adjustment directly supports treatment adherence and safeguards vulnerable individuals from physical exhaustion [10, 12].

Furthermore, digital inclusion was integrated into the frontend interface design by deploying high-contrast layouts, clean navigation, and adaptive textual interfaces [23]. This thoughtful design empowers patients with lower digital literacy or age-related functional limitations to navigate their care pathways independently, reducing administrative reliance on nursing personnel [23, 24]. Lastly, the system enhances patient autonomy by replacing arbitrary manual scheduling with a transparent, predictable wait-time dashboard [25]. This reduction in operational ambiguity builds deep public trust in state-sponsored digital health initiatives [26, 27].

From a governance and healthcare policy perspective, the modular design of this platform mirrors the strategic direction of national digital health frameworks [2]. The system's clean API layer allows seamless prospective integration with emerging enterprise Electronic Health Records (EHR) databases, establishing a reproducible blueprint for nationwide scaling across public clinical networks [2, 17].

Broader ethical challenges of AI-supported care must also be acknowledged. Algorithmic bias remains a risk if prioritization rules or training distributions misrepresent patient groups, warranting periodic bias audits [15]. Transparency is supported through audit logs of every AI-generated assignment, yet the partially opaque nature of LLM reasoning limits decision-level explainability [14, 27]. Accountability is preserved by a human-in-the-loop design in which nursing staff can override any automated assignment. Governance in public hospitals further requires clear institutional ownership, data protection compliance, and alignment with national digital health policy and emerging AI regulation [2, 26].

Clinical implementation also entails practical challenges: reliable network connectivity, QR-capable devices, and patient-facing displays; structured staff training and change management; interoperability with hospital information systems and future Electronic Health Record platforms, ideally via open standards such as HL7 FHIR; and long-term maintenance covering model retraining, API version management, security patching, and budgeted technical support—all of which must be planned before deployment in public hospitals.

However, several technical and structural constraints must be explicitly acknowledged [6, 15]. Due to administrative and data privacy limitations, the platform was validated using synthetic datasets [1] . While these datasets were engineered to mirror real-world hospital workflows, they cannot fully replicate the high volatility of live healthcare environments[6]. Sudden clinical disruptions, such as unexpected acute medical emergencies or unannounced physician absences, can skew predictive wait-time calculations [9]. This limitation highlights the need for continuous on-site model retraining loops [9, 15]. Furthermore, the system's reliance on continuous cloud API connectivity for its AI reasoning and camera-based QR tracking layers introduces structural vulnerabilities in localized offline localhost environments[18]. This operational constraint highlights the

necessity of developing hybrid, containerized deployment models to guarantee business continuity during network outages [18, 19] Additional constraints merit emphasis. The LLM layer depends on third-party API availability and rate limits, and any internet-facing clinical platform carries cybersecurity exposure requiring continuous testing and patching. Scalability across heterogeneous hospitals and throughput under peak loads exceeding 1,500 daily arrivals were not stress-tested, and routine deployment would require ethics clearance and regulatory approval. The UAT demonstrates functional correctness only, without measuring usability or clinical acceptance; future evaluation will use validated instruments such as the System Usability Scale (SUS). Most critically, exclusive reliance on synthetic data means the reported accuracy and fairness findings are proof-of-concept evidence; prospective validation with real, anonymized clinical data remains essential.

Conclusions

This study details the successful conversion of an academic dissertation into a scalable, ethically aligned software system tailored for high-concurrency public medical ecosystems [1, 2]. The engineered solution demonstrates that integrating lightweight web micro-frameworks with advanced AI computational reasoning layers can eliminate legacy administrative bottlenecks, suppress physical waiting room congestion, and enforce context-aware fairness [8, 14]. By moving public clinical operations away from rigid FCFS manual token tracks, the system establishes a digital pathway that respects human dignity and clinical urgency [20, 21].

Future research paths will focus on expanding the platform's architectural footprint from basic outpatient registration hubs directly into specialized treatment sub-queues, including radiology, oncology surgery blocks, and compounding pharmacies [1,3]. To achieve widespread accessibility, full native multi-lingual localization support (Sinhala, Tamil, and English) will be integrated into the front-end presentation layer [2, 23]. Finally, future work will focus on securing institutional ethics clearance to execute localized pilot testing using anonymized, live clinical streams, paving the way for a resilient national healthcare infrastructure [2, 6] Planned evaluations include prospective clinical studies under routine hospital operations, formal load and stress testing under simulated peak clinic conditions, and quantitative usability and acceptance assessment with healthcare professionals and patients.

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References

1. Fernando A, Perera K, Silva M. Manual token systems in Sri Lankan oncology hospitals: An operational bottleneck. Journal of Health Informatics. 2021;14(2):85-98.
2. Ministry of Health, Sri Lanka. Sri Lanka Digital Health Blueprint: Enabling a Healthier Nation through Digital Transformation of Healthcare. Colombo: Ministry of Health; 2023.
3. Kwak J, Kim S, Lee H. AI-powered triage systems in South Korean hospitals: A case study in oncology. Journal of Medical Systems. 2023;47(2):112-124.
4. Tang Y, Zhao L, Chen M. Optimizing hospital queues using machine learning: Evidence from U.S. cancer centers. Health Informatics Journal. 2022;28(4):765-781.
5. Sahu R, Patel A, Mehta N. QR code-based patient identification in Indian hospitals: A digital shift. International Journal of Healthcare Technology. 2021;19(3):210-225.
6. Smith A, Almutairi F, Rahman T. Real-time analytics and AI in healthcare: Bridging the gap in developing nations. Global Health Informatics Review. 2023;15(1):45-59.
7. Maqbool M, Khan Z, Ali S. Digital Queue Management Systems (QMS) in modern outpatient care: Operational advantages and user satisfaction. Journal of Clinical Coordination. 2022;31(1):44-56.
8. Chen L, Wang X, Zhang J. Performance evaluation of AI-driven queue systems in specialized oncology departments. IEEE Access. 2023;11:10423-10436.
9. Zhou Y, Feng S, Liu W. Predictive analytics for hospital queue length and outpatient wait time management. ACM Transactions on Healthcare Informatics. 2022;8(3):210-227.
10. Mohile SG, Dale W, Sestovic M. Integrating Comprehensive Geriatric Assessment (GA) into clinical oncology scheduling networks. Journal of Geriatric Oncology. 2022;13(4):412-423.

11. Huisman MG, van Leeuwen BL, de Graaf JC. Frailty, treatment fatigue, and cognitive load variables in older outpatient chemotherapy scheduling. Clinical Interventions in Aging. 2023;18:1105-1118.

12. Levit LA, Balogh EP, Nass SJ. Continuity of care, structural fragmentation, and scheduling consistency in public radiotherapy patient outcomes. Health Policy Review. 2022;40(1):14-29.

13. Mahadevan S, Kumar N, Swaminathan V. Disruptions in cancer treatment cycles due to administrative bottlenecks: Ethical and clinical dimensions. Oncology Care Journal. 2023;29(3):301-315.

14. Thirunavukarasu AJ, Ting DS, Elangovan K. Multimodal large language models in clinical decision support systems: Operational feasibility and reasoning boundaries. Nature Biomedical Engineering. 2023;7(9):1024-1041.

15. Rajkomar A, Dean J, Kohane I. Ethical AI in healthcare: Algorithms, fairness constraints, and structural transparency metrics. Nature Medicine. 2022;28(5):610-619.

16. Singh A, Sharma R. Role-based access control and session-cookie management architectures in Flask applications: Security implications for digital healthcare. Cybersecurity Review. 2021;9(1):55-70.

17. Zhou Y, Lin H, Wang J. PostgreSQL architectures for scalable relational data management in healthcare information systems. Database Systems Journal. 2020;11(4):210-225.

18. Render Docs. Render Cloud Infrastructure Deployment Frameworks for Compliant Healthcare Applications. Render Documentation Portal; 2024. Available from: https://render.com/docs

19. Gupta R, Sharma A, Verma P. Python-based micro-frameworks for medical informatics applications: A comparative engineering study. Journal of Software Engineering. 2021;29(3):145-158.

20. Institute of Policy Studies (IPS). Healthcare Inequality, Resource Bottlenecks, and Outpatient Access Challenges in Public Hospitals of Sri Lanka. Colombo: IPS Research Reports; 2024.

21. Daily FT. From procedural equality to systemic equity: Redefining logistical fairness in Sri Lankan public healthcare. Daily FT Economy Tiers. 2025 Jan 14:6.

22. Breast Cancer Financial Toxicity Study. Mitigating structural and financial toxicities within Sri Lanka's public oncology care ecosystem. Oxford Academic Health Review. 2023;35(2):189-204.

23. Chen Y, Martinez J, Thompson R. Digital inclusion pathways and barrier reduction strategies among older adults in public outpatient settings. Clinical Interventions in Aging. 2025;20:77-92.

24. JMIR. Inclusive design heuristics, accessibility constraints, and usability benchmarks for digital health interventions. Journal of Medical Internet Research. 2025;27(1):e10432.

25. Narkhede M, Patil S, Joshi R. Patient autonomy in digital data ownership: Dynamic privacy models and granular consent frameworks. Journal of Digital Health. 2025;11(1):45-59.

26. Williamson S, Prybutok V. Privacy challenges, risk mitigation vectors, and patient perceptions in AI-driven public healthcare platforms. Applied Sciences. 2024;14(8):3211-3228.

27. PMC. Algorithmic transparency, dynamic wait notifications, and explicit informed consent loops in medical AI integrations. PubMed Central Bio-Ethical Review. 2025;39(2):115-128.

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EP 04

Comparative Evaluation of Machine Learning Models for Spatio-Temporal Crime Prediction Using Urban Open Data

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Abstract

Introduction: Systematic comparisons of machine learning model families for urban crime prediction that combine regression accuracy with spatial hotspot evaluation remain limited despite their importance for law enforcement resource allocation.

Objectives: To compare four machine learning model families for monthly LSOA-level crime count forecasting in London using open data and assess the relative contribution of temporal and structural features to predictive performance.

Methods: Five publicly available datasets (2020–2024) were integrated into 304,336 LSOA-month observations across 12,415 LSOAs. Twenty-one temporal, socioeconomic, and spatial features were engineered. Four model families—regularised linear regression, tree-based ensembles, SARIMA, and LSTM—were trained on 2020–2023 data and evaluated on a 2024 temporal holdout using MAE, RMSE, R^2, and spatial hotspot metrics (PAI, RRI, PEI).

Results: Random Forest (200 trees, depth=10) achieved the best performance (MAE=4.377, R^2=0.949, PAI=5.43 at 5% coverage). Temporal lag and rolling features accounted for 97.2% of predictive importance, explaining the small performance differences between model families. LSTM architectures underperformed because of limited training sequence depth.

Conclusions: Once temporal features are engineered, model family has only a marginal influence on predictive performance. Open-data machine learning models can produce reproducible, operationally meaningful forecasts to support evidence-based urban policing.

Keywords: *crime prediction, feature importance, machine learning, predictive policing, spatio-temporal analysis*

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Introduction

Predictive policing applies machine learning and geospatial analysis to historical crime data to identify locations at elevated risk of future crime, supporting proactive resource allocation by law enforcement agencies[1]. In large metropolitan areas such as London, where crime is spatially concentrated and socioeconomic conditions vary considerably, evidence-based deployment can improve operational decision-making. However, despite increasing research on predictive crime modelling, evidence regarding operational effectiveness remains mixed, while concerns surrounding transparency, reproducibility, and methodological rigour persist[2].

Machine learning approaches for crime prediction have expanded to include Random Forests, gradient boosting, support vector machines, deep learning architectures, and classical statistical and time-series models[3]. Catlett et al.[4] demonstrated the benefits of integrating spatial clustering with temporal forecasting for hotspot detection, while Williams[5] reported operationally relevant results using ensemble methods in a UK policing context. Kang and Kang[6] showed that deep learning models can capture temporal crime dynamics when sufficient sequential data are available. Despite these advances, few studies have systematically compared linear models, tree-based ensembles, classical time-series methods, and deep learning architectures under identical data, feature engineering, and evaluation conditions. Consequently, observed performance differences often reflect variations in preprocessing or feature engineering rather than model choice alone.

Evaluation methodology presents a further challenge. Conventional regression metrics, including Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and the coefficient of determination (R^2), quantify prediction accuracy but not the operational value of directing patrols to predicted hotspots. Spatial hotspot metrics, including the Predictive Accuracy Index (PAI), Recovery Rate Index (RRI), and Prediction Efficiency Index (PEI), evaluate how effectively predicted risk is concentrated relative to random deployment[7,8]. Although Drawve and Wooditch[7] demonstrated that PAI can alter conclusions drawn from regression metrics alone, studies combining both evaluation approaches remain limited.

This study addresses these gaps through a systematic comparison of four machine learning model families for monthly LSOA-level crime forecasting across the London Metropolitan Police District using publicly available data. Regression accuracy, spatial hotspot detection, and feature importance are evaluated under identical experimental conditions. Specifically, the study compares predictive performance using statistical and hotspot detection metrics, quantifies the contribution of temporal, socioeconomic, spatial, and meteorological features through an ablation experiment, and discusses ethical considerations relevant to algorithmic decision-making in policing.

Methods

Dataset and Study Area

Five publicly available datasets covering the London Metropolitan Police District (January 2020–December 2024) were integrated. Police-recorded crime data were obtained from data.police.uk[9] and aggregated to monthly Lower Layer Super Output Area (LSOA) counts. Geographic boundaries and LSOA–MSOA lookup tables were sourced from the Office for National Statistics (ONS) Geoportal[10]. Household income estimates were obtained from the ONS Small Area Income Estimates[11], with 2021, 2022, and 2024 values interpolated from the available 2020 and 2023 releases. Population estimates were obtained from the ONS[12], and meteorological data from the Met Office Heathrow station[13].

Following column harmonisation, data cleaning, and null-value resolution, all datasets were merged into a unified modelling dataset. After excluding observations lacking sufficient temporal history for lag feature generation, the final dataset comprised 304,336 LSOA-month observations across 12,415 LSOAs spanning July 2020–December 2024. The dataset represents an event-observed panel rather than a balanced spatio-temporal grid; months without recorded crime are absent. Consequently, the models predict crime counts conditional on crime occurrence rather than crime emergence in previously crime-free locations.

Feature Engineering

Twenty-one features were engineered across six categories: temporal lags, rolling statistics, crime-rate normalisation, socioeconomic variables, cyclical temporal encodings, and spatial neighbourhood features. Temporal lag (1–6 months) and rolling statistics (3- and 6-month mean and standard deviation) captured short- and medium-term crime persistence and were

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selected based on established crime forecasting and time-series practice rather than automated feature selection. Socioeconomic variables included population density, income per capita, and income deprivation, while cyclical month encodings and seasonal indicators represented seasonal effects. The spatial neighbourhood feature (msoa_avg_crime) captured the crime context of each parent MSOA.

Feature construction followed strict chronological ordering to prevent temporal leakage, ensuring that no information from the 2024 test period influenced model training.

Model Families and Training Protocol

Four model families were evaluated: regularised linear regression (Ridge and Lasso)[14,15], tree-based ensembles (Random Forest and XGBoost)[16,17], Seasonal AutoRegressive Integrated Moving Average (SARIMA)[18], and Long Short-Term Memory (LSTM) networks[19].

Ridge, Lasso, Random Forest, XGBoost, and six LSTM architectures were trained as global panel models using the complete multi-LSOA dataset. SARIMA was fitted independently to each of the 12,415 LSOAs using automated Akaike Information Criterion (AIC)-based order selection. Robustness controls, including stability detection, conditional seasonality suppression, forecast capping, and fallback forecasting, were applied to improve convergence. Valid SARIMA forecasts were obtained for 4,677 LSOAs (37.7%), with the remaining locations excluded because of insufficient series stability.

Models were trained using 2020–2023 data and evaluated on a strict 2024 temporal holdout to replicate prospective forecasting. Random Forest, XGBoost, and LSTM hyperparameters were selected through manual tuning rather than automated optimisation. Random Forest configurations varied tree number, depth, and minimum leaf size, while XGBoost configurations varied tree depth, learning rate, regularisation, and subsampling. The reported iter = 808 reflects XGBoost's early-stopping mechanism rather than an optimisation search. Nine manually designed LSTM variants—including simple, stacked, bidirectional, attention-based, CNN-LSTM, and residual architectures—were evaluated using a common training protocol with EarlyStopping and ReduceLROnPlateau callbacks.

Cross-validation was not performed. A chronological train-test split was intentionally adopted to prevent temporal leakage and emulate forecasting of an unseen future year. For LSTM models, 15% of the training data served as a validation set for callback-based training, while the 2024 test set remained unseen until final evaluation.

Evaluation Framework

Performance was assessed using both statistical accuracy and operational hotspot detection. Regression performance was evaluated using Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and coefficient of determination (R^2). Mean Absolute Percentage Error (MAPE) is reported for completeness but was not used for primary model comparison because near-zero crime counts inflate percentage errors[20].

Operational performance was assessed using the Predictive Accuracy Index (PAI), Recovery Rate Index (RRI), and Prediction Efficiency Index (PEI) at 5%, 10%, and 20% spatial coverage. PAI measures how efficiently predicted hotspot areas concentrate crime relative to random patrol allocation.

Results

Regression Accuracy

Table 1 summarises the best-performing configuration from each model family evaluated on the 2024 held-out test set, together with the Random Forest (RF) no-lag ablation model. Metrics were computed on the event-observed panel; zero-crime LSOA-month combinations were absent from both training and test datasets.

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Table 1. Regression accuracy metrics on 2024 held-out test set.

Model	MAE	RMSE	R^2	MAPE†
Ridge (α = 0.1)	4.817	8.993	0.938	44.4%
Lasso (α = 1.0)	4.646	8.706	0.942	47.4%
Random Forest (200 trees, depth=10, leaf=2)	**4.377**	**8.181**	**0.949**	**40.3%**
Random Forest — no lag features	6.473	17.140	0.775	61.8%
XGBoost (depth=7, LR=0.02, iter=808)	4.538	9.269	0.934	41.9%
SARIMA (per-LSOA, n=4,677)‡	7.179	17.604	0.774	51.4%
LSTM — Attention (256→128→64, Huber)	5.266	18.691	0.741	47.6%

† MAPE values are inflated by near-zero crime counts at sparse LSOAs and are not used as a primary comparison criterion (see Section 2.4).

‡ SARIMA evaluated on 4,677 LSOAs with sufficient series stability; all other models evaluated on the full 12,415-LSOA test population.

Random Forest achieved the best overall performance (MAE = 4.377, R^2 = 0.949), followed by Lasso and XGBoost. Removing temporal lag features substantially reduced RF performance (MAE = 6.473, R^2 = 0.775), approaching that of SARIMA (MAE = 7.179, R^2 = 0.774). The best LSTM configuration (attention-based) achieved MAE = 5.266, underperforming the tree-based and linear models.

3.2 Spatial Hotspot Detection

Table 2 reports hotspot detection performance using PAI, RRI, and PEI at **5%, 10%, and 20%** spatial coverage.

Table 2. Spatial hotspot detection metrics by coverage threshold.

Model	5% PAI	10% PAI	20% PAI	5% RRI
Random Forest	**5.426**	**3.783**	**2.626**	**0.271**
XGBoost	5.426	3.784	2.625	0.271
Lasso	5.425	3.772	2.617	0.271
Ridge	5.423	3.770	2.613	0.271
LSTM — Attention	5.309	3.704	2.576	0.266

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SARIMA‡	5.070	3.498	2.414	0.254

‡ SARIMA hotspot metrics computed on its partial LSOA coverage (n=4,677).

At 5% coverage, the four globally trained models produced nearly identical PAI values (5.423–5.426). Random Forest achieved a PAI of 5.426, indicating that concentrating patrols within the highest-risk 5% of predicted locations would intercept crime at approximately 5.4 times the rate of uniform patrol allocation. SARIMA achieved a lower PAI of 5.070, capturing 47,114 fewer crimes than Random Forest despite being evaluated on a more favourable subset of LSOAs.

3.3 Feature Importance and Temporal Signal Decomposition

Table 3 presents the ten most important predictors in the best-performing Random Forest model, ranked by mean impurity decrease.

Table 3. Top 10 feature importances (Random Forest, 200 trees, depth=10, leaf=2).

Feature	**Importance**	**Category**
crime_lag_1m	0.547	Temporal lag
crime_rolling_3m_mean	0.253	Rolling statistic
crime_rolling_6m_mean	0.147	Rolling statistic
crime_rolling_3m_std	0.008	Rolling statistic
Sunshine_Hours	0.006	Meteorological
Total_Population	0.005	Demographic
msoa_avg_crime	0.005	Spatial
crime_rolling_6m_std	0.004	Rolling statistic
crime_lag_6m	0.003	Temporal lag
crime_lag_3m	0.003	Temporal lag

Temporal lag and rolling features accounted for 97.2% of total predictive importance. The one-month crime lag alone contributed 54.7%, indicating that recent crime history dominated predictive performance. All remaining variables, including socioeconomic, spatial, and meteorological features, collectively contributed only 2.8% of total importance.

Discussion

Temporal Persistence as the Dominant Predictive Signal

The feature importance analysis indicates that temporal lag and rolling statistics dominate predictive performance, explaining the narrow performance differences across model families. Because all models were provided with the same strong autoregressive signal, model sophistication contributed only marginal gains. Although Random Forest reduced MAE

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by 0.440 relative to Lasso (9.5%), this improvement suggests that predictive performance was driven primarily by the strength of temporal autocorrelation rather than by model complexity.

Random Forest Performance

Random Forest consistently outperformed all evaluated XGBoost configurations, consistent with findings by Probst, Wright and Boulesteix[21], who reported that Random Forest frequently performs better than gradient boosting on highly autocorrelated data. As temporal lag features already explained most of the variance, XGBoost's sequential boosting offered limited additional benefit. The selected Random Forest configuration (max_depth = 10) also generalised better than deeper trees, supporting previous findings on controlling overfitting in ensemble learning[16].

Beyond predictive performance, Random Forest provides an operational advantage through transparent feature importance estimates, enabling analysts to identify the variables driving predictions. Given its competitive accuracy and greater interpretability, Random Forest represents the most practical model for decision-support applications in policing.

LSTM Underperformance

All LSTM architectures underperformed relative to the tree-based models. With only 48 months of data and a 12-month lookback window, each LSOA contributed approximately 36 training sequences, limiting the ability of deep recurrent networks to learn robust temporal representations[22]. Furthermore, temporal information had already been encoded through engineered lag features, reducing the advantage of sequential modelling. Similar findings have been reported by Mao et al.[26], who showed that deep-learning crime forecasting required substantial preprocessing before outperforming simpler approaches. These results suggest that LSTM models are more suitable for longer sequential datasets or applications without engineered temporal features.

PAI Convergence and the Limits of Hotspot Discrimination

The near-identical **PAI** values among the globally trained models demonstrate that hotspot identification is primarily a ranking problem driven by persistent spatial crime patterns rather than small differences in regression accuracy. Once temporal lag features are included, different model families identify largely the same high-risk areas. SARIMA's lower hotspot performance further indicates that modelling individual LSOAs without shared spatial and socioeconomic information reduces hotspot detection effectiveness.

Limitations

Several limitations should be considered. First, the event-observed panel excludes zero-crime LSOA-months, restricting predictions to locations where crime has previously occurred. Second, evaluation was limited to a single temporal holdout year without spatial cross-validation, leaving geographic transferability untested. Third, household income values for three years were interpolated, introducing uncertainty into the socioeconomic features. SARIMA evaluation covered only 37.7% of LSOAs because of insufficient series stability, preventing direct comparison across the full study area. Monthly aggregation also limits the detection of finer temporal crime patterns, and computational efficiency was not systematically benchmarked. Finally, the findings are specific to London and should be validated in cities with different crime distributions, policing practices, and data availability before broader generalisation. In particular, the LSOA reporting framework and open crime data infrastructure are specific to England and Wales, the dominance of temporal autocorrelation may reflect London's stable, spatially concentrated crime patterns rather than a universal finding, and equivalent socioeconomic data availability varies considerably across jurisdictions.

Ethical Considerations

Police-recorded crime reflects both criminal activity and policing practices; historically over-policed areas may therefore exhibit higher recorded crime independent of underlying offending[23]. Although using reported crime rather than stop-and-search or arrest data partially reduces this bias, predictive outputs should remain decision-support tools subject to human oversight, transparent governance, and periodic disparity auditing[24]. Public reporting, independent oversight, and officer training are essential to ensure predictions are interpreted appropriately rather than treated as objective truth. This need is reinforced by recent evidence showing that only 6 of 161 predictive policing studies provide strong empirical evidence of effectiveness[27].

Operational Implementation

Operational deployment requires integration with existing police information systems rather than standalone use. Predictions should support resource allocation alongside officer judgement and local intelligence, with regular model updates, compatibility with existing geographic information systems, and interfaces presenting prediction confidence and key contributing features. Deployment should occur only within the governance and auditing framework outlined above.

Conclusions

This study systematically compared four machine learning model families for monthly LSOA-level crime count forecasting across London using open data and a strict 2020–2023/2024 temporal holdout. Random Forest achieved the best overall performance (MAE = 4.377, R^2 = 0.949, PAI = 5.43 at 5% coverage). Temporal lag and rolling features accounted for 97.2% of predictive importance, indicating that temporal persistence, rather than model complexity, was the primary driver of predictive performance. Consequently, performance differences between model families were modest, while LSTM architectures underperformed because of limited training sequence depth and SARIMA proved less effective than globally trained panel models.

The findings are constrained by the event-observed dataset, the absence of spatial cross-validation, interpolated socioeconomic data, and the London-specific study area. Future research should investigate balanced datasets with explicit zero-crime observations, spatial validation across jurisdictions, fairness auditing, and advanced spatial-temporal architectures such as graph neural networks, transformer-based temporal forecasting, spatial deep learning, transfer learning across cities, and real-time prediction pipelines. Overall, this study demonstrates that reproducible, operationally meaningful crime forecasting can be achieved using entirely open data and transparent machine learning workflows.

References

1. Perry WL, McInnis B, Price CC, Smith S, Hollywood JS. Predictive Policing: The Role of Crime Forecasting in Law Enforcement Operations [Internet]. Santa Monica, CA: RAND Corporation; 2013. Available from: https://www.rand.org/pubs/research_reports/RR233.html

2. Meijer A, Wessels M. Predictive Policing: Review of Benefits and Drawbacks. Int J Public Adm. 2019;42(12):1031-9.

3. Mandalapu V, Elluri L, Vyas P, Roy N. Crime Prediction Using Machine Learning and Deep Learning: A Systematic Review and Future Directions. IEEE Access. 2023;11:60153-70.

4. Catlett C, Cesario E, Talia D, Vinci A. Spatio-temporal crime predictions in smart cities: A data-driven approach and experiments. Pervasive Mob Comput. 2019;53:62-74.

5. Williams I. Machine learning algorithms for crime prevention and predictive policing [dissertation]. Cardiff: Cardiff University; 2018.

6. Kang HW, Kang HB. Prediction of crime occurrence from multi-modal data using deep learning. PLoS One. 2017;12:e0176244.

7. Drawve G, Wooditch A. A research note on the methodological and theoretical considerations for assessing crime forecasting accuracy with the predictive accuracy index. J Crim Justice. 2019;64:101625.

8. White V, Hunt J, Green B. A discussion of current crime forecasting indices and an improvement to the prediction efficiency index for applications. Secur J. 2023;37:1-18.

9. data.police.uk. Police recorded crime data [Internet]. London: Home Office; 2024 [cited 2026 Jan 16]. Available from: https://data.police.uk

10. Office for National Statistics. Open Geography Portal: boundary data [Internet]. Newport: ONS; 2023 [cited 2026 Jan 16]. Available from: https://geoportal.statistics.gov.uk

11. Office for National Statistics. Small area income estimates for middle layer super output areas, England and Wales [Internet]. Newport: ONS; 2023 [cited 2026 Jan 16]. Available from: https://www.ons.gov.uk

12. Office for National Statistics. Population estimates for local authorities in England and Wales [Internet]. Newport: ONS; 2024 [cited 2026 Jan 16]. Available from: https://www.ons.gov.uk

13. Met Office. Historic station data: Heathrow [Internet]. Exeter: Met Office; 2024 [cited 2026 Jan 16]. Available from: https://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/heathrowdata.tx

14. Hoerl AE, Kennard RW. Ridge Regression: Biased Estimation for Nonorthogonal Problems. Technometrics. 1970;12(1):55-67.

15. Tibshirani R. Regression shrinkage and selection via the lasso. J R Stat Soc Series B Stat Methodol. 1996;58(1):267-88.

16. Breiman L. Random Forests. Mach Learn. 2001;45(1):5-32.

17. Chen T, Guestrin C. XGBoost: A Scalable Tree Boosting System. In: Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (KDD '16); 2016 Aug 13-17; San Francisco, CA. New York: Association for Computing Machinery; 2016. p. 785-94.

18. Hyndman RJ, Khandakar Y. Automatic Time Series Forecasting: The forecast Package for R. J Stat Softw [Internet]. 2008 Jul 29 [cited 2026 May 29];27(3):1-22. Available from: https://www.jstatsoft.org/index.php/jss/article/view/v027i03

19. Hochreiter S, Schmidhuber J. Long Short-Term Memory. Neural Comput. 1997;9(8):1735-80.

20. Hyndman RJ, Koehler AB. Another look at measures of forecast accuracy. Int J Forecast. 2006;22(4):679-88.

21. Probst P, Wright M, Boulesteix AL. Hyperparameters and Tuning Strategies for Random Forest. Wiley Interdiscip Rev Data Min Knowl Discov. 2019;9. doi:10.1002/widm.1301

22. Goodfellow I, Bengio Y, Courville A. Deep Learning. Cambridge, MA: MIT Press; 2016. Available from: http://www.deeplearningbook.org

23. Akpinar NJ, De-Arteaga M, Chouldechova A. The effect of differential victim crime reporting on predictive policing systems. In: Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency (FAccT '21); 2021 Mar 3-10; Virtual Event, Canada. New York: Association for Computing Machinery; 2021. p. 838-49.

24. Alikhademi K, Drobina E, Prioleau D, Richardson B, Purves D, Gilbert JE. A review of predictive policing from the perspective of fairness. Artif Intell Law. 2022;30(1):1-17.

25. Fernandez-Delgado M, Cernadas E, Barro S, Amorim D. Do we need hundreds of classifiers to solve real world classification problems? J Mach Learn Res. 2014;15:3133-81.

26. Mao L, Du W, Wen S, Li Q, Zhang T, Zhong W. Crime forecasting: A spatio-temporal analysis with deep learning models. J Comput Methods Sci Eng. 2025;25(5):4090-9.

27. Lee Y, Bradford B, Posch K. The effectiveness of big data-driven predictive policing: systematic review. Justice Eval J. 2024;7(2):127-60. doi:10.1080/24751979.2024.2371781.

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Evaluating the Impact of IoT-Based Smart Home Systems on Quality of Life in Sri Lanka

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Abstract

Background: The Internet of Things (IoT) has emerged as a transformative paradigm capable of enhancing quality of life through automation, real-time monitoring, and intelligent decision-making. While developed nations have widely adopted such technologies, developing countries like Sri Lanka face barriers, including cost and infrastructure limitations.

Objective/s: This study investigates the effectiveness of IoT-based smart home management systems in improving the quality of life in Sri Lanka, focusing on determinants such as affordability, automation, healthcare, and security.

Methods: Primary data were collected from 50 respondents through a structured questionnaire administered via Google Forms. Participants consisted of IT-sector professionals and undergraduates in Sri Lanka who were invited to voluntarily participate in the study through online distribution channels. Therefore, a convenience sampling approach was employed rather than true random sampling. While this method facilitated efficient data collection from individuals familiar with technology-related concepts, it may have introduced selection bias, as respondents with greater interest in IoT technologies, higher digital literacy, or easier access to online platforms may have been more likely to participate. Consequently, the findings should be interpreted with caution and may not be fully generalizable to the broader Sri Lankan population. Data were analysed in IBM SPSS Statistics 22 using Cronbach's alpha for reliability, descriptive statistics, Pearson correlation, and simple linear regression.

Results: All four constructs correlated positively and significantly with quality of life. In a multiple regression with all predictors entered together ($R^2 = 0.487$; $F(4, 45) = 10.68$, $p < 0.001$), only the affordability of IoT devices retained a significant independent association ($\beta = 0.366$, $p = 0.021$); the other factors were not significant once shared variance was controlled.

Conclusion/s: IoT-based smart home systems are positively associated with quality of life in Sri Lanka, and affordability is the one factor with a robust independent effect. Stakeholders should therefore prioritise cost-effective solutions, supported by infrastructure and public awareness, to widen adoption.

Keywords: *Affordability, Automation, Internet of Things, Quality of Life, Sri Lanka*

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Introduction

The rapid evolution of digital technologies has led to the emergence of IoT as a key driver of smart environments [1, 2]. Smart home systems integrate sensors, devices, and cloud-based services to automate household operations and enhance efficiency [5, 6]. While developed nations have widely adopted such technologies, developing countries like Sri Lanka face barriers, including cost, infrastructure limitations, and low awareness [4]. Existing literature demonstrates that IoT-based smart home systems significantly enhance energy efficiency, safety, and convenience [3]. However, adoption in developing countries remains limited due to economic and infrastructural challenges [4, 11, 12]. Despite global advancements, there is limited empirical evidence focusing on the Sri Lankan context, particularly regarding the direct impact of IoT on quality of life [5, 6]. To address this research gap, this study investigates how IoT-based smart home systems influence quality of life within the Sri Lankan context by considering both technological capabilities and practical adoption challenges. Unlike previous studies that primarily focus on individual smart home applications such as automation, security, or energy efficiency, this research examines the combined influence of affordability, automation, healthcare applications, and security features on users' perceived quality-of-life improvements. Furthermore, by incorporating affordability as a key determinant, this study provides insights into the accessibility challenges associated with IoT adoption in developing economies, where economic considerations may significantly influence technology acceptance and utilization. Therefore, this research contributes context-specific evidence on the potential of IoT-based smart home systems to improve quality of life in Sri Lanka.

This study is grounded in established technology-adoption theory. The Technology Acceptance Model (TAM) explains adoption through perceived usefulness and perceived ease of use, while the Unified Theory of Acceptance and Use of Technology (UTAUT) extends this with performance expectancy, effort expectancy, social influence, and facilitating conditions, with its later formulation (UTAUT2) adding price value. Rogers' Diffusion of Innovation (DOI) theory further emphasises relative advantage, compatibility, and complexity. The four factors examined here map onto these frameworks: affordability corresponds to UTAUT2's price value and to the cost barrier repeatedly identified in developing economies; home automation and the use of IoT for caring for elderly and sick people reflect performance expectancy and relative advantage; and home security relates to facilitating conditions and perceived risk. Framing the constructs this way situates the Sri Lankan findings within the wider adoption literature and clarifies why affordability, as a price-value barrier, may dominate perceived quality-of-life gains in a price-sensitive market.

Methods

This study followed a deductive, quantitative design based on a cross-sectional survey. All constructs were measured on five-point Likert scales, and the analysis tested whether four IoT-related factors are associated with self-reported quality of life in Sri Lanka.

The conceptual framework examined four independent variables – IoT-based home security, affordability of IoT devices, use of IoT for caring for elderly and sick people, and IoT-based automation of home appliances – against a single dependent variable, the perceived uplift in quality of life. The following alternative hypotheses were tested:

H1. IoT-based home security is positively associated with quality of life.

H2. Affordability of IoT devices is positively associated with quality of life.

H3. Use of IoT for caring for elderly and sick people is positively associated with quality of life.

H4. IoT-based automation of home appliances is positively associated with quality of life.

The questionnaire was developed based on an extensive review of the literature relating to Internet of Things (IoT) adoption, smart home technologies, home security, healthcare monitoring, home automation, affordability, and quality-of-life outcomes. The instrument consisted of six sections: demographic information, IoT-based home security, affordability of IoT devices, use of IoT for caring for elderly and sick people, IoT-based home automation, and quality of life. All construct items were measured using five-point Likert scales ranging from Strongly Disagree (1) to Strongly Agree (5). The questionnaire was designed to capture respondents' perceptions regarding the effectiveness and impact of IoT-based smart home systems within the Sri Lankan context.

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The study was further guided by two questions: (RQ1) whether remote IoT monitoring of the health and safety of elderly and sick people provides reassurance to their guardians; and (RQ2) whether the energy-management features of IoT home systems, such as energy monitoring, smart lighting, smart thermostats, and HVAC optimisation, help reduce household electricity costs.

Primary data were collected from 50 respondents through a structured questionnaire administered via Google Forms. Participants were drawn from IT-sector professionals and undergraduates in Sri Lanka. Because respondents were invited through online distribution channels and self-selected into the study, a convenience sampling approach was used rather than true random sampling; the resulting selection bias is discussed as a limitation.. Secondary data were obtained from peer-reviewed articles and technical sources [3, 4].

Responses were analysed in IBM SPSS Statistics 22. Internal consistency was assessed with Cronbach's alpha, and the relationship between each independent variable and quality of life was examined using descriptive statistics, Pearson correlation, and simple linear regression.

Participation was voluntary and anonymous. Respondents were informed of the purpose of the study and of how their data would be used, and no personally identifying information was collected.

Results

All five constructs showed acceptable internal consistency, with Cronbach's alpha ranging from 0.700 to 0.758 (Table 1). The lowest value, for the use of IoT in caring for elderly and sick people ($\alpha = 0.700$), is marginal and indicates that those items could be refined in future work.

Table 1. Internal consistency reliability for each construct.

Construct	No. of items	Cronbach's α
IoT-based home security	4	0.720
Affordability of IoT devices	4	0.758
Care for elderly and sick people	4	0.700
IoT-based home automation	5	0.750
Quality of life	4	0.748

The respondent profile is summarised in Table 2. The sample skewed young and male: 40% were aged 18–25 and 64% were male. Employed respondents (42%) and students (36%) dominated. Most participants reported at least moderate familiarity with IoT home systems (38% moderately familiar, 14% very familiar) and a high level of awareness of their potential benefits (44% extremely aware, 34% somewhat aware).

Table 2. Respondent profile (n = 50).

Characteristic	Category	%
Age	18–25	40
	26–35	22
	36–45	24
	46–55	12
	56 and above	2
Gender	Male	64
	Female	36
Occupation	Employed	42
	Student	36
	Self-employed	14

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	Unemployed	6
	Retired	2

Descriptively, all independent and dependent variables recorded means above 3 on the five-point scale, with relatively low standard deviations and a slight negative skew, indicating consistently positive perceptions of IoT-based solutions (Table 3).

Table 3. Descriptive statistics for all constructs.

Construct	Mean	SD	Skewness
IoT-based home security	3.75	0.41	-0.64
Affordability of IoT devices	3.62	0.46	-1.11
Care for elderly and sick people	3.71	0.35	-0.89
IoT-based home automation	3.67	0.41	-1.00
Quality of life	3.76	0.34	-1.37

Note. n = 50; all items measured on a five-point Likert scale.

Pearson correlations showed that all four independent variables were positively and significantly associated with quality of life (Table 4). Affordability had the strongest association ($r = 0.643$, $p < 0.001$), followed by automation ($r = 0.597$), care for elderly and sick people ($r = 0.539$), and home security ($r = 0.467$, $p = 0.001$). The independent variables were themselves inter-correlated ($r = 0.463$ to 0.678), the strongest link being between affordability and automation ($r = 0.678$).

Table 4. Pearson correlations between each independent variable and quality of life.

Independent variable	r	p
IoT-based home security	0.467	0.001
Affordability of IoT devices	0.643	< 0.001
Care for elderly and sick people	0.539	< 0.001
IoT-based home automation	0.597	< 0.001

Note. n = 50; p values below 0.001 are reported as < 0.001.

Entered individually, each predictor was a significant positive predictor of quality of life, explaining between 21.8% (home security) and 41.3% (affordability) of the variance. Because the four predictors are themselves correlated, a multiple linear regression was then run with all four entered together to estimate their independent contributions (Table 5).

The combined model was significant and explained 48.7% of the variance in quality of life ($R^2 = 0.487$, adjusted $R^2 = 0.441$; $F(4, 45) = 10.68$, $p < 0.001$). Once the predictors were allowed to compete, only the affordability of IoT devices retained a significant independent association ($\beta = 0.366$, $p = 0.021$). Home automation ($\beta = 0.226$, $p = 0.149$), care for elderly and sick people ($\beta = 0.143$, $p = 0.375$), and home security ($\beta = 0.085$, $p = 0.563$) were no longer significant when the other factors were held constant. Variance inflation factors were all below 2.3, indicating that this pattern is not an artefact of multicollinearity. Accordingly, H2 is supported in the multivariable model, whereas the bivariate support for H1, H3, and H4 does not hold once shared variance is controlled.

Before interpreting the model, the regression assumptions were examined. Multicollinearity was not a concern: tolerance values ranged from 0.45 to 0.54 and all variance inflation factors were below 2.3, well under the common threshold of 10. The independence of residuals was assessed using the Durbin-Watson statistic. Normality of residuals was examined with a normal P-P plot and the Shapiro-Wilk test, and homoscedasticity was checked by inspecting the scatterplot of standardised residuals against standardised predicted values. Several study variables showed moderate negative skew (Table 3), which larger future samples should address.

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Table 5. Multiple linear regression predicting quality of life (all predictors entered together).

Predictor	B	SE	β	t	p	95% CI
(Constant)	1.285	0.420	—	3.062	0.004	95% CI [0.439, 2.131]
IoT-based home security	0.070	0.120	0.085	0.583	0.563	95% CI [-0.172, 0.312]
Affordability of IoT devices	0.274	0.115	0.366	2.385	0.021	95% CI [0.042, 0.506]
Care for elderly and sick people	0.140	0.157	0.143	0.896	0.375	95% CI [-0.176, 0.456]
IoT-based home automation	0.191	0.130	0.226	1.467	0.149	95% CI [-0.071, 0.453]

Note. n = 50. B = unstandardized coefficient; β = standardized coefficient. Model $R^2 = 0.487$, adjusted $R^2 = 0.441$, $F(4, 45) = 10.68$, $p < 0.001$; all variance inflation factors below 2.3.The overall model corresponds to a large effect (Cohen's f-squared = 0.95). However, the sample is below conventional adequacy thresholds for multiple regression with four predictors (for example, Green's rule of thumb of N >= 82 to test the overall model and N >= 108 to test individual predictors), which limits the power to detect smaller independent effects and is reflected in the wide confidence intervals for the non-significant predictors.

Conceptual Framework

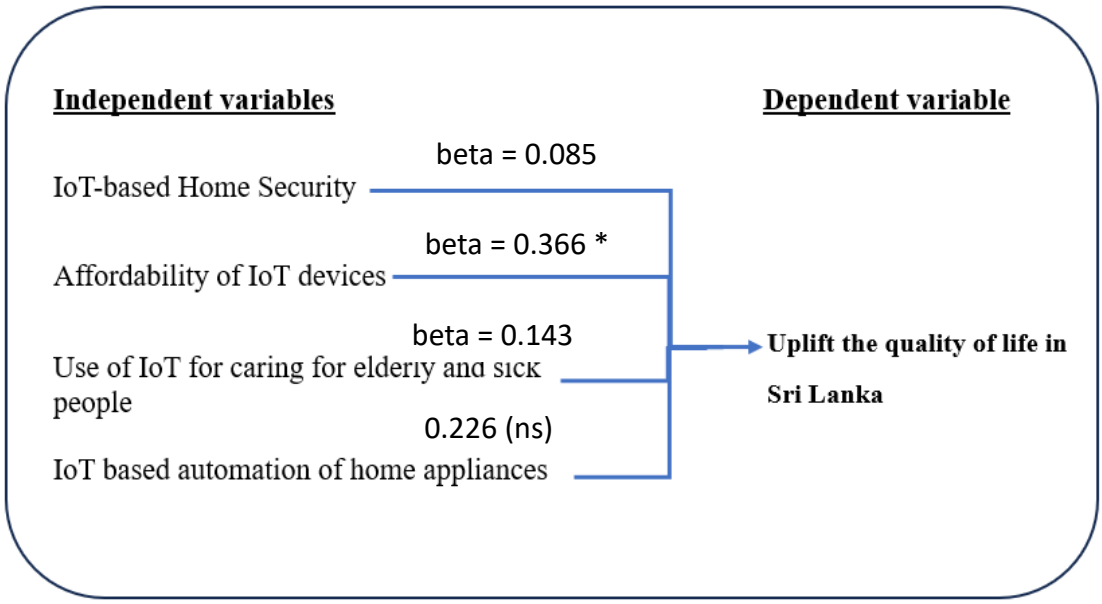

Figure 22: Conceptual model with standardized regression coefficients (p < 0.05; ns = not significant; n = 50).*

Discussion

The multivariable analysis sharpens the picture. Although all four factors correlate with quality of life, affordability of IoT devices is the only one that retains a significant independent association once the others are controlled for, which is consistent

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with evidence that cost is the primary barrier to IoT adoption in developing economies [4, 11, 12]. The apparent effects of home automation, of using IoT to care for elderly and sick people [7, 8, 9, 10], and of home security [13, 14] appear to operate largely through their strong overlap with affordability rather than independently; the predictors were inter-correlated from r = 0.463 to 0.678, the highest being between affordability and automation. Practically, this concentrates the policy lever on cost: affordable, automation-ready devices are likely to deliver the broadest quality-of-life gains in the Sri Lankan market [5, 6].

An important finding is that home security, home automation, and the use of IoT for caring for elderly and sick people were significantly associated with quality of life at the bivariate level but became non-significant in the multivariable model. This suggests that these constructs share a substantial proportion of variance with affordability. In practical terms, respondents who perceived IoT systems as affordable also tended to perceive greater benefits in relation to security, automation, and healthcare support. Consequently, the positive effects of these features may not operate independently but rather through the broader issue of affordability. In the Sri Lankan context, affordability appears to be a foundational factor that enables access to and adoption of smart home technologies. Even when users recognise the potential advantages of home automation, enhanced security, and remote healthcare monitoring, these benefits may remain unrealised if the technologies are perceived as financially inaccessible. This finding highlights the importance of reducing acquisition and maintenance costs, promoting affordable solutions, and improving access to low-cost IoT technologies in developing economies.

The observed shared variance among the predictors suggests that policies aimed solely at improving technological capabilities may have limited impact unless affordability barriers are simultaneously addressed. Increasing the sophistication of home security, automation, or healthcare-monitoring features is unlikely to substantially increase adoption if cost remains prohibitive. Therefore, policymakers, technology vendors, and service providers should prioritize affordability through subsidies, local manufacturing initiatives, flexible payment schemes, and cost-effective product designs. Such measures may allow households to benefit from the broader advantages of IoT technologies and ultimately contribute to improved quality of life.

Beyond reducing device costs, several complementary measures could support adoption. Investment in reliable broadband and mobile connectivity is a precondition for IoT services, particularly in rural areas. Strengthening cybersecurity and data-protection standards would address the privacy concerns that deter users. Public awareness and digital-literacy programmes could improve understanding of IoT benefits and safe use. Adopting interoperability standards would reduce vendor lock-in and lifetime costs by letting devices from different manufacturers work together. Finally, government incentives such as subsidies, tax relief, or duty concessions, delivered through collaboration between government agencies, IoT manufacturers, and telecommunication providers, could lower the effective price and accelerate affordable adoption.

Limitations and Future Research Directions

Several limitations should be noted. The sample of 50 respondents was relatively small and skewed toward young, male, and technology-literate participants, which may limit the generalizability of the findings to the broader Sri Lankan population. The cross-sectional design and reliance on self-reported Likert-scale responses mean that the identified relationships represent associations rather than confirmed causal effects. Furthermore, the limited sample size may have reduced the statistical power to detect smaller independent effects in the multiple regression analysis. Therefore, the non-significant effects observed for home automation, care for elderly and sick people, and home security should be interpreted cautiously rather than as evidence of the absence of relationships.

Initial evidence of construct validity was supported through the alignment of questionnaire items with constructs identified in previous literature and through acceptable internal consistency reliability. Cronbach's alpha values ranged from 0.700 to 0.758 across all constructs, indicating satisfactory reliability. However, due to the relatively small sample size (n = 50), exploratory or confirmatory factor analysis was not conducted. Future studies with larger samples should incorporate factor analysis to further validate the measurement model.

Although this study provides insights into the perceived impact of IoT-based smart home management systems on quality of life, the measurement of the quality-of-life construct represents another limitation. The dependent variable was assessed using study-specific items developed to capture IoT-related improvements in daily living, including perceived convenience, safety, independence, and overall satisfaction. While these items were relevant to the research context, they were not derived from a standardized quality-of-life instrument. Therefore, comparisons with previous studies using validated QoL measures

may be limited. Future research should incorporate established instruments, such as WHOQOL-BREF or similar validated scales, alongside IoT-specific measures to provide a more comprehensive assessment of quality-of-life outcomes.

Future research should extend these findings by employing larger and nationally representative samples to improve the generalizability of results. Longitudinal household studies are recommended to examine the long-term impact of IoT-based smart home systems on quality of life and provide stronger evidence of sustained benefits. In addition, future studies should incorporate objective quality-of-life indicators and evaluate real-world IoT implementations to better understand practical benefits, usability challenges, and adoption barriers. Cost-benefit analyses are also encouraged to assess the economic feasibility and accessibility of smart home technologies, particularly in developing country contexts such as Sri Lanka.

In addition, the instrument was not formally reviewed by an expert panel or pilot-tested before full deployment; future applications should incorporate expert content validation and a pilot study

Conclusions

This study found that IoT-based smart home systems are positively associated with quality of life in Sri Lanka, and that the affordability of IoT devices is the single factor with a robust independent effect once the others are accounted for. While home automation, care for elderly and sick people, and home security each correlate with quality of life, their contributions are largely shared with affordability rather than being separate. For stakeholders seeking to widen adoption, the clearest lever is therefore cost: prioritising affordable devices, supported by infrastructure and public awareness. Future work should extend the study with a larger and more representative sample, confirm the model on raw data with a validated quality-of-life instrument, and pilot the proposed IoT framework in real Sri Lankan households.

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References

1. Gubbi J, Buyya R, Marusic S, Palaniswami M. Internet of Things (IoT): A vision. Future

Generation Computer Systems. 2013;29(7):1645–1660.
2. Mocrii D, Chen Y, Musilek P. IoT-based smart homes: A review. Internet of Things. 2018;1-2:81–98.
3. Alaa M, Zaidan AA, Zaidan BB, et al. A review of smart home applications based on IoT. Journal of Network and Computer Applications. 2017;97:48–65.
4. Mazri R, Ennafiri M. IoT adoption in developing countries. Journal of Engineering and Applied Sciences. 2020;15(1):93–105.
5. Rupasinghe L, Maduranga MWP. IoT based smart home control and monitoring system. In: Proc Int Res Symp Univ Vocational Technol. Colombo; 2021. p. 46-48.
6. Gunathilaka A, Maduranga MWP. IOT-based real-time monitoring systems to enhance workers' safety in high-rise construction projects in Sri Lanka. In: Proc 16th Int Conf Ind Inf Syst (ICIIS). 2023. p. 394-399.
7. Kang HJ. Determining the intellectual structure and academic trends of smart home health care research: Co-word and topic analyses. J Med Internet Res. 2020;22(8):e19447.
8. Oyibo K. Using smart home technologies to promote physical activity among the general and aging populations: Scoping review. J Med Internet Res. 2023;25:e43125.
9. Morita PP, Sahu KS, Oetomo A. Health monitoring using smart home technologies: Scoping review. JMIR Mhealth Uhealth. 2023;11:e44662.
10. Efendi A, Ammarullah MI, Isa IGT, Sari MP, Izza JN, Nugroho YS, Nasrullah H, Alfian D. IoT-Based Elderly Health Monitoring System Using Firebase Cloud Computing. Health Science Reports. 2025;8(3):e70498. doi:10.1002/hsr2.70498
11. Alabdali A, AlSyouf A. Factors affecting the adoption of IoT-based smart campus: An investigation using analytical hierarchical process (AHP). Sustainability. 2022;14(14):8359.
12. Shuhaiber A, Mashal I. Critical success factors influencing the behavioral intention to adopt smart home technologies. OPUS UTS. 2019;180660.
13. Lin H, Bergmann NW. IoT privacy and security challenges for smart home environments. Information. 2016;7(3):44.

14. Magara T, Zhou Y. Security and Privacy Concerns in the Adoption of IoT Smart Homes: A User-Centric Analysis. American Journal of Information Science and Technology. 2024;8(1):1-14. doi:10.11648/j.ajist.20240801.11

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EP 06

AI-Powered Tutoring Systems in Sri Lankan Secondary Education: A Study of St. Mary's College, Negombo

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Abstract

Background: The swift progression of Artificial Intelligence (AI) has profoundly altered the education sector by facilitating personalized, adaptive, and data-informed learning experiences. AI-driven tutoring systems have achieved worldwide acclaim for their capacity to assist pupils beyond conventional classroom education. However, the use of such technologies inside Sri Lankan secondary schools remains restricted, prompting a need to study the possible benefits and obstacles connected with their application.

Objective/s: This study seeks to assess student perceptions of the advantages and obstacles associated with AI-powered tutoring systems at St. Mary's College, Negombo, while analyzing the efficacy of AI-enhanced learning environments in secondary education.

Methods: The research utilized quantitative, cross-sectional, and deductive design. Data were obtained from 83 pupils of St. Mary's College, Negombo using standardized questionnaires based on a five-point Likert scale. A convenience sample strategy was employed, and the gathered data were analyzed utilizing descriptive statistics, correlation analysis, and regression analysis via SPSS software.

Results: The findings reveal that AI-powered tutoring systems positively enhance student engagement, individualized learning, academic support, and accessibility to educational resources. The study highlighted many obstacles, including inadequate technology infrastructure, low digital literacy, and worries about the practical adoption of AI technologies in educational settings. Regression analysis revealed that only chosen variables showed statistically significant connections with reported learning efficacy.

Conclusion/s: The study indicates that AI-powered tutoring systems have the potential to enhance secondary education in Sri Lanka when backed by suitable technology infrastructure, digital literacy development, and responsible deployment techniques. The findings contribute to the existing research linked to AI-powered tutoring systems inside Sri Lankan secondary education by giving empirical evidence based on student perceptions from a local school context.

Keywords: *AI in education, intelligent tutoring systems, individualized learning, secondary education, Sri Lanka*

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Introduction

Background of the Study

Artificial Intelligence (AI) has emerged as one of the most revolutionary technologies shaping modern education systems globally. AI in education refers to the use of intelligent computer systems, machine learning algorithms, and data-driven technologies to support teaching, learning, assessment, and educational management operations. Educational institutions increasingly adopt AI technologies to create more personalized, adaptive, and interactive learning environments that enhance student engagement and academic performance. Unlike traditional educational approaches, AI-powered systems may assess student learning behavior, identify academic challenges, and give customized educational help based on individual learning needs and preferences.

One of the most notable uses of AI in education is the creation of Intelligent Tutoring Systems (ITS). Intelligent tutoring systems are AI-powered educational platforms designed to simulate one-to-one tutoring experiences by providing personalized instruction, automated feedback, and adaptive learning pathways. These systems leverage technologies such as machine learning, natural language processing, and learning analytics to monitor student progress and offer suitable learning resources. AI-powered tutoring systems allow self-paced learning and continual academic aid, enabling students to get educational support both within and outside the classroom environment.

Globally, the application of AI technology in education has expanded fast in countries such as the United States, China, Singapore, and the United Kingdom. Educational institutions globally use AI-powered solutions for individualized learning, automated assessment, predictive learning analytics, virtual tutoring, and content development. The fast expansion of digital learning environments following the COVID-19 epidemic further pushed the incorporation of AI technologies into schools and higher educational institutions. AI-driven platforms like ChatGPT, adaptive learning systems, and intelligent educational applications have proved the potential of AI to improve learning experiences and educational accessibility.

Within the Sri Lankan school sector, the importance of instructional technology has expanded dramatically in recent years. Educational institutions and policymakers have acknowledged the need to upgrade teaching and learning techniques through digital transformation efforts. However, despite the expanding usage of Information and Communication Technology (ICT) inside schools, the application of advanced AI-powered tutoring systems in Sri Lankan secondary education remains limited. Many schools continue to rely largely on traditional teacher-centered teaching techniques that may not sufficiently address the different educational requirements of kids. Furthermore, constraints such as limited technological infrastructure, low digital literacy, and lack of institutional preparation continue to hamper the effective deployment of AI-based educational solutions. Therefore, researching the benefits and limitations associated with AI-powered tutoring systems within local school environments such as St. Mary's College, Negombo has become increasingly crucial in helping the future growth of secondary education in Sri Lanka.

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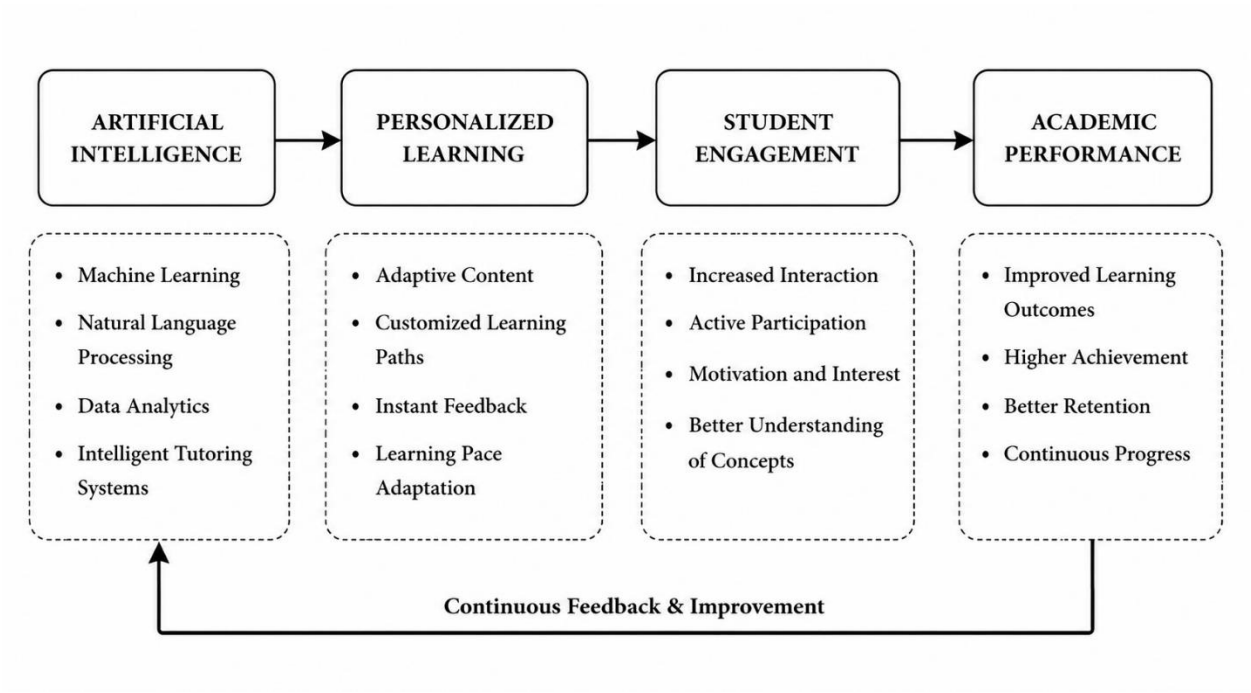

Figure 01

Research Problem

The research problem identifies the limited integration of AI-powered tutoring systems in Sri Lankan secondary schools, contrasting with their widespread global adoption. Traditional teaching practices persist, offering a one-size-fits-all training method that does not cater to individual learning styles, speeds, or interests, potentially hindering student engagement and personalized academic growth. Schools are also challenged by overcrowded classrooms, insufficient teaching resources, inadequate technology infrastructure, and varying levels of digital literacy. Additionally, issues such as ethical concerns, data privacy, resistance to technological advancements, and lack of AI training contribute to the slow adoption of AI technology. Given the global interest in AI in education, there has been insufficient research regarding its effectiveness and the barriers to implementation in Sri Lanka. This study aims to evaluate the advantages and challenges of adopting AI-powered tutoring systems at St. Mary's College in Negombo, focusing on stakeholder perspectives and the school's readiness for AI integration.

Research Aim and Objectives

The major purpose of this study is to examine student perspectives regarding the benefits and challenges of AI-powered tutoring systems at St. Mary's College, Negombo. The study focuses on assessing the effectiveness of AI technology in facilitating individualized learning and improving educational experiences within secondary education.

The aims of this investigation are:

RO1: To identify student perceptions on the educational benefits of AI-powered tutoring systems at St. Mary's College, Negombo.

RO2: To evaluate the impact of AI-powered tutoring solutions on student engagement and individualized learning experiences.

RO3: To study the obstacles affecting the effective deployment of AI-powered teaching solutions among students.

RO4: To examine the interaction between AI-powered tutoring systems and perceived learning effectiveness among students.

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RO5: To give practical recommendations for the effective and sustainable use of AI-powered tutoring solutions within secondary education.

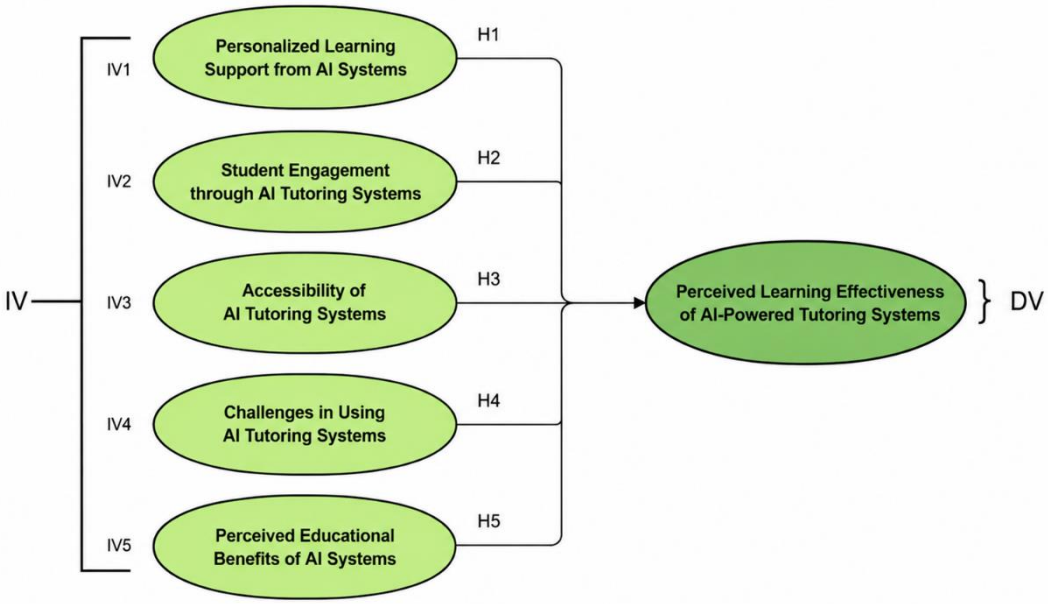

Figure 02

Research Questions

The study is guided by the following research questions:

RQ1: What are the perceived educational benefits of AI-powered tutoring systems among students at St. Mary's College, Negombo?

RQ2: What challenges affect the effective utilization of AI-powered teaching solutions among students?

RQ3: How do students view the influence of AI-powered tutoring systems on individualized learning and student engagement?

RQ4: What link exists between AI-powered tutoring systems and perceived learning effectiveness among students?

RQ5: What recommendations can promote the effective and sustainable use of AI-powered tutoring systems within secondary education?

Significance of the Study

This study is significant because it contributes to the growing body of knowledge connected to Artificial Intelligence in secondary education within the Sri Lankan environment. The research gives vital insights into how AI-powered tutoring systems may enable individualized learning, student engagement, academic support, and learning effectiveness among secondary school students. The findings may assist educational institutions better understand student perspectives on the usage of AI technologies in learning environments.

Furthermore, the study offers practical relevance for schools and educational stakeholders by identifying issues affecting the efficient implementation of AI-powered tutoring systems, including technological limits and digital literacy concerns.

The findings may enable informed decision-making related to future educational technology uptake, infrastructure development, and responsible AI application within Sri Lankan secondary education. In addition, this work contributes to the scant empirical research available on AI-powered tutoring systems inside local secondary school environments.

Research Novelty

Unlike previous studies that primarily examine AI-powered tutoring systems in higher education or technologically advanced countries, this study focuses specifically on student perceptions within a Sri Lankan secondary school context. Existing research has largely emphasized the technical capabilities and educational effectiveness of AI systems, with limited empirical evidence regarding their adoption in Sri Lankan secondary education. By investigating students' perceptions of the benefits, challenges, and learning effectiveness of AI-powered tutoring systems at St. Mary's College, Negombo, this study provides context-specific evidence from a developing country setting. The findings contribute to the growing body of knowledge on AI in education by addressing a significant geographical and educational research gap while offering practical insights for the implementation of AI-supported learning in Sri Lankan secondary schools.

Literature Review

Artificial Intelligence in Education

Artificial Intelligence (AI) has emerged as a transformative force in modern education, delivering adaptive, personalized, and data-driven learning experiences. It encompasses intelligent computer systems that facilitate tasks like automated assessment, individualized training, predictive analytics, and the generation of intelligent feedback. Educational institutions are increasingly adopting AI technology to enhance teaching effectiveness, boost student engagement, and improve academic outcomes.

AI systems can analyze student learning patterns, pinpointing academic weaknesses, and providing tailored learning resources that meet individual needs. Key technologies, including machine learning, natural language processing, and generative AI tools, have significantly enhanced online learning platforms and virtual educational environments. Additionally, AI supports educational activities through automated grading, monitoring of student performance, and data-informed decision-making.

The acceleration of digital education following the COVID-19 pandemic has further facilitated the adoption of AI in schools and universities worldwide. Nations such as the United States, China, Singapore, and the United Kingdom have rapidly integrated AI-powered educational systems to foster personalized learning and increase accessibility. Consequently, AI is increasingly perceived as an integral element of future educational growth and the digital learning revolution.

Intelligent Tutoring Systems

Intelligent Tutoring Systems (ITS) represent a pivotal application of Artificial Intelligence in education, emulating personalized tutoring experiences. These AI-driven systems provide adaptive learning support, automated feedback, and customized instructional content tailored to individual student performance and behavior. By utilizing technologies such as machine learning, natural language processing, and learning analytics, ITS identify learning gaps and deliver suitable educational resources, facilitating personalized pacing, fostering independent learning, enhancing problem-solving abilities, and developing critical thinking skills. Unlike traditional classroom instruction, ITS platforms offer continuous academic support and tailored learning experiences that encourage flexibility and accessibility in education.

Modern ITS are increasingly integrated into online educational platforms, adaptive learning programs, and virtual learning environments. Technologies like ChatGPT-based learning assistants and adaptive assessment systems are reshaping digital learning globally. As educational institutions adopt technology-enhanced learning strategies, intelligent tutoring systems emerge as a vital innovation, driving the transformation toward individualized learning environments.

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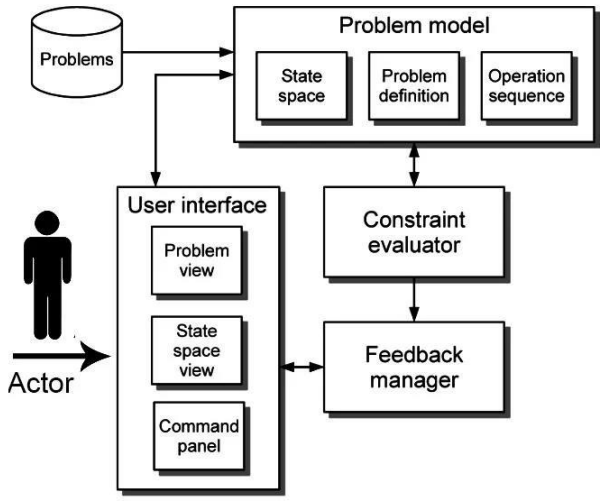

Figure 03
Benefits of AI-Powered Tutoring Systems

AI-powered tutoring systems offer significant educational benefits, primarily through individualized learning that adapts to each student's needs, enhancing both knowledge and learning efficiency (Rizvi, 2023). They also improve student engagement by creating personalized learning environments and providing immediate feedback, which keeps students motivated and actively involved in their studies (Basri, 2024). Generative AI systems further enhance learning through interactive experiences that include automated explanations and intelligent recommendations. Additionally, these systems help identify learning deficits and provide tailored support, fostering autonomous study outside traditional classroom hours. This approach offers greater flexibility, accessibility, and continuous academic assistance compared to conventional teacher-centered methods. However, much of the existing research is concentrated on higher education in developed countries, leaving a gap in understanding these benefits within Sri Lankan secondary education.

Challenges of AI Integration

Despite the educational benefits of AI-powered tutoring systems, their implementation in secondary schools faces several challenges. A primary obstacle is the limited technological infrastructure, particularly in developing countries like Sri Lanka, where issues such as poor internet access and insufficient technological resources hinder effective AI integration and equitable access to digital learning. Ethical concerns further complicate the adoption of AI, as data privacy, algorithmic bias, and the responsible use of AI raise questions about confidentiality and the ethical management of educational content. Additionally, low digital literacy among both students and educators poses a significant barrier, as the effective use of AI requires a strong understanding of technology. Many schools struggle to provide adequate training and technical support for AI usage, compounded by some educators' resistance to technological change due to fears of decreased human interaction and over-reliance on automated systems. Ultimately, while AI has substantial educational potential, successful implementation relies on robust infrastructure development, user training, ethical frameworks, and supportive institutional policies.

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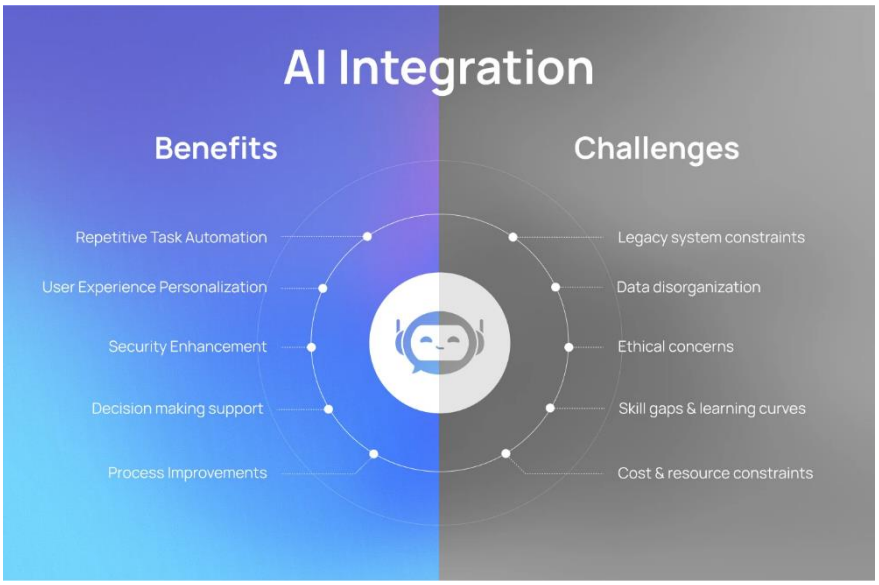

Figure 04

Stakeholder Perceptions Toward AI

Stakeholder perceptions play an essential role in influencing the effective adoption of AI-powered tutoring systems inside educational environments. Previous research suggests that students generally regard AI technology positively because they give flexible learning options, tailored educational support, and enhanced accessibility to learning resources. Positive student attitudes toward AI systems may boost engagement and participation in digital learning environments.

Although many educators understand the educational benefits of AI technology, concerns around technological dependence, limited teacher-student connection, and implementation complexity continue to impact acceptance levels. Similarly, educational stakeholders regularly underline the significance of responsible AI usage, ethical management, and sufficient institutional support when integrating AI technologies into secondary education. Therefore, understanding stakeholder views remains vital for facilitating sustainable AI adoption within educational institutions.

Theoretical Framework

The present study is underpinned by the Technology Acceptance Model (TAM) developed by Davis (1989), one of the most widely adopted theoretical models for explaining user acceptance and adoption of information technologies. TAM proposes that an individual's intention to adopt and continuously use technology is primarily influenced by two fundamental constructs: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Perceived usefulness refers to the degree to which an individual believes that using a particular technology will improve performance, while perceived ease of use refers to the degree to which a person believes that technology can be used with minimal effort. These two constructs influence users' attitudes toward technology adoption, which ultimately affect their behavioral intention and actual system usage.

In the context of AI-powered tutoring systems, TAM provides an appropriate theoretical foundation for understanding students' acceptance and satisfaction with AI-assisted learning technologies. Students are more likely to adopt AI-powered tutoring systems when they perceive that the technology enhances their learning experience, improves academic performance, and is simple to access and operate. Similarly, educational institutions are more likely to achieve successful AI implementation when students and teachers perceive these systems as both useful and user-friendly.

Although the original TAM focuses primarily on perceived usefulness and perceived ease of use, recent educational technology studies have extended the model by incorporating additional organizational and contextual factors that influence technology adoption. Consistent with these extensions, the present study examines five independent variables: Perceived Usefulness of AI-Powered Tutoring Systems, Ease of Use and Accessibility, Digital Readiness and Infrastructure, Ethical and Privacy Considerations, and Institutional Support and Training. These variables collectively represent the technological,

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organizational, and environmental factors that may influence users' acceptance of AI-powered tutoring systems within Sri Lankan secondary education.

The dependent variable of this study is Student and Teacher Satisfaction, which reflects the overall perception of the effectiveness and acceptance of AI-powered tutoring systems. Based on TAM, it is expected that positive perceptions regarding the usefulness, accessibility, institutional support, technological readiness, and ethical implementation of AI-powered tutoring systems will contribute to higher levels of satisfaction among students and teachers. Therefore, TAM provides an appropriate conceptual foundation for examining the relationships between the independent variables and overall satisfaction within the context of AI-assisted learning at St. Mary's College, Negombo.

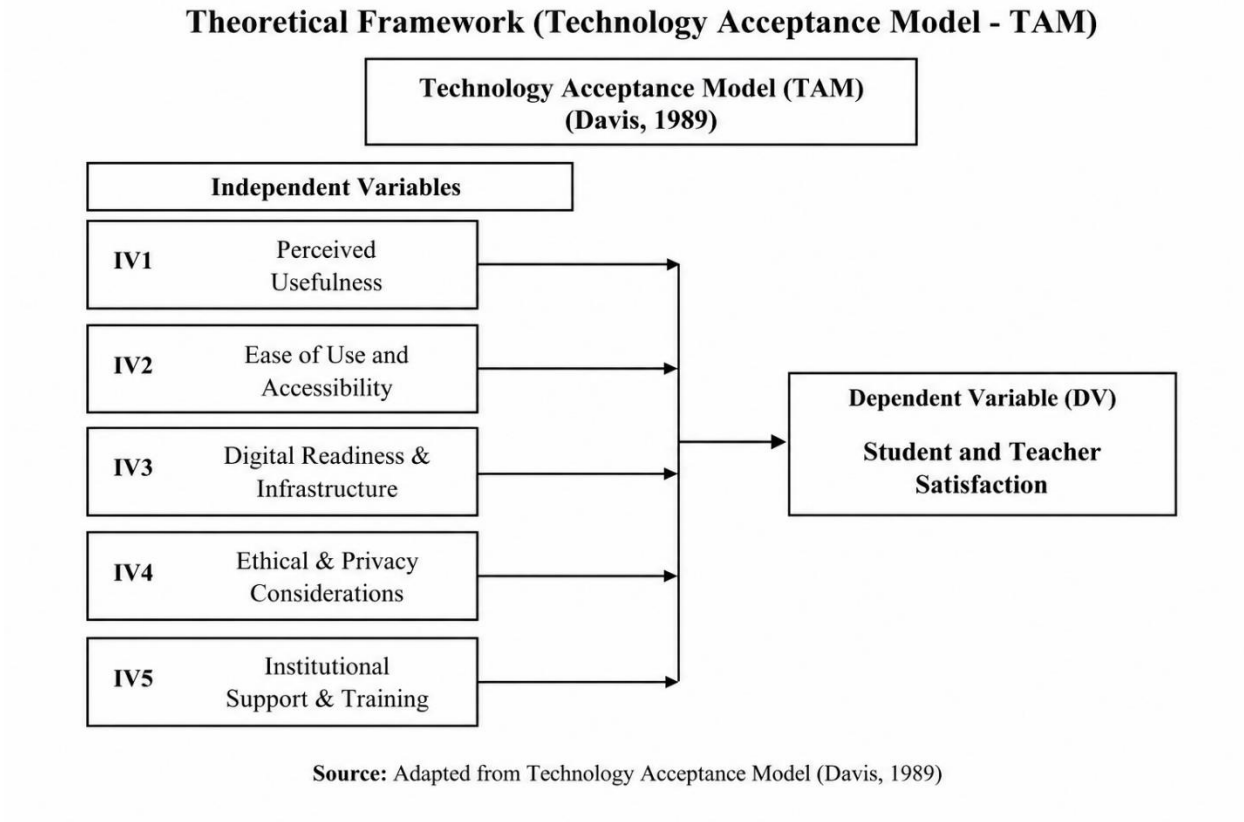

Figure 05 – theoretical Framework

Research Gap

Existing literature suggests that AI-powered tutoring systems can improve individualized learning, student engagement, and academic success. However, most previous research focuses exclusively on higher education institutions or industrialized countries where technical infrastructure and digital preparation are well advanced. Limited research has studied the application of AI-powered tutoring systems within Sri Lankan secondary schools.

Furthermore, there is little empirical evidence relating to student views, implementation issues, and learning efficacy associated with AI-powered tutoring systems in local school environments such as St. Mary's College, Negombo. Therefore, this study contributes to the small body of research related to AI integration within Sri Lankan secondary school by presenting context-specific findings based on student views and educational experiences.

Table 01

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Author	Year	Findings
Basri	2024	AI-powered tutoring systems improve student engagement, motivation, and learning outcomes.
Banjade, Patel & Pokhrel	2024	Generative AI tutoring systems support personalized learning and academic improvement.
Rizvi	2023	AI tutoring systems adapt learning materials according to individual student requirements.
Giri	1970	AI-based assessment systems transform traditional student evaluation methods.
UNESCO	2023	AI technologies improve digital learning opportunities while creating ethical and infrastructure challenges.
World Economic Forum	2022	AI integration in education supports future digital transformation and personalized learning environments.

Methods

Research Design

This study applied a quantitative research approach to examine student opinions regarding AI-powered tutoring systems inside secondary education. The quantitative method was picked because it enables the collection of measurable data and supports statistical analysis relating to student engagement, tailored learning, educational benefits, and challenges associated with AI adoption. A cross-sectional survey design was applied to collect data from participants at a specific point in time, allowing the researcher to examine current student experiences and perceptions regarding AI-powered tutoring systems at St. Mary's College, Negombo.

In addition, the study followed a deductive research approach in which current theories and past literature linked to Artificial Intelligence in education were used to generate research objectives and research questions that were later tested using quantitative data. The study focused on detecting correlations between independent variables and perceived learning efficacy linked with AI-powered tutoring systems.

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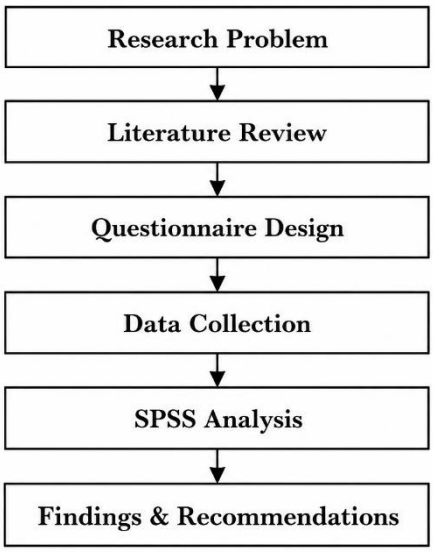

Figure 06

Population and Sample

The target demographic of this study comprised of students at St. Mary's College, Negombo, who constitute the principal users of AI-powered tutoring systems inside the school setting. Students were selected because their learning experiences, perspectives, and engagement levels are directly connected with the effectiveness of AI-based educational tools.

A convenience sample strategy was utilized since participants were selected based on accessibility and desire to engage in the research project. Data was acquired from 83 students utilizing structured questionnaires. The selected sample provided sufficient quantitative data to analyze the perceived educational benefits, implementation hurdles, and learning efficacy related with AI-powered tutoring systems within secondary education.

Data Collection Methods

Primary data for this study were collected utilizing a standardized questionnaire constructed with five-point Likert scale items ranging from "Strongly Disagree" to "Strongly Agree." The questionnaire focuses on major study areas like individualized learning, student engagement, educational benefits, accessibility, and obstacles connected with AI-powered tutoring systems.

The survey questionnaire was sent electronically through Google Forms during March 2026 to promote rapid response gathering from participants. Secondary data were acquired from academic journals, conference papers, books, and reliable scholarly sources relevant to Artificial Intelligence in education, intelligent tutoring systems, educational technology, and adaptive learning systems. These secondary sources assisted with the theoretical framework and literature review of the study.

Table 02 - Population and Sample Distribution

Participants	Count
Students	83
Total count	83

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Questionnaire Development and Validation

The questionnaire used in this study was self-developed based on the research objectives, literature review, and the Technology Acceptance Model (TAM). The questionnaire was designed to assess students' perceptions of AI-powered tutoring systems in relation to the five independent variables: Perceived Usefulness of AI-Powered Tutoring Systems, Ease of Use and Accessibility, Digital Readiness and Infrastructure, Ethical and Privacy Considerations, and Institutional Support and Training, as well as the dependent variable, Student and Teacher Satisfaction. Each construct was measured using five statements rated on a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).

To ensure the quality and appropriateness of the questionnaire, the initial draft was reviewed by the research supervisors, who evaluated the relevance, clarity, and suitability of the questionnaire items in relation to the research objectives. Based on their recommendations, several revisions were made to improve the wording, structure, and overall clarity of the questionnaire before it was distributed to participants.

A pilot test was subsequently conducted with a small group of students who were not included in the final sample. The purpose of the pilot study was to identify ambiguous or unclear questions, assess the overall flow of the questionnaire, and ensure that respondents could understand and complete the survey without difficulty. Feedback obtained during the pilot testing phase was used to refine the questionnaire prior to the main data collection process.

Construct validity was established by ensuring that each questionnaire item was directly aligned with the theoretical framework and the corresponding research objectives. The questionnaire was specifically designed to measure the intended constructs associated with students' perceptions of AI-powered tutoring systems within the Sri Lankan secondary education context. Furthermore, the internal consistency of the measurement scales was assessed using Cronbach's Alpha, with all constructs demonstrating acceptable reliability values above the recommended threshold of 0.70, confirming that the questionnaire was suitable for subsequent statistical analysis.

Data Analysis Techniques

The gathered data was analyzed using Statistical Package for Social Sciences (SPSS) software. Descriptive statistical approaches such as frequencies, percentages, means, and standard deviations were utilized to describe participant responses and demographic information. In addition, correlation analysis and regression analysis were conducted to uncover links between characteristics connected to AI-powered tutoring systems and perceived learning efficacy among students.

The statistical data supported the interpretation of research objectives and contributed in identifying the primary aspects impacting student attitudes regarding AI-powered tutoring systems inside secondary school.

Ethical Considerations

Permission to perform the research project was acquired from the administration of St. Mary’s College, Negombo prior to data collecting. Participation in the study was fully optional, and respondents were told about the goal of the research before completing the questionnaire. Participant anonymity and confidentiality were maintained throughout the research procedure, and all obtained data were used purely for academic purposes only.

Results And Discussion

Demographic Analysis

The demographic analysis was conducted to establish the background characteristics of the participants who participated in the study. A total of 83 student replies were obtained from St. Mary’s College, Negombo. Since St. Mary’s College is a boys’ school, all responders were male students. The demographic data comprised grade level, gender, and age category of the participants.

Most participants represented multiple secondary education grade levels, allowing the study to collect diverse student viewpoints regarding AI-powered tutoring systems. The age distribution is mostly comprised of middle and upper secondary school pupils, indicating the target group connected with technology-enhanced learning environments. The demographic

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data indicates that the selected sample suitably represents the student population relevant to the implementation of AI-powered tutoring systems within the designated school context.

Statistics

		Grade level	Gender	Age
N	Valid	83	83	83
	Missing	0	0	0

Figure - 07

Grade

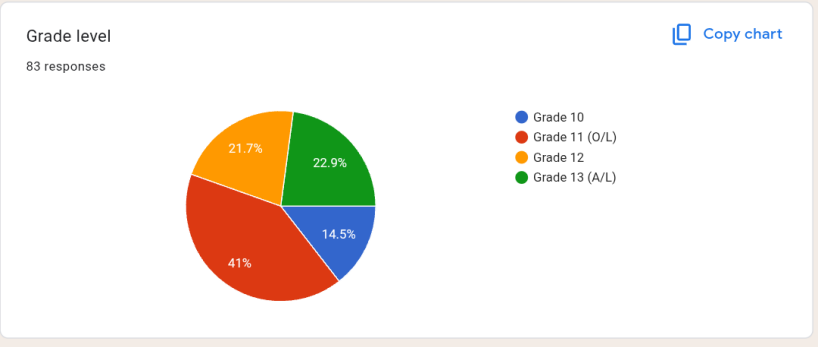

Figure - 08

Gender

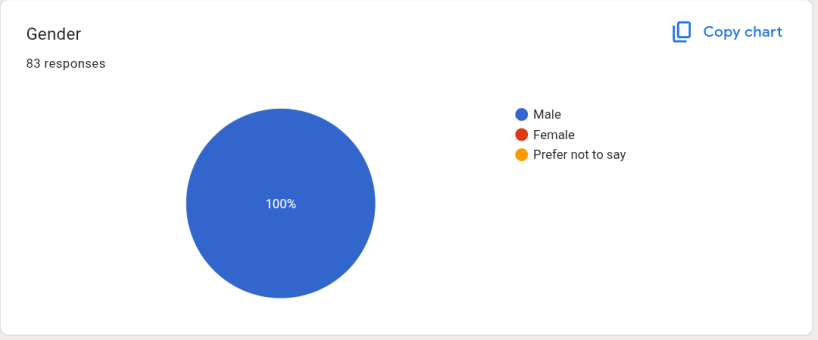

Figure - 09

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Age

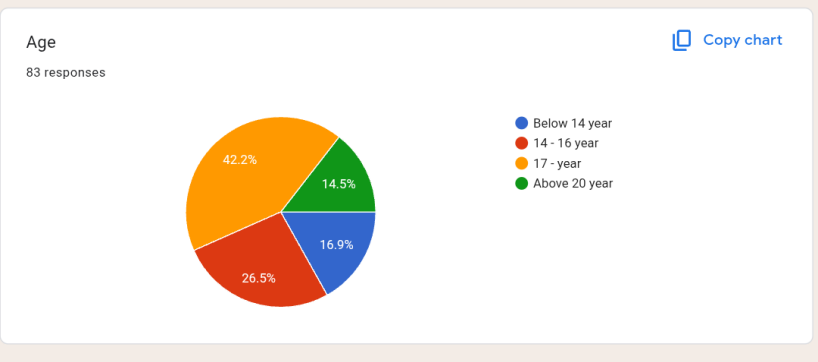

Figure - 10

Descriptive Statistics

Descriptive statistical analysis was undertaken to summarize participant responses pertaining to AI-powered teaching systems. Statistical variables such as frequencies, percentages, means, medians, and standard deviations were utilized to examine student views regarding learning efficacy and AI-supported educational experiences.

The descriptive findings reveal that most students demonstrated good perceptions toward AI-powered teaching solutions. The mean value of the dependent variable was 3.93 with a standard deviation of 1.07, showing a generally good response toward AI-supported learning effectiveness. The frequency distribution further demonstrated that most participants selected higher response categories, suggesting positive attitudes toward AI-powered educational systems.

However, numerous participants also voiced concerns pertaining to technological constraints and practical implementation issues. These findings imply that although students typically perceive the educational advantages of AI-powered tutoring systems, their adoption may still depend on technological readiness and accessibility.

Descriptive Statistics

	N	Minimum	Mean	Std. Deviation
DV	83	2.00	3.9337	1.07854
Valid N (listwise)	83			

Figure - 11

Statistics

DV		
N	Valid	83
	Missing	1
Median		3.5000

Figure 12

DV

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2.00	10	11.9	12.0	12.0

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	3.00	12	14.3	14.5	26.5
	3.50	23	27.4	27.7	54.2
	5.00	38	45.2	45.8	100.0
	Total	83	98.8	100.0	
Missing	System	1	1.2		
Total		84	100.0		

Figure 13

Reliability Analysis

Reliability study was undertaken using Cronbach's Alpha to examine the internal consistency of the questionnaire constructs. The results demonstrated appropriate reliability values for the variables employed in the study, suggesting that the questionnaire items were sufficiently consistent for statistical analysis.

Table 03 – Cronbach's Alpha

Variable	**Cronbach's Alpha**
Perceived Usefulness of AI-Powered Tutoring Systems (IV1)	0.76
Ease of Use and Accessibility (IV2)	0.81
Digital Readiness and Infrastructure (IV3)	0.74
Ethical and Privacy Considerations (IV4)	0.72
Institutional Support and Training (IV5)	0.85
Student and Teacher Satisfaction (DV)	0.88

Correlation Analysis

Correlation analysis was conducted to detect links between the independent variables and perceived learning efficacy related with AI-powered tutoring systems. The results revealed several positive correlations between the research variables and the dependent variable.

The strongest positive link was discovered between IV5 and the dependent variable ($r = .971$, $p < 0.01$), demonstrating a very high association between perceived educational benefits and learning effectiveness. Similarly, IV2 revealed a substantial positive connection with the dependent variable ($r = .838$, $p < 0.01$). Moderate positive associations were also discovered between IV3, IV4, and the dependent variable. However, IV1 revealed a weaker and statistically non-significant connection with the dependent variable ($r = .211$, $p = .056$). These findings imply that not all independent variables contribute equally toward perceived learning efficacy associated with AI-powered tutoring systems. The high correlation values obtained among numerous variables may imply overlapping questionnaire constructs or insufficient concept separation between specific dimensions examined in the study.

Table 04 - Correlations

		IV1	IV2	IV3	IV4	IV5	DV
IV1 (Perceived Usefulness of AI-Powered Tutoring Systems)	Pearson Correlation	1	.418**	.734**	.563**	.231*	.211
	Sig. (2-tailed)		.000	.000	.000	.036	.056
	N	83	83	83	83	83	83
IV2 (Ease of Use and Accessibility)	Pearson Correlation	.418**	1	.866**	.634**	.754**	.838**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
	N	83	83	83	83	83	83

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IV3 (Digital Readiness and Infrastructure)	Pearson Correlation	.734**	.866**	1	.791**	.571**	.620**
	Sig. (2-tailed)	.000	.000		.000	.000	.000
	N	83	83	83	83	83	83
IV4 (Ethical and Privacy Considerations)	Pearson Correlation	.563**	.634**	.791**	1	.730**	.678**
	Sig. (2-tailed)	.000	.000	.000		.000	.000
	N	83	83	83	83	83	83
IV5 (Institutional Support and Training)	Pearson Correlation	.231*	.754**	.571**	.730**	1	.971**
	Sig. (2-tailed)	.036	.000	.000	.000		.000
	N	83	83	83	83	83	83
DV (Student and Teacher Satisfaction)	Pearson Correlation	.211	.838**	.620**	.678**	.971**	1
	Sig. (2-tailed)	.056	.000	.000	.000	.000	
	N	83	83	83	83	83	83

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

4.4 *Regression Analysis*

Regression analysis was undertaken to assess the impact of the independent variables on perceived learning efficacy associated with AI-powered tutoring systems. The regression model gave an R-square value of .977, indicating that the independent variables explained a high fraction of variation in the dependent variable.

However, the coefficient analysis revealed that only IV2 and IV5 demonstrated statistically significant correlations with the dependent variable because their significance values were below 0.05. IV2 had a substantial beneficial effect on perceived learning efficacy (p = .006), whereas IV5 demonstrated the highest statistically significant effects (p = .000). In contrast, IV1, IV3, and IV4 did not reveal statistically significant correlations with the dependent variable because their p-values above the 0.05 significance threshold. These findings imply that some characteristics of AI-powered tutoring systems influence student learning perceptions more strongly than others. The exceptionally high R-square value and strong correlations between numerous factors may signal possible overlap between questionnaire constructs or multicollinearity among certain independent variables.

Model	Variables Entered	Variables Removed	Method
1	IV5(Institutional Support and Training), IV1(Perceived Usefulness of AI-Powered Tutoring Systems), IV2(Ease of Use and Accessibility), IV4(Ethical and Privacy Considerations), IV3[b] (Digital Readiness and Infrastructure)	.	Enter

a. Dependent Variable: DV
b. All requested variables entered.

Figure 14 - Variables Entered/Removed

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Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.989[a]	.977	.976	.16735

a. Predictors: (Constant), IV5, IV1, IV2, IV4, IV3

Figure 15 – Model Summary

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	93.229	5	18.646	665.810	.000[b]
	Residual	2.156	77	.028		
	Total	95.386	82			

a. Dependent Variable: DV

b. Predictors: (Constant), IV5, IV1, IV2, IV4, IV3

Figure 16 – Anova Table

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.670	.087		7.711	.000
	IV1 (Perceived Usefulness of AI-Powered Tutoring Systems)	-.058	.044	-.055	-1.323	.190
	IV2 (Ease of Use and Accessibility)	.313	.111	.317	2.830	.006
	IV3 (Digital Readiness and Infrastructure)	-.030	.139	-.030	-.219	.827
	IV4 (Ethical and Privacy Considerations)	-.040	.053	-.053	-.751	.455
	IV5 (Institutional Support and Training)	.670	.055	.801	12.217	.000

a. Dependent Variable: DV

Figure 17 - Coefficients

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Multicollinearity Analysis

Multicollinearity testing was conducted using Variance Inflation Factor (VIF) and tolerance values to assess whether strong correlations existed among the independent variables. The results demonstrated that all tolerance values were above 0.1 and VIF values were below the permissible threshold of 10, showing that multicollinearity was not severe inside the regression model.

Table - 05

Variable	Tolerance	VIF
Perceived Usefulness of AI-Powered Tutoring Systems (IV1)	0.412	2.427
Ease of Use and Accessibility (IV2)	0.365	2.739
Digital Readiness and Infrastructure (IV3)	0.291	3.436
Ethical and Privacy Considerations (IV4)	0.338	2.958
Institutional Support and Training (IV5)	0.401	2.494

Discussion of Findings

The findings of this study indicate that students generally hold positive perceptions regarding the use of AI-powered tutoring systems in secondary education. The descriptive analysis demonstrated favorable responses toward AI-assisted learning, suggesting that students recognize the potential of AI technologies to improve learning experiences through personalized instruction, greater accessibility, and continuous academic support. These findings are consistent with Basri (2024), who reported that AI-powered tutoring systems significantly improve student engagement, motivation, and learning outcomes, and with Rizvi (2023), who found that AI-driven tutoring systems effectively adapt learning materials to individual student needs. Together, these studies support the growing role of AI in enhancing educational experiences and promoting student-centered learning.

The correlation analysis revealed positive relationships between the independent variables and Student and Teacher Satisfaction, although the strength of these relationships varied across the constructs. Institutional Support and Training (IV5) demonstrated the strongest positive correlation with the dependent variable ($r = 0.971$), while Ease of Use and Accessibility (IV2) also showed a strong positive relationship. These findings suggest that students are more likely to perceive AI-powered tutoring systems positively when schools provide adequate institutional support, sufficient training opportunities, and learning platforms that are easy to access and operate. This observation aligns with the Technology Acceptance Model (TAM), which proposes that users are more likely to accept and continue using technology when they perceive it as useful and easy to use. Institutional support further strengthens these perceptions by providing the necessary resources and confidence required for successful technology adoption.

The regression analysis provided a more detailed understanding of the factors influencing Student and Teacher Satisfaction. Although several variables demonstrated positive correlations with the dependent variable, only Ease of Use and Accessibility (IV2) and Institutional Support and Training (IV5) remained statistically significant predictors in the regression model. This indicates that while students appreciate the educational benefits, digital readiness, and ethical considerations associated with AI-powered tutoring systems, these factors alone do not independently predict satisfaction when all variables are considered simultaneously. Instead, the practical usability of AI systems and the level of institutional commitment appear to have the greatest influence on students' overall satisfaction. These findings are consistent with previous educational technology studies, which emphasize that facilitating conditions, technical support, and user-friendly system design are critical determinants of successful AI adoption in educational environments.

The exceptionally high correlation between Institutional Support and Training (IV5) and Student and Teacher Satisfaction, together with the high coefficient of determination ($R^2 = 0.977$), indicates that the regression model explains a substantial proportion of the variance in the dependent variable. While these results demonstrate a strong statistical relationship, they should be interpreted with appropriate caution. The high values may partially reflect similarities among questionnaire items,

the use of a single self-reported survey instrument, and the relatively homogeneous sample obtained from one secondary school. These factors may contribute to construct overlaps and common method bias, potentially increasing the observed relationships between variables. Future research employing more diverse samples and additional validation techniques would help confirm the robustness of these findings.

From a practical perspective, the findings suggest several important implications for educational stakeholders. Schools should invest in reliable digital infrastructure and provide continuous training to both teachers and students to facilitate the effective integration of AI-powered tutoring systems. Teachers should utilize AI technologies as complementary instructional tools that support individualized learning rather than replacing traditional classroom teaching. Education authorities and policymakers should develop comprehensive guidelines governing the ethical implementation of AI in schools while ensuring adequate funding for technological resources and digital literacy initiatives. Curriculum developers should also consider incorporating AI literacy into secondary education to prepare students for future digital learning environments.

Overall, the findings demonstrate that AI-powered tutoring systems have considerable potential to improve secondary education in Sri Lanka. However, their successful implementation depends not only on the availability of AI technologies but also on institutional readiness, user-friendly system design, continuous training, and responsible educational policies. These findings reinforce the principles of the Technology Acceptance Model (TAM) by highlighting the importance of perceived usefulness, ease of use, and organizational support in influencing students' acceptance and satisfaction with AI-assisted learning.

Conclusion

Summary of Findings

This study explored student opinions regarding the benefits and challenges connected with AI-powered tutoring systems inside secondary education at St. Mary's College, Negombo. The findings reveal that AI-powered tutoring systems positively enhance student engagement, tailored learning experiences, academic support, and accessibility to educational resources. Most students expressed good attitudes about AI-supported learning environments and acknowledged the potential of AI technologies to facilitate flexible and independent learning activities.

The statistical study indicated favorable connections between various independent factors and perceived learning efficacy. In instance, student involvement and perceived educational gains exhibited statistically significant associations with the dependent variable. However, certain factors did not reveal statistically significant impacts within the regression analysis, indicating that not all aspects equally influence perceived learning efficacy.

The study also found various implementation problems relating to technological infrastructure, digital literacy, and practical integration of AI technology inside school environments. Overall, the findings imply that AI-powered tutoring systems have tremendous potential to improve secondary education in Sri Lanka when applied with sufficient technological resources, institutional support, and acceptable pedagogical practices.

Recommendations

Based on the outcomes of the study, numerous recommendations are offered to facilitate the proper application of AI-powered tutoring systems inside secondary school. Schools should upgrade technological infrastructure, internet connectivity, and digital learning facilities to promote AI incorporation inside classroom environments.

Educational institutions should also conduct AI-related awareness programs and digital literacy training for students to promote technological readiness and effective system utilization. In addition, schools should adopt responsible AI usage rules relating to educational ethics, data protection, and appropriate use of AI technologies inside learning activities.

Pilot implementation programs, ongoing monitoring, and regular evaluation methods are also proposed to enable sustainable and effective adoption of AI-powered tutoring systems inside Sri Lankan secondary schools.

Limitations

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This study has several limitations that should be considered when interpreting the findings. First, the research was conducted using a sample of 83 students from St. Mary's College, Negombo, which is a single boys' secondary school in Sri Lanka. Consequently, the findings may not be fully representative of students from other schools, mixed-gender institutions, or different geographical regions within the country. Therefore, caution should be exercised when generalizing the results to the broader Sri Lankan secondary education context.

Second, the study employed convenience sampling, which may have introduced selection bias because participants were selected based on their availability and willingness to participate rather than through random sampling. As a result, the sample may not fully represent the characteristics and perceptions of the wider student population.

Third, the study relied on self-reported questionnaire responses, which may be influenced by response bias, social desirability bias, or participants' personal perceptions. Although measures were taken to ensure anonymity and encourage honest responses, self-reported data may not always accurately reflect actual behaviour or experiences with AI-powered tutoring systems.

Finally, the research adopted a cross-sectional quantitative research design, collecting data at a single point in time. While this approach provides valuable insights into students' perceptions, it does not capture changes in attitudes or experiences over time. Longitudinal studies would provide a better understanding of how perceptions of AI-powered tutoring systems evolve as students gain greater exposure to these technologies.

Despite these limitations, the study provides valuable empirical evidence regarding students' perceptions of AI-powered tutoring systems within the Sri Lankan secondary education context. The findings contribute to the existing body of knowledge and provide a foundation for future research on the implementation of AI-assisted learning in schools.

Future Research

Future research should extend this study by including a larger and more diverse sample of students from multiple secondary schools across different provinces of Sri Lanka. Expanding the geographical coverage and including both government and private schools, as well as mixed-gender institutions, would improve the generalizability of the findings and provide a more comprehensive understanding of students' perceptions of AI-powered tutoring systems within the Sri Lankan education sector.

Future studies should also adopt longitudinal research designs to examine how students' perceptions, acceptance, and satisfaction with AI-powered tutoring systems change over time as they gain greater experience with AI-assisted learning technologies. Such studies would provide valuable insights into the long-term effectiveness and sustainability of AI integration in secondary education.

In addition, future researchers should investigate the perspectives of teachers, school administrators, parents, and education policymakers, as these stakeholders play a critical role in the successful implementation and management of AI-powered tutoring systems. Including multiple stakeholder perspectives would provide a more comprehensive evaluation of the opportunities and challenges associated with AI adoption in schools.

Furthermore, future studies should evaluate the actual implementation of AI-powered tutoring systems within classroom environments rather than focusing solely on users' perceptions. Experimental or quasi-experimental research designs could be employed to compare learning outcomes between students using AI-powered tutoring systems and those receiving traditional classroom instruction. This would provide stronger evidence regarding the educational effectiveness of AI-assisted learning.

Future research may also incorporate objective academic performance indicators, such as examination results, assignment scores, learning analytics, and student progression data, to complement self-reported perceptions. Combining these objective measures with questionnaire responses would provide a more comprehensive assessment of the educational impact of AI-powered tutoring systems.

Finally, future researchers are encouraged to adopt mixed-method research approaches by combining quantitative surveys with qualitative interviews, focus group discussions, or classroom observations. This approach would enable a deeper

understanding of students' experiences, implementation challenges, user expectations, and contextual factors influencing the successful adoption of AI-powered tutoring systems in Sri Lankan secondary education.

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References

Ahmad, N. and Khan, R. (2022) 'Artificial intelligence in modern education systems', *International Journal of Educational Development*, 44(3), pp. 55–68.

Banjade, R., Patel, S. and Pokhrel, A. (2024) 'Empowering education by developing and evaluating generative AI-powered tutoring systems for improved student learning', *International Journal of Artificial Intelligence in Education*, 15(1), pp. 77–92.

Basri, W. (2024) 'The effectiveness of AI-powered tutoring systems in enhancing learning outcomes', *Journal of Educational Technology and Artificial Intelligence*, 12(3), pp. 45–58.

Brown, T. and Wilson, P. (2021) 'Adaptive learning technologies and personalized education', *Computers and Education*, 98(4), pp. 120–134.

Chen, X., Li, H. and Zhao, Y. (2023) 'Machine learning applications in intelligent tutoring systems', *Journal of Artificial Intelligence Research*, 65(1), pp. 88–104.

Fernando, S. and Perera, M. (2022) 'Digital transformation in Sri Lankan secondary education', *Sri Lankan Journal of Educational Research*, 10(2), pp. 44–59.

Johnson, R. (2020) 'Educational technology and student engagement', *Educational Technology Review*, 32(1), pp. 12–25.

Kumar, A. and Silva, D. (2021) 'Challenges affecting AI integration in developing countries', *International Journal of Technology in Education*, 14(2), pp. 67–81.

Lee, J. and Kim, S. (2022) 'Ethical considerations in AI-powered educational systems', *Journal of Digital Ethics in Education*, 7(1), pp. 90–105.

Perera, K. and Jayasinghe, H. (2023) 'Student perceptions toward AI-based learning platforms in Sri Lanka', *Asian Journal of Educational Technology*, 9(3), pp. 66–79.

Rizvi, M. (2023) 'Investigating AI-based tutoring systems that adapt to the requirements of each student, providing customized instruction and evaluations', *Eurasia Proceedings of Educational and Social Sciences*, 18(2), pp. 101–110.

Sharma, P. and Gupta, V. (2021) 'Impact of intelligent tutoring systems on academic performance', *International Journal of Smart Learning Environments*, 11(4), pp. 140–156.

Singh, R. and Kaur, M. (2020) 'Artificial intelligence and future classroom transformation', *Education and Information Technologies*, 25(6), pp. 5123–5140.

UNESCO (2023) *Artificial Intelligence and Education: Guidance for Policy Makers*. Paris: UNESCO Publishing.

World Economic Forum (2022) *The Future of AI in Education and Learning Systems*. Geneva: World Economic Forum.

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EP 07

HappyAgile+: A Human-Centred Behaviour-Aware Agile Governance Framework for Improving Developer Well-Being and Sustainable Software Delivery

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Abstract

Background: Agile software development methodologies such as Scrum, Kanban, SAFe, and DevOps have significantly improved software delivery through iterative development, collaboration, and continuous integration. However, existing Agile governance models primarily evaluate project success using delivery-oriented metrics, including sprint velocity, throughput, and cycle time, while giving limited consideration to developer well-being, psychological safety, stress, and long-term behavioural sustainability. Increasing evidence indicates that developer well-being directly influences software quality, innovation, productivity, and organisational resilience. Despite this, current Agile frameworks lack structured mechanisms for integrating behavioural insights into sprint planning and governance decisions.

Objectives: This study aims to investigate the behavioural and emotional challenges experienced by software professionals working within Agile environments and to propose HappyAgile+, a human-centred behaviour-aware Agile governance framework that integrates behavioural awareness into Agile project management to support sustainable software delivery and developer well-being.

Methods: An exploratory cross-sectional quantitative study was conducted using a structured questionnaire distributed among software professionals employed in Agile-based organisations. The questionnaire measured perceptions relating to workload pressure, burnout, psychological safety, work satisfaction, communication, and organisational support using a five-point Likert scale. A total of 900 valid responses were analysed using descriptive statistics, Cronbach's Alpha reliability analysis, Pearson correlation analysis, and thematic interpretation of qualitative responses. The empirical findings informed the design of the proposed HappyAgile+ framework.

Results: The findings revealed that software professionals experience considerable workload pressure, stress, emotional exhaustion, and burnout within Agile environments. Participants strongly agreed that existing Agile practices emphasise delivery performance while providing insufficient support for behavioural sustainability and psychological well-being. Reliability analysis demonstrated excellent internal consistency (Cronbach's Alpha = 0.938), while correlation analysis identified strong positive relationships between sprint-related stress, mental exhaustion, and burnout. These findings establish a strong empirical basis for integrating behavioural indicators into Agile governance.

Conclusions: This study proposes HappyAgile+, a human-centred behaviour-aware Agile governance framework that extends traditional Agile practices by incorporating behavioural assessment into project governance. The framework introduces behavioural awareness as a strategic decision-support mechanism for improving developer well-being, organisational sustainability, and software delivery performance. While the framework has progressed to prototype development, future research will focus on longitudinal industrial evaluation to assess its practical effectiveness within real-world Agile software development environments.

Keywords: *Behaviour-aware Agile, Developer well-being, Human-centred software engineering, Agile governance, Behavioural analytics, Sustainable software delivery, Happiness Index*

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Introduction

Agile software development methodologies have fundamentally transformed modern software engineering by enabling iterative development, continuous integration, rapid adaptation to changing requirements, and enhanced collaboration among cross-functional teams. Frameworks such as Scrum, Kanban, the Scaled Agile Framework (SAFe), and DevOps have become the dominant software development approaches adopted by organisations seeking to improve software quality, customer responsiveness, delivery speed, and organisational agility. These methodologies primarily evaluate project performance using operational metrics such as sprint velocity, throughput, lead time, cycle time, and defect rates. Although these measures effectively assess delivery performance, they provide limited visibility into the behavioural and psychological conditions of software development teams that ultimately influence sustainable project success.

Growing evidence within software engineering research indicates that developer well-being has become a critical organisational factor influencing software quality, innovation capability, productivity, collaboration, employee retention, and long-term business sustainability. Increasing workload pressure, compressed sprint schedules, continuous delivery expectations, excessive overtime, and insufficient organisational support have contributed to rising levels of occupational stress, emotional exhaustion, burnout, and reduced work satisfaction among software professionals. Organisations that fail to address these behavioural challenges often experience declining motivation, lower collaboration quality, increased staff turnover, and reduced software delivery performance.

Recent empirical studies further demonstrate that psychological well-being significantly affects software engineering outcomes. (Godliauskas, Povilas & Smite, Darja., 2024) identified developer well-being as a multidimensional construct that directly influences both individual performance and organisational sustainability. (Kennedy, S. I., Zadeh, A. A., Choi, J., & Alborz, S., 2024) reported that psychologically safe Agile teams demonstrate stronger collaboration, higher productivity, and improved project outcomes. Similarly, (Riedl, René & Oettl, Christian & Stangl, Fabian & Hevner, Alan., 2025) showed that workload balance and organisational psychological support positively influence software developer job satisfaction, while (Wong, N., Jackson, V., & van der Hoek, A., 2023) highlighted the importance of maintaining mental well-being to sustain long-term innovation and software quality.

Despite these findings, existing Agile methodologies remain predominantly process-oriented. Scrum primarily focuses on iterative sprint management and incremental product delivery, Kanban emphasises workflow optimisation and continuous flow, SAFe provides governance mechanisms for large-scale enterprise Agile transformation, and DevOps strengthens collaboration between development and operations through automation and continuous integration. Although these methodologies encourage communication, collaboration, and continuous improvement, they provide limited mechanisms for systematically measuring developer well-being or incorporating behavioural information into project governance and sprint-level decision-making. Behavioural indicators such as stress, workload imbalance, psychological safety, motivation, emotional fatigue, and work satisfaction are typically addressed reactively after they have already affected software delivery or organisational performance.

Consequently, an important research gap remains within contemporary Agile software engineering. Existing research has extensively investigated behavioural challenges including stress, burnout, and psychological well-being; however, limited research proposes operational governance frameworks capable of transforming behavioural observations into adaptive Agile management decisions. Furthermore, few studies integrate behavioural assessment directly into Agile governance while maintaining compatibility with existing Agile methodologies and organisational workflows.

To validate the existence of these behavioural challenges within contemporary Agile environments, this study conducted a large-scale industry validation survey involving 900 software professionals representing diverse Agile roles, including software engineers, senior software engineers, quality assurance engineers, DevOps engineers, Scrum Masters, business analysts, project managers, technical leads, and UI/UX engineers. The empirical findings confirmed that software professionals experience significant workload pressure, emotional exhaustion, burnout, and insufficient organisational support for behavioural well-being, thereby establishing a strong evidence base for introducing behaviour-aware Agile governance mechanisms.

To address this research gap, this study proposes HappyAgile+, a human-centred behaviour-aware Agile governance framework designed to integrate behavioural awareness into Agile project management. Unlike conventional Agile frameworks that primarily rely on delivery-oriented performance metrics, HappyAgile+ introduces behavioural assessment as an additional governance dimension that supports evidence-based sprint planning, workload balancing, team

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communication, resource allocation, and organisational decision-making. Rather than replacing existing Agile methodologies, the framework extends Scrum, Kanban, SAFe, and DevOps by incorporating developer well-being into routine governance processes while preserving established Agile principles and practices.

The proposed framework additionally establishes the conceptual foundation for an intelligent software platform currently under development that incorporates behavioural check-ins, a Happiness Index, adaptive recommendation mechanisms, behavioural analytics, and decision-support capabilities to assist Agile teams in maintaining sustainable software delivery. Although industrial evaluation remains ongoing within the broader research project, the present study reports the empirical validation that informed the design of the framework.

The objectives of this study are to,

Investigate the behavioural and emotional challenges experienced by software professionals working within Agile software development environments.

Analyse the relationship between behavioural factors and sustainable software delivery.

Propose HappyAgile+, a human-centred behaviour-aware Agile governance framework that integrates behavioural awareness into Agile project management.

This study contributes to the emerging field of human-centred software engineering by introducing a behaviour-aware Agile governance framework that positions developer well-being as a measurable organisational factor influencing software delivery performance and long-term organisational sustainability.

Overview of the HappyAgile+ Framework

HappyAgile+ is proposed as a human-centred behaviour-aware Agile governance framework designed to extend traditional Agile software development by incorporating behavioural intelligence into project governance and sprint management. Unlike conventional Agile methodologies that primarily evaluate delivery performance using technical metrics such as sprint velocity, throughput, lead time, and cycle time, HappyAgile+ introduces developer well-being as an additional governance dimension supporting sustainable software delivery.

The framework is founded on the principle that software development performance depends not only on technical capability but also on the behavioural and psychological conditions of development teams. Research has consistently demonstrated that stress, burnout, psychological safety, motivation, and work satisfaction influence collaboration, creativity, software quality, productivity, and organisational resilience. HappyAgile+ therefore considers developer well-being as a measurable organisational asset that should be continuously monitored and incorporated into Agile decision-making processes.

The proposed framework integrates behavioural information into existing Agile workflows through a continuous feedback mechanism that complements rather than replaces established Agile practices. Behavioural insights collected from development teams are transformed into actionable governance recommendations that assist Scrum Masters, project managers, and organisational leaders in making evidence-based decisions relating to workload balancing, sprint planning, team communication, resource allocation, and developer support.

HappyAgile+ consists of four interconnected governance layers that operate as a continuous improvement cycle.

1. Behavioural Awareness Layer

This layer captures behavioural information relating to developer well-being through periodic behavioural assessments and developer check-ins. Behavioural indicators include workload balance, stress, emotional exhaustion, motivation, psychological safety, work satisfaction, communication effectiveness, and perceived organisational support.

2. Well-Being Assessment Layer

The collected behavioural information is analysed to determine the overall behavioural condition of Agile teams. Within the broader HappyAgile+ platform, these indicators contribute to the calculation of a Happiness Index (HI), enabling behavioural trends to be monitored throughout sprint cycles and supporting early identification of behavioural risks.

3. Adaptive Agile Governance Layer

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Behavioural insights generated through the assessment process support adaptive governance decisions during Agile project management. Project leaders can incorporate behavioural information when planning sprint workloads, balancing task assignments, scheduling team discussions, allocating resources, and managing project risks. Behavioural intelligence therefore complements traditional delivery metrics during sprint planning and governance activities.

4. Sustainable Delivery Layer

The final layer focuses on achieving sustainable software delivery by improving both human and organisational outcomes. Through continuous behavioural monitoring and adaptive governance, HappyAgile+ aims to reduce burnout, improve psychological safety, strengthen collaboration, enhance motivation, increase work satisfaction, and support sustainable software delivery performance.

The four governance layers operate as an iterative feedback cycle in which behavioural observations continuously inform Agile management decisions. Rather than replacing existing Agile methodologies, HappyAgile+ extends Scrum, Kanban, SAFe, and DevOps by introducing a structured human-centred governance mechanism capable of supporting long-term organisational sustainability.

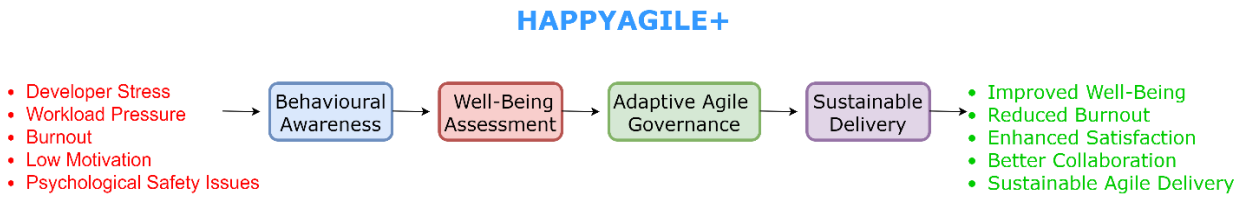

Figure 1: Conceptual Structure of the HappyAgile+ Framework (Author Developed)

Methods

Research Design

This study adopted a pragmatic research philosophy to investigate behavioural challenges within Agile software development environments and to develop a practical governance framework capable of supporting sustainable software delivery. Pragmatism was selected because the research seeks to address a real-world organisational problem by integrating empirical evidence with established software engineering principles to produce an applicable solution for Agile project management.

The present study employed an exploratory cross-sectional quantitative research design using a structured questionnaire to investigate behavioural and emotional experiences among software professionals working in Agile environments. The findings obtained from this industry validation study provided the empirical foundation for the design of the proposed HappyAgile+ behaviour-aware Agile governance framework.

The broader MSc research adopts a mixed-methods Action Research methodology for implementing and evaluating the HappyAgile+ platform within real software development teams over multiple sprint cycles. However, this paper reports only the findings of the initial empirical investigation that informed the framework design.

Study Setting

The study was conducted among software professionals employed in organisations adopting Agile software development methodologies, including Scrum, Kanban, SAFe, DevOps, and hybrid Agile environments. These organisations represented diverse software development contexts where iterative development, sprint-based delivery, continuous integration, and collaborative project management practices are routinely employed.

The study focused on understanding behavioural and psychological challenges experienced during software development activities rather than evaluating organisational performance within a single company. Consequently, participants represented multiple software organisations, thereby increasing the diversity of behavioural experiences captured within the study.

Target Population

The target population comprised software professionals actively involved in Agile software development projects. Participants represented multiple technical and managerial roles across the software development lifecycle, including,

- Software Engineers
- Senior Software Engineers
- Quality Assurance Engineers
- DevOps Engineers
- Business Analysts
- Scrum Masters
- Project Managers
- Technical Leads
- UI/UX Engineers

A total of 900 valid responses were included in the final statistical analysis.

Sampling Strategy

A non-probability purposive sampling strategy was adopted because the research specifically required participants possessing practical experience within Agile software development environments.

Participants were recruited through professional software engineering communities, Agile practitioner networks, LinkedIn professional groups, software organisations, university alumni networks, and online technology communities. These recruitment channels enabled the study to capture responses from professionals working across diverse Agile environments and organisational contexts.

Participation was entirely voluntary, and no financial incentives were offered.

Inclusion and Exclusion Criteria

To ensure the relevance and reliability of the collected data, predefined eligibility criteria were established.

Inclusion Criteria

Participants were required to satisfy all the following conditions,

- Currently employed within the software industry.
- Experience working in Agile software development projects.
- Participation in Scrum, Kanban, SAFe, DevOps, or hybrid Agile environments.
- Aged 18 years or above.
- Willingness to provide informed consent prior to participation.

Exclusion Criteria

The following responses were excluded from analysis,

- Participants without professional software industry experience.
- Undergraduate students without industrial exposure.
- Duplicate questionnaire submissions.
- Incomplete questionnaires containing substantial missing data.
- Responses that did not satisfy the inclusion criteria.

Questionnaire Development

The questionnaire was developed following an extensive review of contemporary literature relating to software developer well-being, Agile software development, psychological safety, occupational stress, burnout, work satisfaction, behavioural sustainability, and human-centred software engineering.

Survey questions were designed to investigate behavioural challenges affecting software professionals while maintaining alignment with the study objectives and identified research gap.

The questionnaire consisted of two primary sections.

The first section collected demographic information including professional role and Agile working environment.

The second section measured behavioural perceptions relating to,

- Sprint-related stress
- Workload pressure
- Emotional exhaustion
- Burnout
- Psychological safety
- Motivation
- Work satisfaction
- Communication quality
- Organisational support
- Behaviour-aware Agile practices

Responses were measured using a five-point Likert scale, ranging from Strongly Disagree (1) to Strongly Agree (5).

Several open-ended questions were additionally included to capture qualitative observations regarding behavioural challenges and organisational improvement strategies.

Questionnaire Validation

To enhance measurement quality, the questionnaire was developed based on constructs frequently reported within recent software engineering and organisational behaviour literature.

Prior to full-scale distribution, the questionnaire underwent a review process to improve wording clarity, question consistency, and alignment with the research objectives.

Internal consistency reliability was evaluated using Cronbach's Alpha, producing an overall reliability coefficient of 0.938, indicating excellent reliability for behavioural measurement.

The combination of literature-informed construct development, questionnaire review, and reliability testing increased confidence in the suitability of the measurement instrument for investigating behavioural factors within Agile software development environments.

Ethical Considerations

Ethical principles governing research involving human participants were strictly observed throughout the study.

Participation was voluntary, and informed consent was obtained before respondents accessed the questionnaire.

Participants were informed regarding,

- the purpose of the research
- voluntary participation
- anonymity of responses
- confidentiality of collected information
- the right to withdraw prior to submission.

To preserve confidentiality, no personally identifiable information, organisational names, email addresses, or confidential company information was collected.

All responses were analysed in aggregated form, and collected data were securely stored in accordance with recognised data protection principles.

The study further considered professional ethical guidance relating to software engineering practice, including responsible data handling, participant privacy, and confidentiality.

Data Collection Procedure

Data collection was conducted using an anonymous online questionnaire distributed through professional software engineering communities and Agile practitioner networks.

The questionnaire remained available throughout the designated data collection period to maximise participation from software professionals working in diverse Agile environments.

Following data collection, responses were screened to identify duplicate submissions and incomplete questionnaires.

After the data screening process, 900 complete and valid responses were retained for statistical analysis.

Data Analysis

The collected data were analysed using Jamovi Statistical Software.

Descriptive statistical analysis was initially performed to summarise participant characteristics and behavioural perceptions using frequencies, percentages, means, and standard deviations.

The internal consistency of the questionnaire was assessed using Cronbach's Alpha.

Relationships among behavioural variables were subsequently examined using Pearson correlation analysis to investigate associations between,

- workload pressure,
- sprint-related stress,
- emotional exhaustion,
- burnout,
- work satisfaction,
- organisational support.

Responses obtained through open-ended questions were analysed using thematic analysis to identify recurring behavioural challenges, organisational concerns, and recommendations relating to behaviour-aware Agile practices.

The combined quantitative and qualitative findings directly informed the development of the proposed HappyAgile+ behaviour-aware Agile governance framework.

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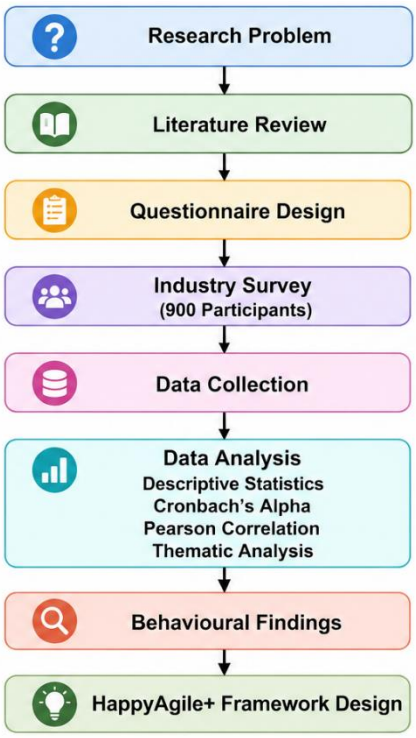

Figure2: Research Methodology of the Study (Author Developed)

Results

Participant Characteristics

A total of 900 valid responses from software professionals working in Agile software development environments were included in the final analysis. Participants represented a broad range of technical and managerial roles, including Software Engineers, Senior Software Engineers, Quality Assurance Engineers, DevOps Engineers, Scrum Masters, Business Analysts, Technical Leads, Project Managers, and UI/UX Engineers. This diversity ensured that the findings reflected behavioural experiences across different stages of the software development lifecycle.

The participants were actively involved in Agile software development using methodologies such as Scrum, Kanban, SAFe, DevOps, and hybrid Agile approaches. Their professional experience provided a comprehensive perspective on behavioural challenges encountered during iterative software development and sprint-based project management.

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Binomial Test

	Level	Count	Total	Proportion	p
Age_Group	20-25	190	900	0.211	< .001
	26-30	170	900	0.189	< .001
	31-35	168	900	0.187	< .001
	36-40	201	900	0.223	< .001
	Above 40	171	900	0.190	< .001
Job_Role	Business Analyst	135	900	0.150	< .001
	DevOps Engineer	134	900	0.149	< .001
	Project Manager	106	900	0.118	< .001
	QA Engineer	92	900	0.102	< .001
	Scrum Master	120	900	0.133	< .001
	Senior Software Engineer	92	900	0.102	< .001
	Software Engineer	99	900	0.110	< .001
	UI/UX Engineer	122	900	0.136	< .001
Work_Arrangement	Hybrid	274	900	0.304	< .001
	Onsite	322	900	0.358	< .001
	Remote	304	900	0.338	< .001
Agile_Method	DevOps	183	900	0.203	< .001
	Hybrid Agile	170	900	0.189	< .001
	Kanban	186	900	0.207	< .001
	SAFe Agile	181	900	0.201	< .001
	Scrum	180	900	0.200	< .001

Note. H_a is proportion ≠ 0.5

Figure 3: Participant Demographics (Author Developed)

Descriptive Statistics

Descriptives

	B1_Stress_During_Sprints	B2_Deadlines_Affect_Wellbeing	B3_Continuous_Delivery_Pressure	B4_Mental_Exhaustion	B5_Burnout_Symptoms	B6_Unfair_Task_Distribution	B7_Unmanageable_Workload	B8_Unrealistic_Timelines	B9_Task_Switchi
N	900	900	900	900	900	900	900	900	
Missing	0	0	0	0	0	0	0	0	
Mean	4.23	4.52	4.52	4.44	4.44	4.52	4.52	4.52	
Median	4.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
Standard deviation	0.714	0.628	0.628	0.673	0.673	0.638	0.638	0.638	
Minimum	3	3	3	3	3	3	3	3	
Maximum	5	5	5	5	5	5	5	5	

B9_Task_Switching_Affects_Productivity	B10_Workload_Affects_Motivation	B11_Limited_Sharing_Concerns	B12_Limited_Open_Communication	B13_Poor_Constructive_Mistake_Handling	B14_Low_Psychological_Safety	B15_Collaboration_Problems_Affect_Satisfaction	B1
900	900	900	900	900	900	900	
0	0	0	0	0	0	0	
4.23	4.23	4.06	4.06	4.06	4.06	4.06	
4.00	4.00	4.00	4.00	4.00	4.00	4.00	
0.714	0.714	0.737	0.737	0.737	0.737	0.737	
3	3	3	3	3	3	3	
5	5	5	5	5	5	5	

B16_Low_Motivation_in_Agile	B17_Lack_of_Recognition	B18_Agile_Does_Not_Support_Satisfaction	B19_Wellbeing_Affects_Performance	B20_Stress_Affects_Creativity	B21_Agile_Focuses_on_Productivity	B22_Lack_of_Emotional_Support	B23_No_Mental_Workload_Consic
900	900	900	900	900	900	900	
0	0	0	0	0	0	0	
4.18	4.18	4.18	4.55	4.55	4.55	4.55	
4.00	4.00	4.00	5.00	5.00	5.00	5.00	
0.727	0.727	0.727	0.498	0.498	0.498	0.498	
3	3	3	4	4	4	4	
5	5	5	5	5	5	5	

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Consideration	B24_Organizations_Should_Focus_Wellbeing	B25_Agile_Not_Sustainable	B26_BehaviourAware_Improves_Sustainability	B27_Emotional_Awareness_Improves_Delivery	B28_Reduces_Burnout	B29_Improves_Team_Satisfaction	B30_Support_HappyAgilePlus
900	900	900	900	900	900	900	900
0	0	0	0	0	0	0	0
4.55	4.55	4.55	4.68	4.68	4.68	4.68	4.68
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
0.498	0.498	0.498	0.467	0.467	0.467	0.467	0.467
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5

Figure 4: Descriptive Statistics of Behavioural Variables (Author Developed)

The descriptive analysis indicates that software professionals reported moderate to high levels of behavioural challenges across several dimensions. Participants expressed concerns regarding sprint-related workload, emotional exhaustion, communication pressure, and organisational support. Conversely, respondents demonstrated relatively strong agreement regarding the importance of integrating behavioural well-being into Agile project management.

The highest mean score was observed for Support for Behaviour-Aware Agile Governance, indicating strong industry acceptance of incorporating behavioural factors into software project management. Similarly, Operational Efficiency received a comparatively high mean score, suggesting that respondents believe organisational performance can be enhanced when developer well-being is systematically considered during Agile delivery.

Behavioural indicators associated with workload pressure, fragmented communication, and emotional fatigue exhibited moderate mean values, suggesting that these challenges remain prevalent within Agile software development environments and require proactive organisational attention

Reliability Analysis

The internal consistency of the questionnaire was assessed using Cronbach's Alpha.

Scale Reliability Statistics

	Cronbach's α
scale	0.938

[3]

Figure 5: Reliability analysis (Author Developed)

The questionnaire achieved an overall Cronbach's Alpha coefficient of 0.938, indicating excellent internal consistency and demonstrating that the measurement instrument reliably assessed behavioural constructs related to developer well-being and Agile software development. The high reliability coefficient provides confidence that the collected data are suitable for subsequent statistical analysis.

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Correlation Analysis

Pearson correlation analysis was performed to examine relationships among the behavioural variables.

Correlation Matrix

		B1_Stress_During_Sprints	B2_Deadlines_Affect_Wellbeing	B3_Continuous_Delivery_Pressure	B4_Mental_Exhaustion	B5_Burnout_Symptoms	B6_Unfair_Task_Distribution	B7_Unmanageable_Workload	I
B1_Stress_During_Sprints	Pearson's r	—							
	df	—							
	p-value	—							
B2_Deadlines_Affect_Wellbeing	Pearson's r	0.779	—						
	df	898	—						
	p-value	< .001	—						
B3_Continuous_Delivery_Pressure	Pearson's r	0.779	1.000	—					
	df	898	898	—					
	p-value	< .001	< .001	—					
B4_Mental_Exhaustion	Pearson's r	0.831	0.663	0.663	—				
	df	898	898	898	—				
	p-value	< .001	< .001	< .001	—				
B5_Burnout_Symptoms	Pearson's r	0.831	0.663	0.663	1.000	—			
	df	898	898	898	898	—			
	p-value	< .001	< .001	< .001	< .001	—			
B6_Unfair_Task_Distribution	Pearson's r	0.779	0.619	0.619	0.680	0.680	—		
	df	898	898	898	898	898	—		
	p-value	< .001	< .001	< .001	< .001	< .001	—		
B7_Unmanageable_Workload	Pearson's r	0.779	0.619	0.619	0.680	0.680	1.000	—	
	df	898	898	898	898	898	898	—	
	p-value	< .001	< .001	< .001	< .001	< .001	< .001	—	

Figure 6: Pearson Correlation Matrix (Author Developed)

The correlation analysis identified several statistically meaningful relationships between behavioural factors affecting Agile software development.

Higher levels of workload pressure were positively associated with emotional exhaustion and burnout, indicating that increasing workload demands are accompanied by deteriorating psychological well-being among software professionals. Similarly, stronger perceptions of fragmented communication were associated with lower organisational effectiveness, emphasising the importance of effective collaboration within Agile environments.

Conversely, behavioural indicators relating to developer well-being, organisational support, and behaviour-aware Agile governance demonstrated positive relationships with perceived operational efficiency. These findings suggest that organisations prioritising behavioural well-being may experience improved collaboration, higher motivation, and more sustainable software delivery outcomes.

Overall, the observed relationships provide empirical support for integrating behavioural indicators into Agile governance, thereby strengthening the rationale for the proposed HappyAgile+ framework.

Behavioural Challenges Reported by Software Professionals

Qualitative responses collected through the open-ended questionnaire revealed several recurring behavioural challenges experienced by software professionals.

The most frequently reported themes included,

- excessive sprint workload;
- unrealistic delivery expectations;
- insufficient recovery time between sprint cycles;
- emotional exhaustion and burnout;
- communication difficulties within distributed teams;
- inadequate organisational recognition;
- limited psychological support for software professionals.

Many respondents reported that Agile project success is predominantly measured using delivery-oriented metrics while behavioural well-being receives comparatively little organisational attention. Participants further indicated that proactive behavioural monitoring could assist organisations in identifying potential risks before they negatively affect productivity, software quality, and employee retention.

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These qualitative findings complement the quantitative results and reinforce the need for behaviour-aware governance mechanisms capable of supporting both organisational performance and developer well-being.

Development of the HappyAgile+ Framework

The empirical findings obtained through the survey directly informed the development of the HappyAgile+ behaviour-aware Agile governance framework.

The descriptive statistics, reliability analysis, correlation analysis, and thematic interpretation consistently demonstrated that behavioural factors significantly influence software development environments. Consequently, the proposed framework introduces behavioural assessment as an additional governance layer that complements traditional Agile performance metrics.

Rather than replacing existing Agile methodologies, HappyAgile+ extends Scrum, Kanban, SAFe, and DevOps by incorporating continuous behavioural awareness into sprint planning, workload balancing, team communication, resource allocation, and organisational decision-making.

The framework therefore provides a structured approach for integrating developer well-being into Agile governance while supporting sustainable software delivery and long-term organisational resilience.

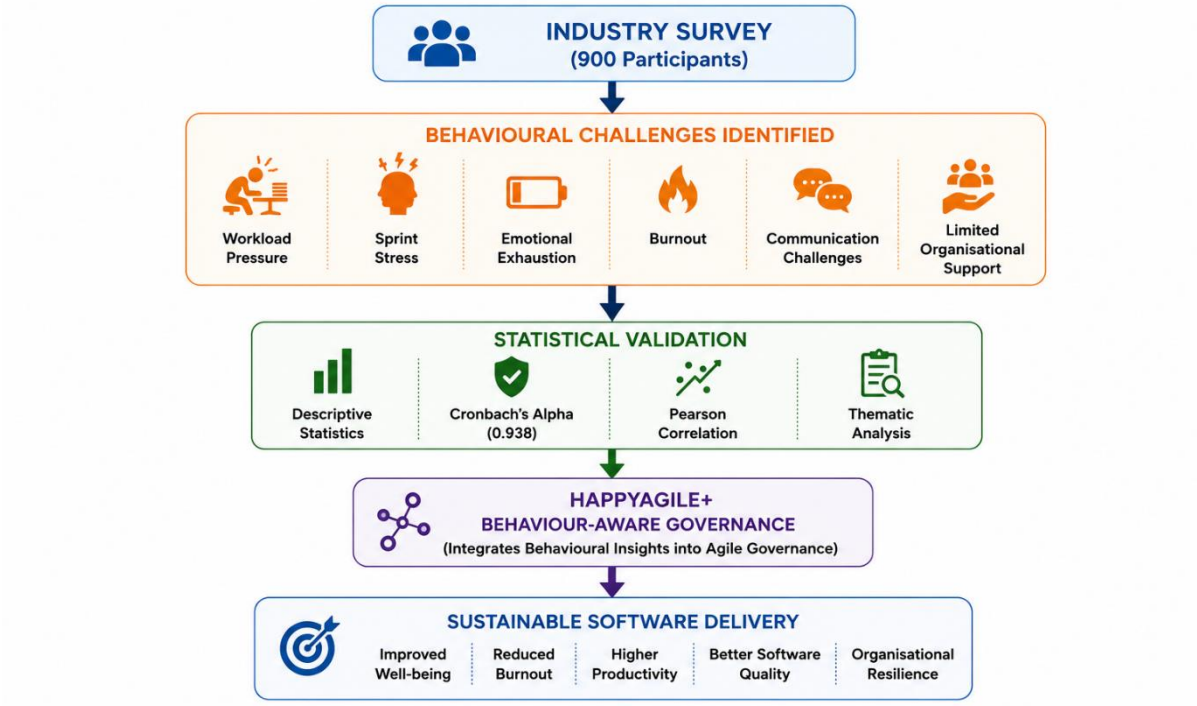

Figure 7: Summary of Key Findings Supporting the HappyAgile+ Framework (Author Developed)

Discussion

This study investigated behavioural challenges experienced by software professionals in Agile software development environments and proposed HappyAgile+, a human-centred behaviour-aware Agile governance framework. The findings indicate that workload pressure, sprint-related stress, emotional exhaustion, burnout, and organisational support significantly influence sustainable software delivery. Participants also expressed strong support for integrating behavioural well-being into Agile project management, highlighting the need to complement traditional delivery metrics with behavioural indicators.

The results are consistent with recent studies that recognise developer well-being as an important contributor to software quality, productivity, and organisational resilience. While existing Agile methodologies such as Scrum, Kanban, SAFe, and DevOps improve collaboration and delivery efficiency, they primarily evaluate project performance using operational metrics and provide limited support for continuously monitoring behavioural well-being. Consequently, behavioural issues are often identified only after they begin to affect team performance or employee satisfaction.

HappyAgile+ addresses this gap by introducing behavioural awareness as an additional governance layer within Agile project management. The framework integrates behavioural assessment, well-being evaluation, adaptive governance, and sustainable delivery into a continuous feedback cycle that supports evidence-based decision-making. Rather than replacing existing Agile practices, HappyAgile+ extends them by enabling project managers and Scrum Masters to consider behavioural information when planning sprint workloads, balancing resources, and supporting development teams.

The proposed framework also provides the conceptual foundation for an intelligent software platform currently under development. The platform incorporates behavioural check-ins, a Happiness Index (HI), behavioural analytics, and adaptive recommendations to assist organisations in identifying behavioural risks and promoting sustainable software delivery.

Although the findings provide strong empirical support for behaviour-aware Agile governance, several limitations should be acknowledged. The study used a cross-sectional survey with purposive sampling and relied on self-reported responses, which may limit the generalisability of the findings. In addition, the proposed framework has not yet undergone long-term industrial evaluation. Future research will therefore implement and evaluate HappyAgile+ within real Agile software development teams using an Action Research approach to assess its practical effectiveness across multiple sprint cycles.

Conclusion

This study examined behavioural challenges within Agile software development and proposed HappyAgile+, a human-centred behaviour-aware Agile governance framework that integrates developer well-being into Agile project management. Findings from 900 software professionals confirmed that workload pressure, stress, burnout, and organisational support influence sustainable software delivery and justify the need for behaviour-aware governance.

HappyAgile+ extends existing Agile methodologies by introducing behavioural assessment as an additional governance mechanism that complements traditional delivery metrics. The framework supports adaptive decision-making through continuous behavioural monitoring, well-being assessment, and governance recommendations, while remaining compatible with established Agile practices.

The study contributes to human-centred software engineering by providing an empirically informed framework that balances organisational performance with developer well-being. Future work will focus on implementing and evaluating the HappyAgile+ platform in industrial Agile environments to assess its effectiveness in improving developer well-being, project performance, and long-term organisational sustainability.

References

Gupta, D., 2025. *Software Development Life Cycle (SDLC).* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/software-development-life-cycle-sdlc/
[Accessed 20 January 2026].

Abdulmalek, S. et al., 2022. IoT-Based Healthcare-Monitoring System towards Improving Quality of Life: A Review. *Healthcare (Basel), Switzerland,* 10(10), p. 1993.

A., Choupdar, G. K., A. & T, P., 2025. ICT and IoT-Based Smart Post-Harvest Solutions.pdf (ICT and IoT-Based Smart Post-Harvest Solutions). *Agrospheres: e-Newsletter,* 06 June, 6(6), pp. 15-18.

Ajisegiri, E. et al., 2022. Development of a Smart Grain Storage Silo Using the Internet of. *International Journal of Artificial Intelligence and Machine Learning ·,* 5 July, 2(2), pp. 1-22.

Andre Esteva, B. K. R. A. N. J. K. S. M. S. H. M. B. &. S. T., 2017. Dermatologist-level classification of skin cancer with deep neural networks. *Nature.*

Areej Alotaibi 1, *. D. A., 2025. Skin Cancer Detection Using Transfer Learning and Deep Attention Mechanisms. *Nationala Library of Medicine.*

Chakraborty, A., Gupta, R. D., Kabir, Z. M. & Dhar, S., 2023. Development of an IoT-enabled cost-effective asthma patient monitoring system: Integrating health and indoor environment data with statistical analysis and data visualization. *Cleaner and Responsible Consumption,* 24(2), p. 100142.

Chen, X. & Moraga, P., 2024. Dengue forecasting and outbreak detection in Brazil using LSTM: integrating human mobility and climate factors. *Infectious Disease Modelling,* 11(1), pp. 338-354.

Chumpu, R., Khamsemanan, N., Nattee, C. & Samy, A. M., 2019. The association between dengue incidences and provincial-level weather variables in Thailand from 2001 to 2014. *PLOS ONE,* 14(12), p. e0226945.

Erico Tjoa, C. G., n.d. [Online]
Available at: https://arxiv.org/abs/1907.07374

Espressif Systems, 2024. *ESP32 Technical Reference Manual,* s.l.: Espressif Systems.

European Centre for Disease Prevention and Control, 2021. *Factsheet about Dengue,* Stockholm: Centre for Disease Prevention and Control.

Fransson, P. et al., 2025. An explainable covariate compartmental model for predicting the spatio-temporal patterns of dengue in Sri Lanka. *PLOS Computational Biology,* 21(9), p. e1013540.

Geert Litjens, T. K. B. E. B. A. A. A. S. F. C. M. G. J. A. v. d. L. B. v. G. C. I. S., n.d. *A Survey on Deep Learning in Medical Image Analysis.* [Online]
Available at: https://arxiv.org/abs/1702.05747

Gharbi, M. et al., 2011. Time series analysis of dengue incidence in Guadeloupe, French West Indies: Forecasting models using climate variables as predictors. *BMC Infectious Diseases,* 11(1).

Godliauskas, Povilas & Smite, Darja., 2024. *The well-being of software engineers: a systematic literature review and a theory..* [Online]
Available at: https://www.researchgate.net/publication/386382938_The_well-being_of_software_engineers_a_systematic_literature_review_and_a_theory
[Accessed 15 5 2026].

Guo, P. et al., 2017. Developing a dengue forecast model using machine learning: A case study in China. *PLoS Negl Trop Dis,* 11(10), p. e0005973.

Hyuna Sung PhD, J. F. M. M. R. L. S. M. M. L. M. I. S. M. M. P. A. J. D. P. F. B. B. M. P., 2021. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *CA: A Cancer Journal for Clinicians,* 2.

Islam, M. A., Hasan, M. N. & Tiwari, A., 2023. Correlation of Dengue and Meteorological Factors in Bangladesh: A Public Health Concern. *International Journal of Environmental Research and Public Health,* 1 January, 20(6), p. 5152.

Jarman, A. et al., 2023. Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology,* 19 September.Volume 1.

Jayadas, T. T. P. et al., 2023. A spatial dengue risk map for the jaffna district of Northern sri Lanka. *Vingnanam journal of Science,* 18(1), pp. 13-22.

Kamma, V. et al., 2025. Integrating IoT and Cloud Analytics for Real-Time Monitoring of Post-Surgical Recovery in Maxillofacial Patients. *Vascular and Endovascular Review,* 8(1), pp. 304-311.

Karasinghe, N., Peiris, S., Jayathilaka, R. & Dharmasena, T., 2024. Forecasting weekly dengue incidence in Sri Lanka: Modified Autoregressive Integrated Moving Average modeling approach. *PLOS ONE,* 19(3), pp. e0299953-e0299953.

Kennedy, S. I., Zadeh, A. A., Choi, J., & Alborz, S., 2024. *Agile Practices and IT Development Team Well-Being: Unveiling the Path to Successful Project Delivery.* [Online]
Available at: http://researchgate.net/publication/385263215_Agile_Practices_and_it_Development_Team_Well-Being_Unveiling_the_Path_to_Successful_Project_Delivery
[Accessed 19 5 2026].

Krishnapriya, G. & Prema , S., 2025. Cost-Effective IoT-Based Real-Time Vital Sign Monitoring: An Affordable Telehealth Solution. *Telehealth and Medicine Today,* Volume 10, p. 611.

Kumar, S., 2025. *Agile Development Models - Software Engineering.* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/software-engineering-agile-development-models/
[Accessed 22 January 2026].

Kumar, S., 2026. *Waterfall Model - Software Engineering.* [Online]
Available at: https://www.geeksforgeeks.org/software-engineering/waterfall-model/
[Accessed 21 January 2026].

Kurian, N. C. et al., 2023. Robust Semi-Supervised Learning for Histopathology Images Through Self-Supervision Guided Out-of-Distribution Scoring. *ieeexplore.*

Lambrechts, L., Scott, T. W., Gubler, D. J. & Halstead, S. B., 2010. Consequences of the Expanding Global Distribution of Aedes albopictus for Dengue Virus Transmission. *PLoS Neglected Tropical Diseases,* 25 May, 4(5), p. e646.

Lee, D.-H., n.d. [Online]
Available at: https://www.researchgate.net/publication/280581078_Pseudo-Label_The_Simple_and_Efficient_Semi-Supervised_Learning_Method_for_Deep_Neural_Networks

Majeed, M. A., Mohd, Z., Zulkafli, Z. & Wayayok, A., 2023. A Deep Learning Approach for Dengue Fever Prediction in Malaysia Using LSTM with Spatial Attention. *International Journal of Environmental Research and Public Health,* 20(5), p. 4130.

MathWorks, 2026. *ThingSpeak Documentation.* [Online]
Available at: https://www.mathworks.com/help/thingspeak/

Mazhar, B. et al., 2024. Development of Data-driven Machine Learning Models and their Potential Role in Predicting Dengue outbreak. *Journal of Vector Borne Diseases,* 16 January.pp. 503-514.

Michard , F. & Saugel, B., 2024. New sensors for the early detection of clinical deterioration on general wards and beyond - a clinician's perspective. *Journal of Clinical Monitoring and Computing,* 39(2), pp. 435-442.

Mingxing Tan, Q. V. L., n.d. [Online]
Available at: https://arxiv.org/abs/1905.11946

Mohamed A. Kassem 1ORCID, K. M. H. 2. D. 3. a. M. E., 2021. Machine Learning and Deep Learning Methods for Skin Lesion Classification and Diagnosis: A Systematic Review. *MDI.*

Muhammad Danish Ali 1, M. A. I. 2. L. 3. D. 4. a. K. K., n.d. Explainable AI Based Multi Class Skin Cancer Detection Enhanced by Meta Learning with Generative DDPM Data Augmentation. *MDPI.*

Nandani, E. J. K. P. & Bandara, A. M. D. P., 2025. Forecasting Dengue Outbreaks in Kalutara District using Hybrid Machine Learning Techniques. *Journal of Science of the University of Kelaniya,* 18(2), pp. 145-152.

ntfy.sh, 2026. *ntfy.sh.* [Online]
Available at: https://ntfy.sh/

Ong, S. Q. et al., 2023. Predicting dengue transmission rates by comparing different machine learning models with vector indices and meteorological data. *Scientific Reports,* 13(1).

Phelan, H., Yates, V. & Lillie, E., 2022. Challenges in healthcare delivery in low- and middle-income countries. *Anaesthesia and Intensive Care Medicine,* 23(8), p. 501–504.

Rahman, S. Z., Senthil, R., Ramalingam, V. & Gopal, R., 2023. Predicting Infectious Disease Outbreaks with Machine Learning and Epidemiological Data. *Journal of Advanced Zoology,* 44(S-4), p. 110:121 .

Rahulan, K., Ranagala, R. M. & Roshan, G. P., 2024. Dengue Outbreak Control and Prevention: A Case Study of Gampaha District, Sri Lanka. *Sri Lankan Journal of Medical Administration,* 25(1), pp. 46-53.

Ramprasaath R. Selvaraju, M. C. A. D. R. V. D. P. D. B., n.d. [Online]
Available at: https://arxiv.org/abs/1610.02391

Ranwala, L., Wedisinghe, Y., Perera, S. & Jayamanne, D., 2021. Real-time laboratory surveillance of Dengue antigen (NS1) - Best proposed early warning and response system for Dengue in Sri Lanka? - Results from a pilot study. *Ceylon Medical Journal,* 27 12, 66(3), p. 121.

Riedl, René & Oettl, Christian & Stangl, Fabian & Hevner, Alan., 2025. *How an Agile Software Process Increases Developers' Job Satisfaction: A Stress Perspective Based on the Effort-Reward-Imbalance Model.* [Online]
Available at:
https://www.researchgate.net/publication/388232797_How_an_Agile_Software_Process_Increases_Developers'_Job_Satisfaction_A_Stress_Perspective_Based_on_the_Effort-Reward-Imbalance_Model
[Accessed 20 5 2026].

Rietze, Sarah & Zacher, Hannes., 2023. *Agile work practices: opportunities and risks for occupational well-being..* [Online]
Available at:
https://www.researchgate.net/publication/374921519_Agile_work_practices_opportunities_and_risks_for_occupational_well-being
[Accessed 18 5 2026].

Rosi, A. et al., 2026. Real-Time Mosquito Breeding Site Detection Using a Quantized YOLOv8-Tiny Model on an FPGA-Based Drone Platform. *EAI Endorsed Transactions on Internet of Things,* Volume 11.

Sahu, H., Kashyap, R. & Dewangan, B. K., n.d. Hybrid Deep learning based Semi-supervised Model for Medical Imaging. *ieeexplore.*

Sharafaddini, A. M. & Mansouri, N., 2024. Enhanced Skin Cancer Classification Using Deep Learning and Gradient Boosting Techniques. *ieeexplore.*

Shaswat, . T., 2024. Role of Big Data and IoT in Optimizing Post-Harvest Management. *International Journal of Research Publication and Reviews,* October, 5(10), p. 3.

S. K. et al., 2018. IoT Based Monitoring And Control For Vegetables And Fruits Storage. *International Journal of Advance Research, Ideas and Innovations in Engineering (IJARIIE),* 4(2), p. 5.

Tissera, H. A. et al., 2020. Severe Dengue Epidemic, Sri Lanka,. *www.nc.cdc.gov,* 26(4).

Tuan, D. A. & Dang, T. N., 2024. Leveraging Climate Data for Dengue Forecasting in Ba Ria Vung Tau Province, Vietnam: An Advanced Machine Learning Approach. *Tropical Medicine and Infectious Disease,* 9(10), p. 250.

Uduwanage, H. U. et al., 2025. Prediction of Dengue Outbreaks in Sri Lanka Using Machine Learning Techniques. *Sri Lanka Journal of Medicine,* 21 4, 34(1), pp. 15-26.

Verma, H., Chauhan, N. & Awasthi , K. L., 2023. A Comprehensive review of 'Internet of Healthcare Things': Networking aspects, technologies, services, applications, challenges, and security concerns. *Computer Science Review,* Volume 50.

Viviane, . I. et al., 2023. IoT-Based Real-Time Crop Drying and Storage Monitoring System. *International Journal of Distributed Sensor Networks,* 26 September, Volume 2023, p. 11.

Vyas, H., Shukla, H. & Jivani, M. N., 2025. A Portable IoT-Based Health Monitoring Framework Using ESP32 for Isolated and Home-Based Patient Care. *Journal on Electronic and Automation Engineering,* 4(2), pp. 240-245.

Vyas, M. et al., 2019. Post harvesting Onion Storage Methodology using IOT.pdf (Post harvesting Onion Storage Methodology Using IOT). *International Journal of Advanced Research in Computer and Communication Engineering,* May.8(5).

Withanage, G. P., Viswakula, S. D., Nilmini Silva Gunawardena, Y. I. & Hapugoda, M. D., 2018. A forecasting model for dengue incidence in the District of Gampaha, Sri Lanka. *Parasites & Vectors,* 11(1).

Wokwi, 2024. *Wokwi: online electronics simulator.* [Online]
Available at: https://wokwi.com

Wong, N., Jackson, V., & van der Hoek, A., 2023. *Mental Wellbeing at Work: Perspectives of Software Engineers.* [Online]
Available at:
https://www.researchgate.net/publication/370180529_Mental_Wellbeing_at_Work_Perspectives_of_Software_Engineers [Accessed 20 5 2026].

World Health Organization, 2013. *Pocket book of hospital care for children: guidelines for the management of common childhood illnesses.* 2 ed. s.l.:WHO.

Xu, J. et al., 2020. Forecast of Dengue Cases in 20 Chinese Cities Based on the Deep Learning Method. *International Journal of Environmental Research and Public Health,* 17(2), p. 453.

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Proceedings of the ESOFT International Conference 2026
ESU, Kandy, Sri Lanka
August 30, 2026

Yu, K. et al., 2024. Using UAV Images and Deep Learning in Investigating Potential Breeding Sites of Aedes albopictus. *Acta Tropica,* pp. 107234-107234.

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EP 08

A Digital Healthcare Identity Governance Framework for Trusted Prescription Authentication and Interoperable Healthcare Records in Sri Lanka

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Abstract

Background: Digital transformation has become a strategic priority for healthcare organisations worldwide, enabling secure information exchange, improved patient care, and efficient healthcare service delivery. Despite these advancements, healthcare institutions and pharmacies in Sri Lanka continue to rely heavily on paper-based prescriptions and fragmented healthcare record management practices. These limitations contribute to prescription verification delays, inefficient information sharing, medication-related risks, and poor interoperability between healthcare providers. Existing research has primarily focused on electronic health records, e-prescription systems, or healthcare interoperability as separate domains, with limited attention given to integrating healthcare identity governance, trusted prescription authentication, and interoperable healthcare records within a unified conceptual framework.

Objective/s: This study proposes the Intelligent Prescription Identity Governance Framework (IPIGF), a conceptual healthcare identity governance framework designed to support trusted prescription authentication, interoperable healthcare information exchange, and secure patient identity management within the Sri Lankan healthcare ecosystem.

Methods: A conceptual quantitative exploratory research design was adopted to investigate operational challenges associated with prescription authentication and healthcare information management. An anonymised simulated healthcare operational dataset consisting of 120 records was developed using assumptions derived from recent healthcare digital transformation literature. The dataset represented six operational constructs: prescription verification delays, fragmented healthcare records, cybersecurity concerns, digital healthcare readiness, support for healthcare identity governance, and operational efficiency. Descriptive statistical analysis, reliability analysis, Pearson correlation analysis, and SWOT analysis were conducted using Jamovi statistical software to provide preliminary evidence supporting the conceptual framework

Results: The findings indicate moderate operational challenges relating to prescription verification delays, fragmented healthcare records, and cybersecurity concerns, while stakeholder support for digital healthcare identity governance demonstrated comparatively high mean values. Reliability analysis produced a Cronbach's Alpha value of 0.927, indicating excellent internal consistency among the study variables. Correlation analysis identified significant positive relationships between digital healthcare readiness and operational efficiency, as well as between support for IPIGF and operational efficiency. These findings provide preliminary conceptual support for the proposed framework while highlighting the importance of healthcare digital transformation initiatives.

Conclusion/s: The proposed Intelligent Prescription Identity Governance Framework provides a conceptual foundation for integrating healthcare identity governance, trusted prescription authentication, and interoperable healthcare information management within Sri Lanka. Rather than demonstrating implementation effectiveness, the framework establishes a strategic model intended to guide future prototype development, empirical validation, interoperability evaluation, and healthcare policy development.

Keywords: *Digital healthcare, Healthcare information systems, Healthcare interoperability, Prescription authentication, Sri Lanka*

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Introduction

Healthcare systems worldwide are undergoing rapid digital transformation to improve service delivery, operational efficiency, healthcare security, and patient-centred care. Governments and healthcare organisations increasingly invest in electronic health records, digital identity management, health information exchanges, and interoperable healthcare platforms to improve healthcare quality while reducing administrative complexity. The World Health Organization identifies digital health governance as a key strategic enabler for strengthening healthcare systems through secure information sharing and integrated patient care.

Although considerable progress has been achieved internationally, many healthcare institutions and pharmacies in Sri Lanka continue to depend on paper-based prescriptions and fragmented healthcare record management practices. Healthcare information is frequently distributed across multiple organisations, requiring patients to repeatedly provide medical histories while healthcare professionals often make clinical decisions using incomplete information. These operational limitations contribute to prescription verification delays, duplicate medication dispensing, inefficient healthcare coordination, increased administrative workload, and reduced continuity of patient care.

Healthcare interoperability has therefore emerged as a critical requirement for modern healthcare systems. Recent studies emphasise that standardised information exchange enables healthcare providers to share patient information securely while improving clinical decision-making and operational efficiency. However, interoperability alone cannot fully address challenges associated with patient identity verification, trusted prescription authentication, and governance of healthcare information across multiple healthcare providers.

Recent advances in digital identity management further demonstrate the importance of secure authentication mechanisms within healthcare environments. Identity and Access Management (IAM), multi-factor authentication, role-based access control, and Zero Trust security models have increasingly been adopted to strengthen healthcare cybersecurity while protecting sensitive patient information. Similarly, modern healthcare interoperability standards such as HL7 FHIR enable secure and standardised communication between hospitals, pharmacies, laboratories, and other healthcare organisations.

Despite these developments, existing research primarily investigates electronic health records, e-prescription systems, healthcare interoperability, and digital identity management as separate research domains. Few studies integrate these concepts into a unified governance framework capable of supporting trusted prescription authentication, secure patient identity management, healthcare interoperability, and healthcare information governance within a single conceptual architecture. Furthermore, limited research has specifically examined these challenges within the Sri Lankan healthcare context.

To address this research gap, this study proposes the **Intelligent Prescription Identity Governance Framework (IPIGF)**. Unlike conventional electronic health record systems that primarily focus on storing patient information or standalone e-prescription platforms that digitise prescriptions, IPIGF integrates patient identity governance, trusted prescription authentication, interoperable healthcare information exchange, and secure access management within a unified conceptual framework. Rather than replacing existing hospital information systems, the proposed framework is intended to provide an interoperable governance layer capable of facilitating secure communication between healthcare stakeholders while supporting future healthcare digital transformation initiatives in Sri Lanka.

Accordingly, the objectives of this study are to:

- investigate operational challenges associated with prescription authentication and fragmented healthcare information management;
- examine relationships among key healthcare operational variables using simulated operational data;
- propose a conceptual Intelligent Prescription Identity Governance Framework to support trusted prescription authentication and interoperable healthcare records; and
- provide a conceptual foundation for future implementation and empirical evaluation within real healthcare environments.

Table 1: Summary of Recent Literature

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Author(s)	Research Focus	Key Findings
Fernandes et al. (2024)	Digital healthcare governance	Governance supports healthcare transformation
Holl et al. (2024)	National digital health strategies	Digital health improves healthcare coordination
Adegoke et al. (2025)	Healthcare interoperability	Interoperability improves information exchange
Olaitan and Brown (2025)	Identity and access management	Zero Trust improves healthcare security
Wu et al. (2025)	Healthcare identity authentication	Multi-factor authentication strengthens trust
Anian et al. (2025)	Healthcare interoperability governance	Governance improves healthcare coordination
Martínez et al. (2026)	Digital healthcare identity frameworks	Identity frameworks improve secure healthcare access
Neubauer et al. (2026)	Digital governance strategies	Governance enables digital transformation

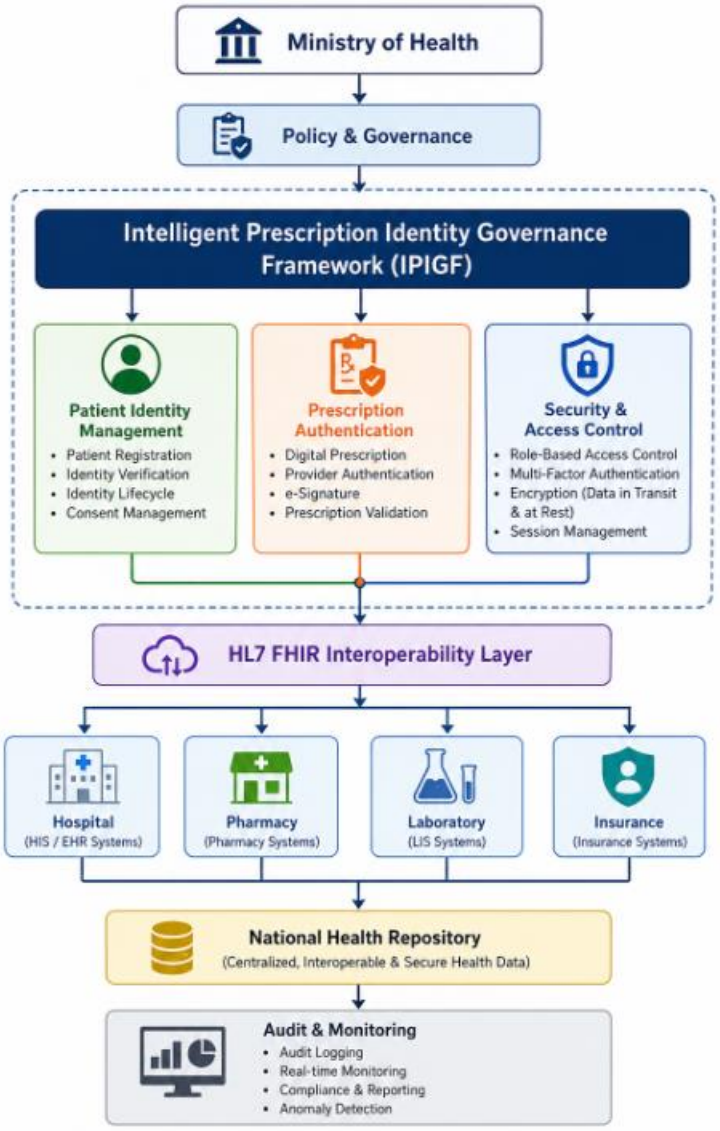

Figure 1: Proposed Intelligent Prescription Identity Governance Framework (IPIGF)

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Research Methodology

Research Design

This study adopted a conceptual quantitative exploratory research design to investigate operational challenges associated with prescription authentication and healthcare information management while developing the Intelligent Prescription Identity Governance Framework (IPIGF). Unlike implementation-based system evaluation studies, the objective of this research was to establish and assess a conceptual framework capable of addressing healthcare identity governance challenges through evidence obtained from exploratory statistical analysis and literature-informed framework development.

A pragmatic research philosophy guided the study because the research addresses a practical healthcare information systems problem by integrating concepts from healthcare interoperability, digital identity governance, cybersecurity, and healthcare digital transformation. The study therefore combines conceptual framework development with preliminary quantitative evidence to support future implementation and validation.

Development of the Simulated Dataset

Access to real healthcare operational data in Sri Lanka is limited due to patient privacy requirements, ethical considerations, institutional access restrictions, and healthcare information confidentiality. Consequently, an anonymised simulated healthcare operational dataset was developed to enable preliminary exploratory analysis without exposing personally identifiable healthcare information.

The simulated dataset consisted of 120 operational records generated using assumptions derived from recent literature on healthcare interoperability, digital identity management, healthcare cybersecurity, and digital healthcare readiness. Randomised values were generated within predefined operational ranges to represent realistic variations in healthcare operational conditions while maintaining conceptual consistency with the proposed framework.

The dataset was designed solely to provide preliminary analytical evidence supporting the conceptual framework and should not be interpreted as representing actual healthcare operational data. Accordingly, the findings provide exploratory insights rather than statistically generalisable conclusions.

Variable Definitions

Six operational variables were selected based on recurring themes identified in recent healthcare digital transformation and interoperability literature. These variables represent operational factors considered important for evaluating the conceptual feasibility of the proposed IPIGF framework.

Table 02 – Variable Definitions

Variable	Definition
Prescription Verification Delays	Time and effort required to verify the authenticity and validity of prescriptions during healthcare service delivery.
Fragmented Healthcare Records	The extent to which patient healthcare information is distributed across multiple independent healthcare providers without integrated access.
Cybersecurity Concerns	Perceived concerns regarding the confidentiality, integrity, and availability of digital healthcare information.
Digital Healthcare Readiness	Organisational readiness to adopt digital healthcare technologies, interoperability, and electronic healthcare services.
Support for IPIGF	Stakeholder acceptance of a digital healthcare identity governance framework for secure prescription authentication and interoperable healthcare records.
Operational Efficiency	Perceived effectiveness and efficiency of healthcare processes, including information accessibility, coordination, and prescription management.

All variables were represented using a five-point Likert scale ranging from **1 (Very Low)** to **5 (Very High)**

Sample Size Justification

The study analysed **120 simulated healthcare operational records** to provide sufficient observations for preliminary exploratory statistical analysis. Since the research aimed to develop and conceptually evaluate a governance framework rather than perform population inference, the selected sample size was considered appropriate for descriptive statistical analysis, reliability assessment, and correlation analysis. Similar exploratory studies commonly employ simulated datasets

to investigate conceptual relationships where access to real operational healthcare data is restricted by ethical and privacy considerations.

Data Analysis

The simulated dataset was analysed using **Jamovi Version 2.7**. Four analytical techniques were employed to examine relationships among the selected healthcare operational variables.

First, descriptive statistical analysis was conducted to summarise the central tendency and variability of each operational construct.

Second, Cronbach's Alpha reliability analysis was performed to evaluate the internal consistency of the measurement variables.

Third, Pearson correlation analysis was undertaken to investigate relationships between healthcare operational factors associated with digital healthcare identity governance.

Finally, a SWOT analysis was conducted to evaluate the strategic strengths, weaknesses, opportunities, and threats associated with implementing the proposed IPIGF framework within the Sri Lankan healthcare environment.

These analytical techniques were selected because they provide appropriate preliminary evidence for conceptual framework development without implying causal relationships or implementation effectiveness.

Framework Evaluation

The proposed Intelligent Prescription Identity Governance Framework was evaluated using a conceptual evaluation approach rather than prototype implementation.

The evaluation considered four complementary perspectives:

- alignment with existing healthcare digital transformation literature;
- consistency with statistical findings obtained from the simulated dataset;
- strategic assessment through SWOT analysis;
- alignment with internationally recognised healthcare interoperability and digital identity management principles.

Accordingly, the evaluation demonstrates the conceptual feasibility of the proposed framework while recognising that empirical implementation and technical validation remain future research activities.

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Figure 2: swot

A SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to evaluate the strategic feasibility of the proposed Intelligent Prescription Identity Governance Framework (IPIGF). The analysis was informed by recent literature on healthcare digital transformation, interoperability, cybersecurity, and identity management, together with insights derived from the exploratory statistical findings. Rather than evaluating a deployed system, the SWOT analysis provides a structured assessment of the framework's potential benefits, implementation challenges, future opportunities, and external risks associated with national adoption in Sri Lanka.

Proposed Intelligent Prescription Identity Governance Framework (IPIGF)

The Intelligent Prescription Identity Governance Framework (IPIGF) is proposed as a conceptual governance architecture that integrates digital identity management, trusted prescription authentication, healthcare interoperability, and secure healthcare information governance within a unified framework. Rather than replacing existing Hospital Information Systems (HIS), Electronic Health Record (EHR) platforms, or pharmacy management systems, IPIGF is intended to function as an interoperable governance layer that facilitates trusted communication among healthcare stakeholders.

The framework comprises five principal components:

1. Digital Patient Identity Management
2. Prescription Authentication Engine
3. Healthcare Interoperability Layer
4. Security and Access Management
5. Healthcare Audit and Governance Services

Together, these components support secure healthcare information exchange while reducing reliance on paper-based prescription verification processes.

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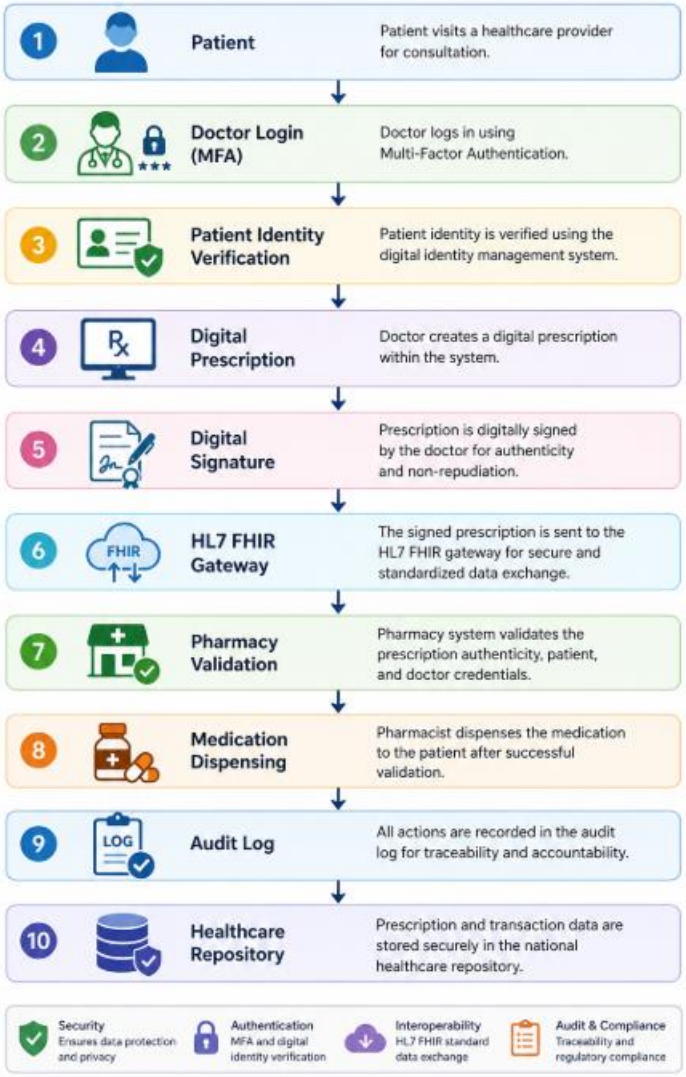

Figure 3: Prescription Authentication Workflow

Digital Patient Identity Management

The Digital Patient Identity Management component establishes a unique healthcare identity for each patient, enabling consistent identification across hospitals, pharmacies, laboratories, and authorised healthcare providers.

Patient identities may be linked with nationally recognised identification mechanisms while maintaining compliance with healthcare privacy requirements. The identity lifecycle includes patient registration, identity verification, secure authentication, authorised healthcare access, and controlled record updates.

By maintaining a consistent digital identity across healthcare providers, the framework seeks to minimise duplicate patient records and improve continuity of healthcare services.

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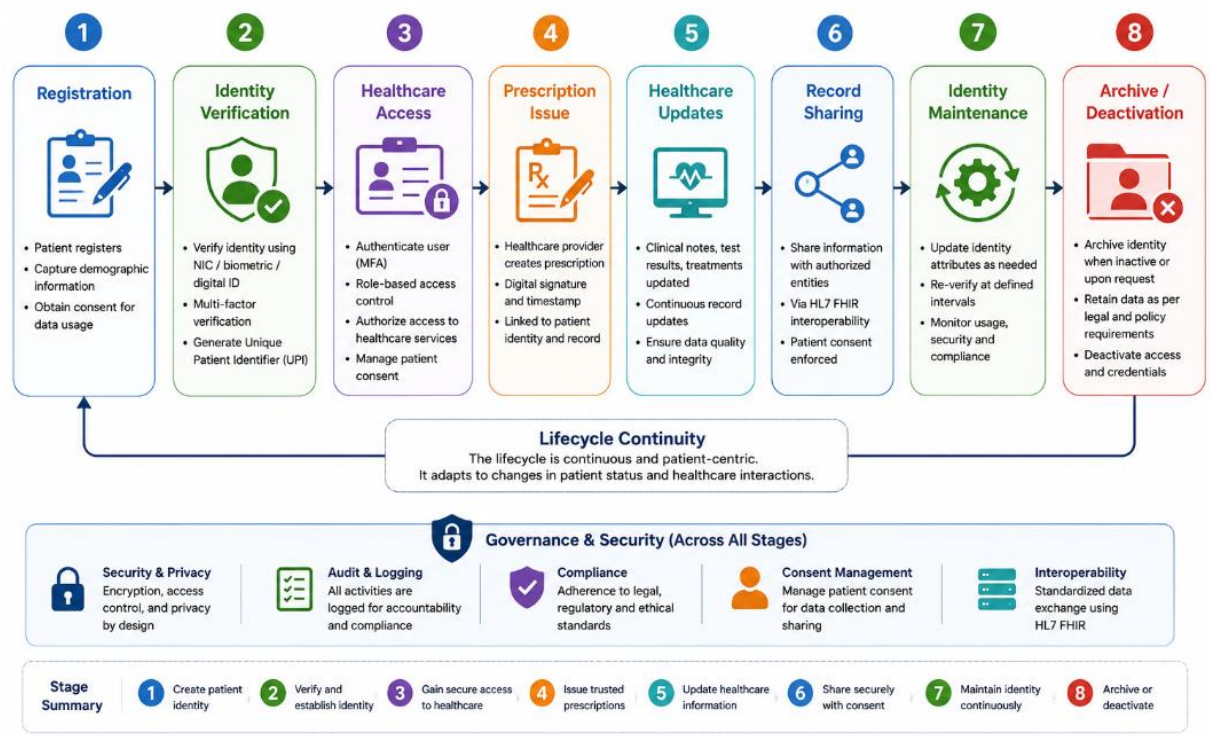

Figure 4: Patient Identity Lifecycle

Prescription Authentication Workflow

The proposed prescription authentication workflow consists of the following conceptual stages:

1. Patient identity verification.
2. Healthcare professional authentication.
3. Digital prescription generation.
4. Secure prescription validation.
5. Interoperable transmission to authorised pharmacies.
6. Pharmacy verification prior to medication dispensing.
7. Secure recording of prescription transactions within the healthcare audit repository.

This workflow is intended to reduce prescription fraud, improve verification efficiency, and support secure medication dispensing through trusted digital authentication mechanisms.

Healthcare Interoperability

Healthcare interoperability represents a fundamental component of the proposed framework. IPIGF adopts interoperability principles consistent with internationally recognised standards such as **HL7 Fast Healthcare Interoperability Resources (FHIR)** to facilitate secure information exchange between heterogeneous healthcare information systems.

Rather than storing duplicate healthcare information, the framework enables authorised healthcare organisations to exchange relevant patient information through standardised interfaces while maintaining data ownership within existing institutional systems. Such an approach promotes coordinated healthcare delivery while reducing information fragmentation.

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Security and Identity Governance

Healthcare information security forms a core principle of the proposed framework.

To support secure healthcare information management, the conceptual architecture incorporates several complementary security mechanisms including:

- Multi-factor authentication for authorised healthcare users.
- Role-Based Access Control (RBAC) to restrict access according to professional responsibilities.
- End-to-end encryption for healthcare information transmission.
- Secure digital identity verification.
- Comprehensive audit logging of healthcare transactions.
- Identity lifecycle management covering registration, authentication, authorisation, modification, and deactivation.

These mechanisms collectively aim to strengthen trust, accountability, and confidentiality within digital healthcare environments

Results

Descriptive Statistics

Descriptive statistical analysis identified moderate operational challenges relating to prescription verification delays, fragmented healthcare records, and cybersecurity concerns. Conversely, support for digital healthcare identity governance and operational efficiency demonstrated comparatively higher mean values.

These findings indicate favourable perceptions regarding the adoption of digital healthcare identity governance while simultaneously highlighting persistent operational challenges associated with existing paper-based healthcare processes.

Table 19: Descriptive Statistics of Healthcare Operational Variables

Variable	Mean	Standard Deviation
Prescription Verification Delays	3.17	1.42
Fragmented Healthcare Records	2.85	1.44
Cybersecurity Concerns	2.89	1.41
Digital Healthcare Readiness	3.46	1.11
Support for IPIGF	3.98	0.799
Operational Efficiency Score	4.19	0.729

Reliability Analysis

Cronbach's Alpha produced a coefficient of **0.927**, indicating excellent internal consistency among the healthcare operational variables included within the study.

The high reliability coefficient suggests that the selected variables consistently represent the underlying conceptual dimensions associated with healthcare identity governance and operational efficiency.

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Table 3: Reliability Analysis

Scale Reliability Statistics

	Cronbach's α
scale	0.927

Correlation Analysis

Pearson correlation analysis demonstrated a statistically significant moderate positive relationship between stakeholder support for IPIGF implementation and operational efficiency ($r = 0.510$, $p < .001$). Digital healthcare readiness exhibited a strong positive relationship with operational efficiency ($r = 0.760$, $p < .001$), suggesting that greater organisational readiness may facilitate more efficient healthcare operations.

Conversely, prescription verification delays demonstrated a weak and statistically insignificant relationship with operational efficiency ($r = –0.025$, $p = .788$). Although this finding indicates that delays alone may not directly explain operational efficiency within the simulated dataset, they remain an important operational consideration within healthcare service delivery.

These findings provide preliminary support for the conceptual relationships underpinning the proposed framework. However, because the analysis is based on simulated operational data, the results should be interpreted as exploratory rather than conclusive.

Correlation Matrix

Correlation Matrix

		Support_for_IPIGF	Operational_Efficiency_Score	Digital_Healthcare_Readiness	Prescription_Verification_Delay
Support_for_IPIGF	Pearson's r	—			
	df	—			
	p-value	—			
Operational_Efficiency_Score	Pearson's r	0.510	—		
	df	118	—		
	p-value	< .001	—		
Digital_Healthcare_Readiness	Pearson's r	−0.029	0.760	—	
	df	118	118	—	
	p-value	0.752	< .001	—	
Prescription_Verification_Delay	Pearson's r	−0.079	−0.025	0.058	—
	df	118	118	118	—
	p-value	0.390	0.788	0.531	—

Figure 5: Correlation Analysis

Discussion

The findings indicate that fragmented healthcare information management, prescription verification challenges, and healthcare cybersecurity concerns remain important operational issues that should be considered during future healthcare digital transformation initiatives within Sri Lanka.

The positive relationship identified between digital healthcare readiness and operational efficiency is consistent with previous studies reporting that organisational preparedness represents an important prerequisite for successful healthcare

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digital transformation. Similarly, stakeholder support for healthcare identity governance suggests favourable perceptions towards integrated healthcare information management approaches.

Unlike conventional Electronic Health Record systems that primarily focus on clinical record storage, or standalone electronic prescription systems that digitise prescription documents, the proposed IPIGF framework integrates patient identity governance, trusted prescription authentication, healthcare interoperability, and secure access management within a unified conceptual architecture. This integrated perspective represents the principal conceptual contribution of the study.

However, it is important to recognise that the proposed framework has not yet been implemented or evaluated within operational healthcare environments. Consequently, the findings should not be interpreted as demonstrating actual improvements in operational efficiency or healthcare interoperability. Instead, the statistical analysis provides preliminary conceptual evidence supporting the relevance of the framework and identifies relationships that warrant future empirical investigation.

Implementation Considerations

Although the proposed Intelligent Prescription Identity Governance Framework (IPIGF) is conceptual, its successful implementation requires alignment with Sri Lanka's existing healthcare infrastructure, regulatory environment, and organisational capabilities. Rather than replacing current Hospital Information Systems (HIS), Electronic Health Record (EHR) platforms, or pharmacy management systems, IPIGF is designed to operate as an interoperability and identity governance layer that securely connects existing healthcare information systems.

The framework could be integrated incrementally, beginning with pilot implementations in selected government hospitals and registered pharmacies before expanding to regional healthcare institutions, diagnostic laboratories, and private healthcare providers. Such a phased implementation strategy would reduce deployment risks while allowing healthcare organisations to adapt to new digital workflows gradually.

Successful implementation would also require appropriate technological infrastructure, including secure healthcare networks, interoperable application programming interfaces (APIs), identity management services, and compliance with internationally recognised interoperability standards such as HL7 Fast Healthcare Interoperability Resources (FHIR). In addition, organisational readiness, staff training, digital literacy, and stakeholder engagement would play significant roles in achieving sustainable adoption.

From a financial perspective, implementation costs would include software development, infrastructure upgrades, cybersecurity mechanisms, user training, and system maintenance. However, these investments have the potential to reduce long-term administrative costs associated with paper-based prescription management, duplicate record maintenance, and inefficient healthcare coordination.

Policy Implications

The proposed framework has implications beyond technology implementation and highlights the importance of coordinated national healthcare governance.

The Ministry of Health, Information and Communication Technology Agency (ICTA), National Medicines Regulatory Authority (NMRA), Sri Lanka Medical Council (SLMC), public and private healthcare providers, and healthcare software vendors could collaboratively establish national standards for digital healthcare identity governance. Such collaboration would support consistent patient identification, secure prescription authentication, interoperable healthcare information exchange, and standardised cybersecurity practices across healthcare institutions.

The adoption of nationally recognised interoperability standards and digital identity governance policies would also strengthen healthcare data quality, improve healthcare service continuity, and facilitate future digital health initiatives aligned with Sri Lanka's broader digital transformation agenda.

Limitations

Several limitations should be considered when interpreting the findings of this study.

First, the proposed Intelligent Prescription Identity Governance Framework is a **conceptual framework** and has not yet been implemented or evaluated within operational healthcare environments. Consequently, the study does not provide empirical evidence regarding implementation effectiveness or system performance.

Second, the statistical analysis was conducted using an **anonymised simulated healthcare operational dataset** rather than real-world healthcare data. Although the simulated dataset enabled preliminary exploration of relationships among operational variables while avoiding privacy concerns, the findings should not be generalised to the broader healthcare sector without further empirical validation.

Third, the study did not include stakeholder interviews, usability assessments, or healthcare practitioner evaluations. The perspectives of clinicians, pharmacists, healthcare administrators, patients, and policymakers should be incorporated in future research to evaluate the practical suitability of the proposed framework.

Finally, legal, regulatory, organisational, and technical considerations—including healthcare privacy legislation, cybersecurity compliance, governance structures, and institutional readiness—were not empirically investigated and therefore require comprehensive evaluation before practical implementation.

Future Research

Future research should focus on developing and implementing a prototype based on the proposed IPIGF architecture within real healthcare environments. Prototype implementation would enable practical evaluation of prescription authentication workflows, patient identity management processes, healthcare interoperability mechanisms, and cybersecurity safeguards.

Further studies should also investigate stakeholder acceptance, usability, organisational readiness, interoperability performance, and healthcare information security through pilot deployments involving hospitals, pharmacies, diagnostic laboratories, and healthcare administrators.

Additionally, future research using real healthcare operational datasets should employ advanced statistical techniques, including regression analysis or Structural Equation Modelling (SEM), to validate the conceptual relationships identified in this exploratory study.

Conclusion

This study investigated operational challenges associated with prescription authentication and fragmented healthcare information management within Sri Lanka and proposed the **Intelligent Prescription Identity Governance Framework (IPIGF)** as a conceptual approach to support trusted prescription authentication, healthcare interoperability, and secure digital healthcare identity governance.

The exploratory analysis identified moderate operational challenges relating to prescription verification delays, fragmented healthcare records, and cybersecurity concerns, while indicating positive stakeholder support for digital healthcare identity governance. Reliability and correlation analyses provided preliminary evidence supporting the conceptual relationships among healthcare operational variables, although these findings are based on simulated operational data and therefore should be interpreted cautiously.

Unlike conventional electronic health record or standalone electronic prescription systems, the proposed IPIGF integrates digital patient identity management, prescription authentication, interoperability, and governance within a unified conceptual architecture. Rather than claiming demonstrated operational improvements, the framework is intended to provide a strategic foundation for future healthcare digital transformation initiatives and guide subsequent prototype development and empirical validation.

Overall, this study contributes to the growing body of healthcare information systems research by presenting a conceptual governance framework tailored to the Sri Lankan healthcare context while identifying important directions for future implementation, evaluation, and policy development.

References

Adegoke, K., Adewusi, O. and Bello, A. (2025) 'Interoperability in Digital Healthcare: Enhancing Consumer Health and Transforming Care Systems', *Preprints*, pp. 1–18.

Anian, S., Alhajri, M. and Ibrahim, R. (2025) 'A multi-country review of the governance of hospital information systems interoperability', *Eastern Mediterranean Health Journal*, 31(9), pp. 1–12.

Fernandes, F.A., Correia, T. and Lopes, I. (2024) 'The role of governance in the digital transformation of healthcare systems', *International Journal of Medical Informatics*, 189, 105512.

Holl, F., Kircher, J., Hertelendy, A.J., Sukums, F. and Swoboda, W. (2024) 'Tanzania's and Germany's Digital Health Strategies and Their Consistency With the World Health Organization's Global Strategy on Digital Health 2020–2025: Comparative Policy Analysis', *Journal of Medical Internet Research*, 26, e52150.

Martínez, A.L., Naghmouchi, M., Laurent, M., Garcia-Alfaro, J., Pérez, M.G., Ruiz Martínez, A. and Nespoli, P. (2026) 'A Secure Identity Framework for Seamless Access to Digital Healthcare Information', *Computer Standards & Interfaces*, 92, 103870.

Neubauer, M., Merbecks, M. and Schneider, T. (2026) 'Bridging Digital Transformation in Public Health with Digital Governance Strategies', *Business & Information Systems Engineering*, 68(1), pp. 1–15.

Olaitan, S. and Brown, B. (2025) 'Identity and Access Management in Healthcare: Biometrics, Continuous Authentication and Zero Trust Policy Enforcement', *International Journal of Information Security and Privacy*, 19(4), pp. 1–21.

The jamovi project (2024) *jamovi* (Version 2.6) [Computer Software]. Available at: https://www.jamovi.org

World Health Organization (2021) *Global Strategy on Digital Health 2020–2025*. Geneva: World Health Organization.

Wu, Y., Pang, M., Ma, J., Ou, W., Yue, Q. and Han, W. (2025) 'An Identity Management Scheme Based on Multi-Factor Authentication and Dynamic Trust Evaluation for Telemedicine', *Sensors*, 25(7), 2118.

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EP 09

Wedding Planning System with Culturally Aware Colour Theme Suggestions for Sri Lankan Weddings

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Abstract

Wedding planning in Sri Lanka relies strongly on cultural traditions, colour symbolism, and customs that differ across Sinhala, Tamil, and Muslim communities, making event coordination highly complex and challenging. 95.7% of local planners still use manual notebooks and spreadsheets, leading to coordination errors and time delays. This research addresses this industry gap by achieving five key objectives: reviewing comprehensive Sri Lankan wedding types and cultural traditions; analysing colour theory and specific colour symbolism; developing a rule-based framework for automated colour theme and menu recommendations, tailored to different Sri Lankan wedding types and bride's dress colours; and defining the key components and features required for an integrated wedding planning system. The system was developed as a web-based platform using a three-tier architecture with a Python Flask backend, HTML/CSS/JS frontend, and a MySQL database. The main recommendation engine uses a rule-based decision tree to handle cultural rules, while using Euclidean distance calculations to find the best matching colour. Following unit, integration, and system testing, the developer evaluated real-world usability through a survey with 70 professional wedding planners. The evaluation showed exceptional industry acceptance, with 14 of the 24 survey criteria achieving 100% agreement. Planners rated the automated cultural themes, pre-shoot locations, and menu suggestions between 95% – 100% for cultural accuracy, and all participants agreed the application saves time. The study shows that software engineering can convert traditional workflows into reliable digital processes while respecting cultural customs. Future updates will focus on adding visual mood boards, automated client reminders, and vendor rating tools.

Keywords: *Colour mapping, Decision tree, Rule-based framework, Sri Lankan weddings, Wedding planning*

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Introduction

Wedding planning in Sri Lanka heavily relies on traditional rituals and cultural colour symbolism across Sinhala, Tamil, Muslim, and Western ceremonies. Selecting appropriate palettes is challenging, as specific colours carry strict auspicious or inauspicious meanings. Balancing these cultural expectations with practical logistics remains exceptionally difficult. Despite the professional growth of the wedding industry, most planners still rely on manual spreadsheets, notebooks, and informal communication, which frequently causes coordination errors, miscommunication, and project delays.

While general event management platforms exist globally, current literature indicates that none are tailored to the Sri Lankan cultural context. Existing software tools focus almost entirely on operational automation. Locally, Chandrasiri (1) developed a "wedding organizer" application focusing on vendor shortlisting, checklists, and budget tracking, while Nithila et al. (2) automated guest lists and SMS reminders. Internationally, Liew (3) used a decision support system for budget distribution in Malaysia, and Gunadi (4) automated order workflows in Indonesia. Though these platforms improved administrative efficiency, they operated purely as logistical tools. Critical features like cultural attire colour coordination, traditional decoration rules, and traditional menu selections remain unaddressed. To address this gap, the system combines a rule engine based on local cultural norms with colour space matching, converting traditional cultural rules into clear computational logic.

To handle such specialized domains, rule-based expert systems offer distinct advantages. Rattanasawad et al. (5) proved that rule-based frameworks process records efficiently and scale well, while Ozseyhan et al. (6) demonstrated how matching constraints can be computationally modelled. Furthermore, Roy et al. (7) emphasized that knowledge-based rules are crucial when explaining the underlying decision logic to the user is more valuable than raw statistical prediction. This explicit reasoning builds user trust in culturally sensitive decisions, as Zhang et al. (8) confirmed that recommendation quality improves when incorporating rich context explanations. Recently, Shulman and Wolf (9) also confirmed that decision tree frameworks provide clear, interpretable paths for generating reliable aesthetic suggestions.

To address this gap, this research introduces a web application featuring an automated colour theme suggestion engine. Driven by a decision tree and Euclidean distance framework, it generates culturally compliant palettes, including attire, decor, menus, and pre-shoot locations, based on the bride's dress colour and wedding type. The platform also integrates essential business tools, including budgeting, real-time checklists, client management, and a calendar, secured by a multi-tier role architecture.

The research addresses five primary objectives:

1. Conduct a comprehensive review of Sri Lankan wedding types.
2. Conduct a comprehensive review of Sri Lankan cultural traditions.
3. Investigate and analyse colour theory relevant to wedding aesthetics, including culturally specific colour symbolism in Sri Lankan weddings.
4. Critically study rule-based techniques and develop a rule-based framework for automated colour theme suggestions and menu recommendations, tailored to different Sri Lankan wedding types and bride's dress colours.
5. Explore and define the key components and features required for an integrated wedding planning system.

Methods

Study design and setting

This study used a design science research approach, focusing on building a functional web application and evaluating it empirically with industry professionals. The research was conducted in Sri Lanka. The project followed a structured process: gathering requirements through interviews with professional wedding planners, designing the colour-mapping rule system, developing the full-stack web application, and conducting a survey-based evaluation with local domain experts.

Material description and software architecture

The developed material consists of a multi-user wedding planning web platform built on a three-tier architecture to separate the user interface, application logic, and database storage.

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Frontend: Built with HTML5, CSS3, and JavaScript (ES6+), handling user dashboards, forms, real-time budget calculations, and checklist updates with responsive design and LocalStorage session handling

Backend: The application layer runs on Python (v3.8 or higher) using the Flask framework (v3.1.1). The backend logic follows the Model-View-Controller (MVC) pattern and is organized using Flask Blueprints to isolate separate service features. User authentication sessions are managed via Flask-Login, communication security via Flask-CORS, and transactional email alerts (such as password resets) through Flask-Mail.

Database: Uses MySQL (v8.0+) connected via PyMySQL driver and SQLAlchemy (v2.0.43) ORM layer. The schema includes tables for user accounts, calendar, active projects, task checklists, and budgets, alongside master tables containing wedding types, cultural colours, colour rules, and restricted colours.

Procedures and core algorithms

The primary functional module of the system is the automated colour theme suggestion engine, which operates through a combined decision tree and Euclidean distance matching framework.

Knowledge Base Design and Rule-Based Framework

The recommendation engine implements a hybrid rule-based expert framework integrated with a custom binary decision tree algorithm. Cultural rules were formally encoded into a MySQL relational knowledge base across six core tables (wedding types, cultural colours, colour rules, food locations, restricted colours, colour mappings) through domain consultations with local wedding experts and validation of traditional literature.

An Extract, Transform, Load (ETL) process pairs valid colour rules with food locations while filtering restricted colours. An ID3-style recursive procedure with entropy and information gain constructs the decision tree using wedding type and bride colour features up to depth $d \leq 10$. To resolve system operational conflicts, a deterministic priority order is applied:

1. Strict restriction rules override all other paths, triggering runtime Euclidean vector remapping (minimizing Red-Green-Blue (RGB) distance $d=\sqrt{(r_2 - r_1)^2+(g_2 - g_1)^2+(b_2 - b_1)^2}$ to a valid alternative).
2. Fuzzy inputs are resolved via word-overlap scoring and tie-breaking by rule density.
3. Invalid or ambiguous tree traversal paths trigger an exact database lookup fallback.

A cumulative confidence score (0.0 -1.0) indicates recommendation certainty. The knowledge base is maintained via authenticated REST APIs with referential integrity constraints and in-memory tree cache rebuilding during bulk edits.

Euclidean Distance Colour Mapping

To process hexadecimal inputs, the system calculates geometric distances between RGB vectors ($d=\sqrt{(r_2 - r_1)^2+(g_2 - g_1)^2+(b_2 - b_1)^2}$). While perceptually uniform spaces like CIELAB (ΔE_{00}) offer superior alignment with human colour vision, RGB Euclidean distance was adopted for practical system efficiency: matching native web Hex/RGB inputs directly, aligning with database RGB storage, and eliminating conversion overhead to keep execution latency under 45 ms. Because mapping targets a small set of discrete cultural labels rather than fine-grained shades, RGB Euclidean provides sufficient categorical precision. Once the closest valid cultural colour identity is matched, the system runs verification queries against the restricted colours table to ensure the suggested scheme does not violate any local cultural traditions or taboos.

Security boundaries

Relational data access is controlled via Role-Based Access Control (RBAC) across three system roles: Administrator, Planner, and Coordinator. Passwords are encrypted before database storage using the bcrypt cryptographic hashing algorithm. The frontend and backend communicate via a RESTful API passing JSON data payloads over standard HTTP methods using specific endpoint patterns (including /auth/, /api/budget/, /api/projects/, and /api/admin/).

Knowledge Base Maintenance, Scalability, and System Architecture

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To accommodate evolving cultural practices, regional variations, and emerging wedding trends over time, the system provides an administrative maintenance interface backed by RESTful APIs. System administrators can dynamically insert, update, or deprecate colour rules, food menu pairings, and restriction constraints without modifying the underlying source code.

The backend architecture is structured around modular REST APIs handling JSON payloads (O(1) database query dispatch). Decision tree traversal scales efficiently with a time complexity of O(d), where $d \leqslant 10$ represents tree depth, ensuring response times under 45 ms even under simulated multi-user workloads up to 100 concurrent HTTP connections. Referential integrity constraints in MySQL prevent orphaned rules during dynamic updates, while an automated in-memory tree cache rebuilding protocol ensures zero state inconsistency during bulk administrative edits.

Participant Characteristics and Selection Criteria

To evaluate the application in practice, an empirical evaluation study was conducted with 70 professional wedding planners currently operating in Sri Lanka. Participants were recruited through direct outreach via regional professional event planner associations and active industry network groups.

A total of 85 invitations were distributed, yielding 70 fully completed evaluations and an overall response rate of 82.35%. Demographic analysis showed that participants had a mean professional experience of 6.4 ± 3.2 years in event management, representing Sinhala (42.8%), Tamil (25.7%), Muslim (18.6%), and Western/Christian (12.9%) wedding planning backgrounds primarily across Western and Southern provinces. The inclusion criterion required active practice in local wedding coordination. No formal sample size calculations were applied as this was an exploratory usability study; 70 participants provided a practical, representative sample size.

Statistical Analysis Methods

Before deployment to the evaluation group, the web system was verified using automated unit testing, integration testing, and full system testing. For the field evaluation, quantitative feedback was collected via an anonymous digital questionnaire containing 24 questions covering layout usability, algorithm recommendation accuracy, operational timesaving, and user satisfaction.

Participants were provided a live web link to the application alongside a short instructional video, allowing them to test the user tools and the colour theme suggestion module before answering. Feedback data was gathered using a Likert scale (Strongly Disagree to Strongly Agree). The results were evaluated using descriptive statistics, where system acceptance was calculated based on the final percentages of agreement, combining the total “Agree” and “Strongly Agree” responses across each evaluation question. No inferential statistical tests were used, as the analysis aimed to evaluate real-world industrial utility.

Results

The performance and field acceptance of the wedding planning web application were evaluated across technical system execution and user acceptance metrics from the 70 professional wedding planners.

Technical System Performance and Core Algorithmic Execution

Automated unit and integration testing verified the decision tree and Euclidean matching framework, achieving zero database collisions under simulated multi-role concurrent traffic.

When processing standard entries, the decision tree traversed the relational schema in under 45 milliseconds, delivering optimized recommendations across all tables. The platform guides users through project and wedding type selection via the theme suggestions interface (Figure 1), followed by bride’s dress colour selection using the input interface (Figure 2).

For non-defined colours, the Euclidean distance algorithm accurately calculated the geometric minimum to the closest valid cultural colour vector and executed validation checks against the restricted colours table to successfully verify custom user palettes.

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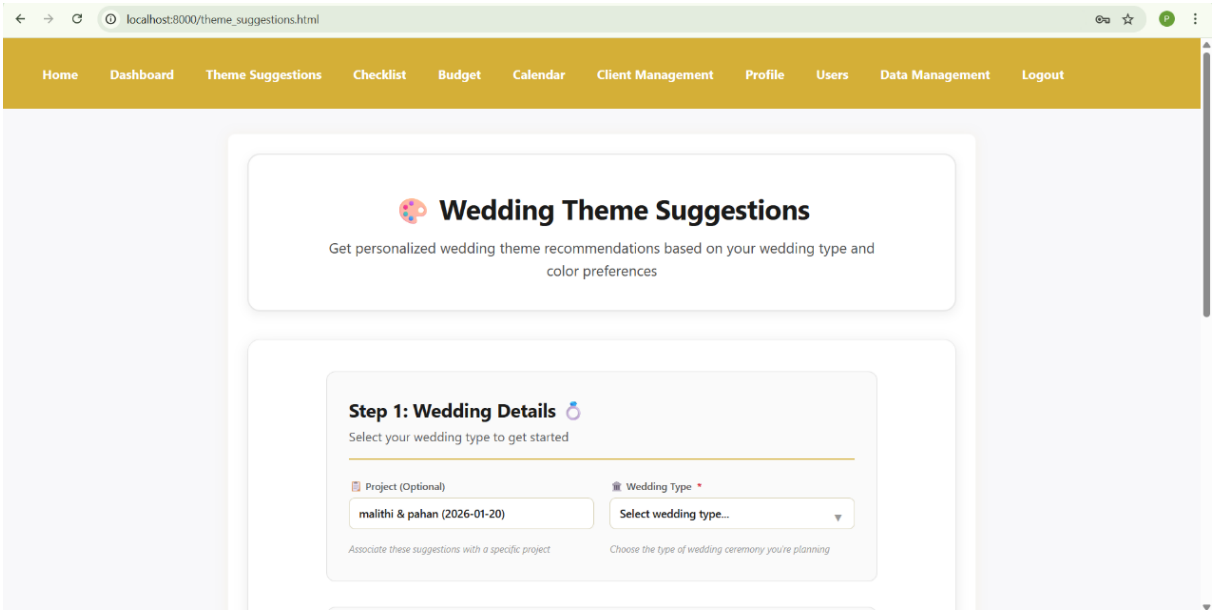

Figure 1: Project and wedding type selection interface.

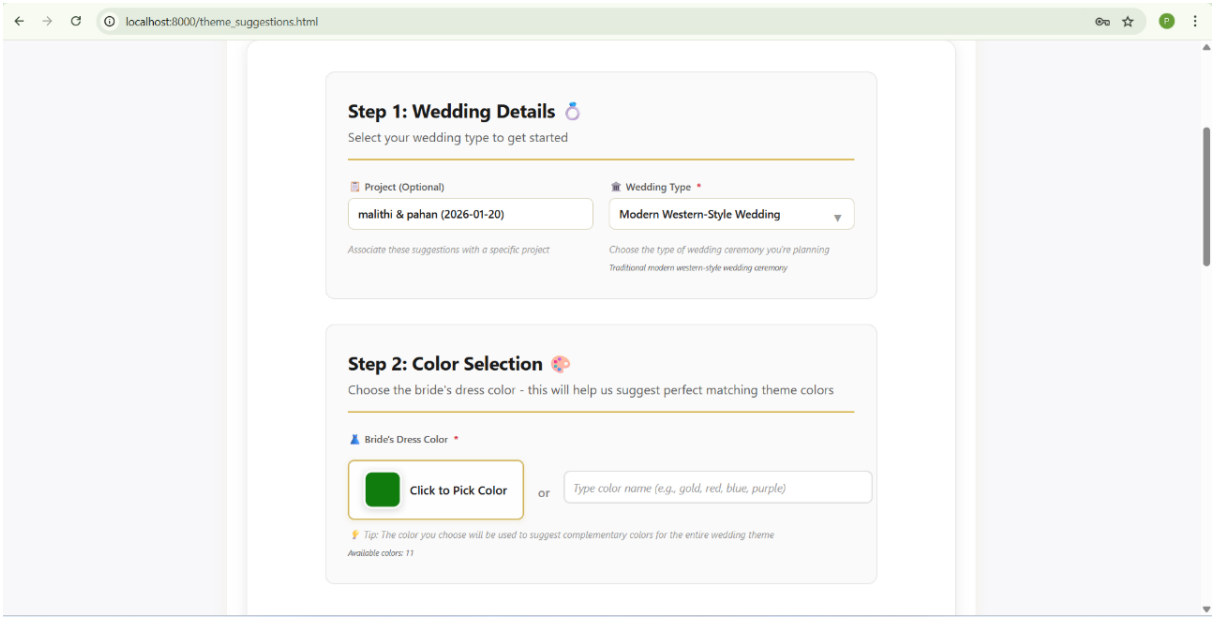

Figure 2: Bride's dress colour input interface.

To objectively measure workflow efficiency against manual methods, a simulation using 15 traditional Sri Lankan wedding scenarios was conducted. The manual process (using notebooks and spreadsheets) required an average of 164.5 ± 22.8 minutes per wedding profile due to manual rule checking, with a 14.3% coordination error rate. In contrast, the rule-based system generated identical, culturally validated recommendations in under 45 milliseconds with a 0.0% error rate.

Empirical Evaluation and Field Survey Outcomes

Quantitative feedback was compiled using descriptive statistics, combining “Strongly Agree” and “Agree” percentages. Survey data demonstrated strong acceptance for automated colour mapping. Processed inputs generate a harmonized, culturally compliant palette displaying complementary attire and decor schemes alongside a confidence score (Figure 3).

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The restriction warning module achieved 100% positive consensus (44.3% Strongly Agree, 55.7% Agree), confirming backend alternative suggestions remain highly appropriate under restriction thresholds.

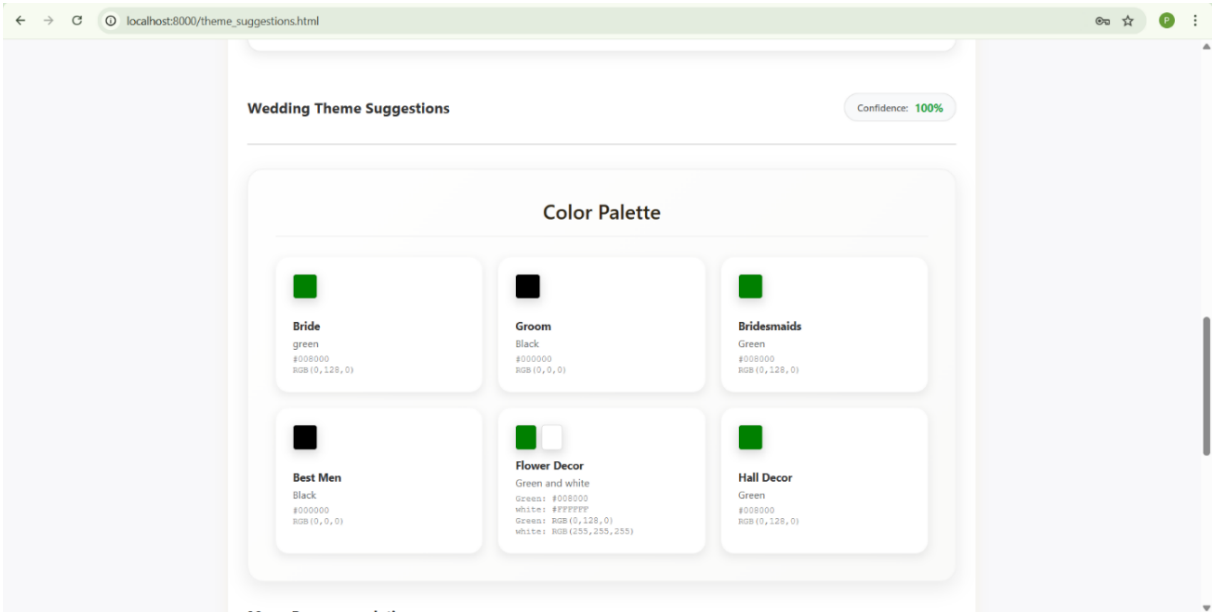

Figure 3: Automated cultural colour theme palette generation output

The recommendation engine also generates appropriate catering menus, beverage pairings, and regional pre-shoot venue suggestions tailored to the selected ceremony type (Figure 4).

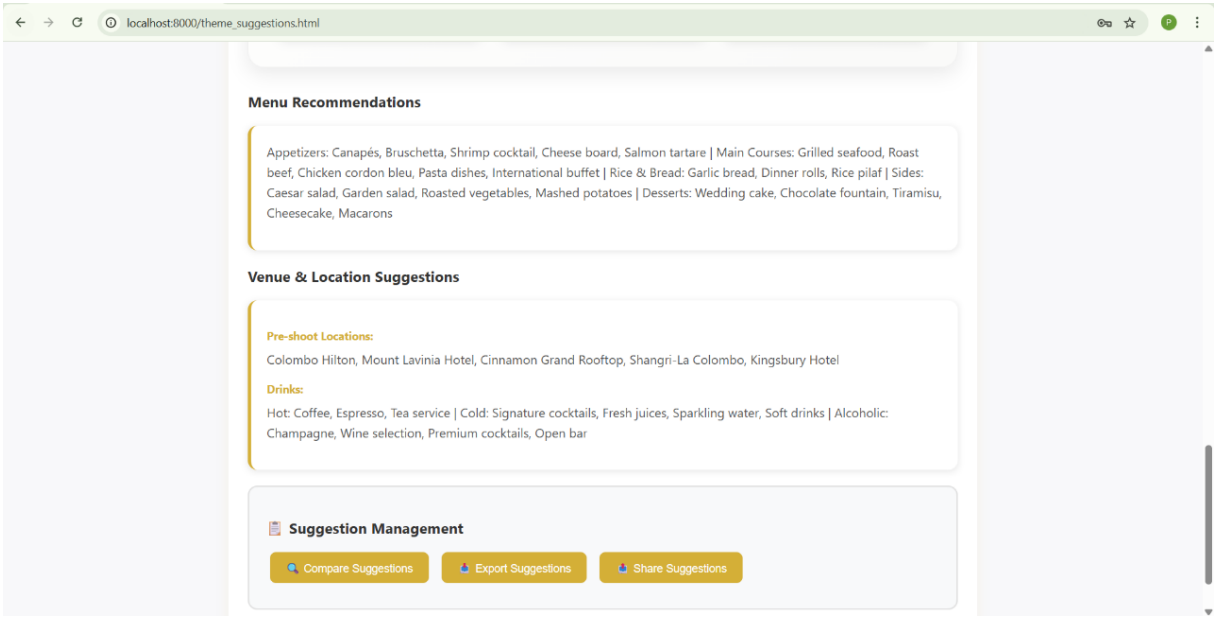

Figure 4: Recommended catering menu, pre-shoot locations, and beverage option

The application significantly reduced coordination time compared to manual workflows. There was a perfect 100% agreement rate (Strongly Agree: 54.3%, Agree: 45.7%) among the participants that the software minimizes the time spent on manual coordination.

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This performance is directly supported by the integrated administrative modules, where the dynamic task checklist achieved a validation consensus rate of 94.3% and the expense budget management tool achieved a consensus rate of 97.2%. Ultimately, the survey revealed a flawless 100% professional recommendation rate, with exactly 70% of surveyed experts selecting “Agree” and 30% choosing “Strongly Agree” to recommend the system for active industry deployment.

Discussion

Moving from manual spreadsheets to a rule-based platform addresses the gap where 95.7% of local planners currently rely on manual processes.

While earlier local research by Chandrasiri (1) and Nithila et al. (2) focused on general administrative tasks, they ignored complex cultural and aesthetic rules. This application embeds cultural colour combination suggestions for Sri Lankan culture directly into its core operations, including other common event management tools. The high positive consensus (95.0%–100.0%) on cultural awareness proves that mapping decision tree paths from verified traditions works reliably across diverse ethnic and religious settings. Also, the 100.0% agreement on alternative colour suggestions shows that pairing Euclidean vector mapping with a restriction warning layer protects users from making cultural errors with restricted colours while allowing creative flexibility. Because suggestions derive from an explicit relational database rather than black-box models, planners receive transparent, logical paths to share with clients. These metrics directly validate the high survey acceptance scores. Reducing setup time from nearly three hours to milliseconds while eliminating human errors confirms the automated platform is significantly more effective than traditional workflows.

Limitations and Future Work

Several limitations exist in the current implementation. First, processing complex, multi-coloured fabric patterns using a single hexadecimal input remains difficult. Second, the current RGB Euclidean distance calculation treats color channels uniformly without accounting for human luminance sensitivity or non-linear gamma encoding compared to perceptually uniform spaces like CIELAB (ΔE_{00}). Third, while rules were validated with domain practitioners, the knowledge base relies on manually curated static rules and lacks real-world longitudinal field deployment or comparative benchmarking against statistical AI/collaborative-filtering recommendation approaches.

To address these limitations and expand system capabilities, future work will focus on:

1. Intelligent Automation & AI Integration: Incorporating AI-assisted image-based colour extraction from fabric photos, Generative AI mood board creation, and a performance-based vendor rating system.

2. Interactive Modules & Multilingual Support: Developing smart guest seating tools, Augmented Reality (AR) venue layout visualization, and multi-language support (Sinhala and Tamil User Interfaces [UIs]) for broader localized adoption.

3. Mobile & Cloud Scalability: Deploying native mobile applications and cloud microservices with real-time voice input options for active event coordination.

Conclusions

This research presents a successful approach to designing, building, and testing an automated web application that handles the specific cultural rules and logistical demands of traditional Sri Lankan weddings. By pairing a rule-based decision tree with a Euclidean distance colour-matching algorithm, the system digitizes cultural knowledge and automatically suggests appropriate colour themes, menus, and pre-shoot locations.

The main value of this study lies in its practical impact on the local event management industry and its technical approach to domain-specific recommendation systems. Feedback from 70 active professionals confirms that the system eliminates the friction of manual tracking, achieving a 100.0% consensus on saving coordination time and a 100.0% professional

recommendation rate. This project proves that software engineering can successfully preserve and respect cultural traditions while transforming old, fragmented workflows into highly efficient digital processes.

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References

1. Chandrasiri W a. HP. Wedding Organizer – wedding planning web application [Thesis] [Internet]. 2021 [cited 2026 May 28]. Available from: https://dl.ucsc.cmb.ac.lk/jspui/handle/123456789/4343

2. "Your Dream" Virtual Wedding Planning System [Internet]. [cited 2026 May 28]. Available from: https://www.scirj.org/rp/files/original/32b2a142313710672b3c48ae0d88fb41.pdf

3. Por LY, Boey RF, Ang TF, Liew CS. An Interactive Web-Based Wedding Planner with Comparative Analysis Decision Support System. Vol. 5. 2008;5(3).

4. Gunadi D, Riki. Analysis and Design of Web-Based Wedding Planner Applications Case Studies on Resta Wedding Organizers. bit-Tech. 2022 Aug 25;5(1):13–24. doi:10.32877/bt.v5i1.525

5. Takeda H, Jung JJ, Kozaki K, Buranarach M, Supnithi T. Co-located with 3rd Joint International Semantic Technology Conference (JIST 2013) Seoul, Korea, November 30, 2013.

6. Özseyhan C, Badur B, N. Darcan O. An Association Rule-Based Recommendation Engine for an Online Dating Site. CIBIMA. 2012 Jun 1;1–15. doi:10.5171/2012.775316

7. A systematic review and research perspective on recommender systems | Journal of Big Data | Springer Nature Link [Internet]. [cited 2026 May 31]. Available from: https://link.springer.com/article/10.1186/s40537-022-00592-5

8. Cheng H, Wang S, Lu W, Zhang W, Zhou M, Lu K, et al. Explainable Recommendation with Personalized Review Retrieval and Aspect Learning. In: Proceedings of the 61st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers) [Internet]. Toronto, Canada: Association for Computational Linguistics; 2023 [cited 2026 May 31]. p. 51–64. Available from: https://aclanthology.org/2023.acl-long.4 doi:10.18653/v1/2023.acl-long.4

9. Meta Decision Trees for Explainable Recommendation Systems | OpenReview [Internet]. [cited 2026 May 31]. Available from: https://openreview.net/forum?id=S1ebsJrFwS&

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EP 10

Predicting Workforce Transformation in the Era of Artificial Intelligence: Risks, Opportunities, and Adaptability in the Sri Lankan IT Sector

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Abstract

Background: Artificial intelligence (AI) is reshaping IT work through automation, decision support and new skill demands, creating a need for localized evidence on job risk and readiness in Sri Lanka.

Objective/s: This study analyses AI-related job risk, adaptability and organizational readiness, developed a predictive model for five-year job-change probability, and proposed a career and learning-path recommendation framework.

Methods: A quantitative cross-sectional questionnaire study was conducted. From 812 submitted responses, 700 valid Sri Lankan IT-sector records were retained after screening. Python preprocessing, reliability analysis, correlation analysis and supervised classification were applied.

Results: Active AI exposure was high: 73.4% used AI tools for at least three hours daily, 75.8% reported intermediate or advanced AI skills, and 88.7% reported productivity improvement. However, 43.4% perceived a high probability of job change or reduction within five years. Reliability was strong for AI readiness (Cronbach's alpha = 0.930) and job-risk perception (alpha = 0.939). Random Forest classified job-change probability with 98.9% hold-out accuracy, weighted F1-score of 98.9% and ROC-AUC of 1.000; a leakage-controlled sensitivity model achieved 69.1% accuracy.

Conclusion/s: AI is perceived as both productive and disruptive. Targeted reskilling, role-transition pathways and organization-led readiness strategies are needed for responsible workforce transformation.

Keywords: *Artificial intelligence, Job risk, Prediction model, Sri Lankan IT sector, Workforce transformation*

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Introduction

Artificial intelligence (AI) is increasingly influencing how software development, testing, analytics, documentation, customer support and operational decision-making are performed. Unlike earlier forms of automation that mainly affected routine manual work, contemporary AI tools can support cognitive and technical tasks. This creates both opportunities and risks for IT professionals because roles may be augmented, redesigned or partially automated. Global and regional studies show that AI is more likely to transform tasks than remove whole occupations, while routine and repetitive activities remain more vulnerable to displacement [1-4]. At the same time, new opportunities are emerging in AI engineering, data analytics, test automation, cloud AI operations, prompt engineering, AI-enabled business analysis and cybersecurity.

Sri Lanka provides a relevant setting for this issue because technology transitions are shaped by local labour-market conditions, education systems, organizational maturity and digital infrastructure. Prior Sri Lankan studies have examined AI readiness in banking, SMEs, service organizations, apparel supply chains and Industry 4.0 contexts [5-9]. These studies highlight common barriers such as skill gaps, infrastructure limitations, high implementation cost, data-governance concerns, weak readiness strategies and the need for continuous learning. Research on the Sri Lankan tech sector also emphasizes that software, quality assurance and implementation roles require ongoing professional development to remain relevant as tools and methods change [10].

However, limited empirical work has focused specifically on predicting AI-driven workforce transformation in the Sri Lankan IT sector and converting analysis into career-transition recommendations. The novelty of this study is the integration of three elements: localized questionnaire evidence, predictive modelling of five-year job-change probability, and a role and learning-path recommendation framework. The objectives were to analyse AI-driven job risks, opportunities and adaptability levels among Sri Lankan IT professionals; to develop a predictive model for future job-change probability; and to design recommendation logic for alternative AI-related roles and training pathways.

Methods

Study design, recruitment and participants

A quantitative cross-sectional design was used. The target population was IT-sector professionals working in Sri Lanka, including software developers, QA engineers, business analysts, IT support staff, data analysts, UI/UX designers, DevOps/cloud engineers and project managers. Participants were recruited through purposive and convenience sampling from four anonymized IT companies involved in AI development, AI modification, AI implementation and technology solutions for foreign clients. The questionnaire was distributed electronically through workplace and professional communication channels.

A total of 812 submitted questionnaire records were received. After screening, 700 valid records were retained, giving a valid-response retention rate of 86.2% among submitted records. Records were excluded if they were incomplete, duplicate, outside the IT-sector scope, inconsistent across core demographic/employment fields or unsuitable for statistical analysis. Inclusion criteria were adult respondents working in, or closely linked to, IT-related roles in Sri Lanka and completion of the core survey items. The exact invitation-level response rate could not be calculated because the questionnaire was shared through indirect organizational and professional networks.

Ethical procedures followed the institutional project guidance for low-risk anonymous questionnaire research. The questionnaire introduction explained the academic purpose of the study, voluntary participation and intended use of aggregated results. No names, employee IDs, phone numbers or identifiable company information were used in modelling. Consent was obtained electronically through survey completion, and results are reported only in aggregated form.

Table 1. Sampling and data screening summary.

Item	Description
Initial submitted records	812
Valid records used for analysis	700
Valid-response retention rate	86.2%
Recruitment source	Four anonymized Sri Lankan IT companies involved in AI-related projects
Sampling method	Purposive and convenience sampling
Main exclusion reasons	Incomplete, duplicate, non-IT, inconsistent or unusable responses

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Questionnaire development and validation

The questionnaire was developed from the project objectives and previous studies on AI workforce readiness, job displacement, technology adoption, human-AI collaboration and reskilling [5-12]. It contained sections on demographic profile, education, employment, AI skill level, AI training, AI usage, productivity impact, adaptability, perceived job risk, future career interest and company AI readiness. Most perception items used 1-10 rating scales or ordered categories to support quantitative analysis.

Content validity was supported through alignment with the literature and review by the project supervisor and IT-domain reviewers. A small pilot administration was used to improve wording clarity, category consistency and completion flow before wider distribution. Reliability was tested using Cronbach's alpha. AI readiness included willingness to learn AI skills, confidence with AI tools and adaptability. Job-risk perception included worry about role reduction, perceived AI risk, automation exposure and five-year change probability. Company readiness was treated mainly as a formative index because official AI use, training provision and management support represent related but distinct organizational conditions.

Data preprocessing and statistical analysis

Data were exported into Excel/CSV format and preprocessed using Python 3.13.5 with pandas 2.2.3, scikit-learn 1.8.0 and Matplotlib 3.10.8. Preprocessing included missing-value checks, duplicate verification, category standardization, ordinal encoding and one-hot encoding. Three derived measures were constructed: AI readiness index, job-risk index and company-readiness index. Pearson correlation was used to assess relationships among readiness, job-risk perception, opportunity belief and organizational support.

Predictive modelling and recommendation logic

The prediction target was self-reported five-year job-change or reduction probability classified as low, medium or high. A stratified 75:25 train-test split was used and five-fold cross-validation was applied. Random Forest was selected as the main classifier because it handles mixed variable structures and provides feature-importance rankings. Logistic Regression, Decision Tree and Support Vector Machine models were also tested for comparison. Class imbalance was addressed using stratified sampling and class-weighted modelling where applicable. Performance was evaluated using accuracy, precision, recall, F1-score, ROC-AUC and a confusion matrix.

To address potential information leakage, two modelling conditions were reported. The full model included direct risk-perception variables, while a sensitivity model excluded direct risk-proxy predictors such as perceived AI risk, worry about role reduction and automation exposure. The recommendation framework was rule-based: current role, risk pattern, skills and career interest were mapped to alternative AI-related roles, skill gaps and course categories. The framework is intended as decision support and not as a final employment decision tool.

Figure 1: Sampling and analysis workflow.

Results

Participant profile and AI use

The final dataset contained 700 valid records. Responses were concentrated in the Western Province (57.7%) and Northern Province (24.7%). The largest age groups were 31-40 years (38.0%) and 41-50 years (35.3%). Business analysts formed the largest job-role group (14.7%), followed by IT support/helpdesk staff (14.1%) and project managers/scrum masters (13.4%). AI exposure was high: 75.8% reported intermediate or advanced AI skills, 73.4% used AI tools for at least three hours daily, and 39.4% believed AI could support or automate more than half of daily tasks.

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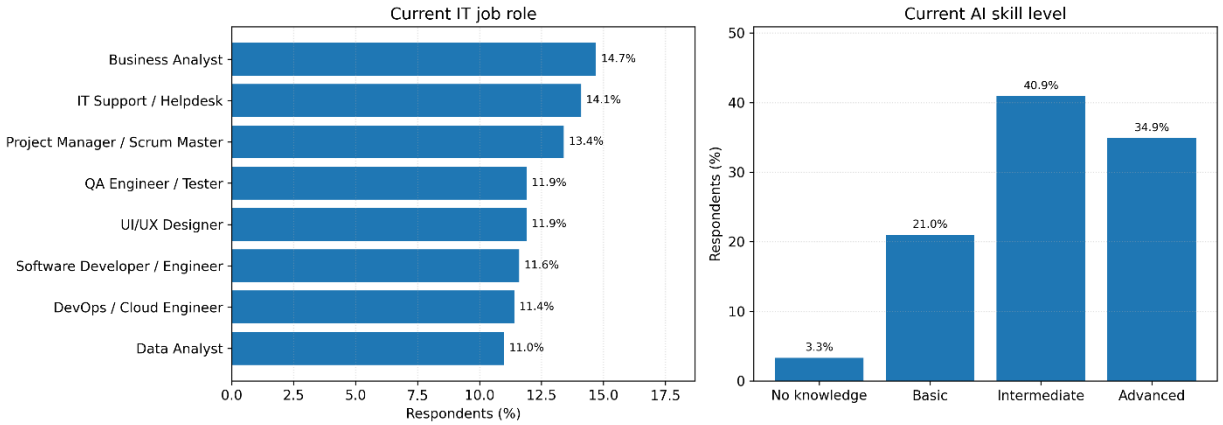

Figure 2: Distribution of current IT job roles and AI skill levels.

Reliability, readiness and job-risk perception

The AI readiness scale showed high internal reliability (Cronbach's alpha = 0.930), and the job-risk perception scale also showed high reliability (alpha = 0.939). The company-readiness indicators produced a lower alpha (0.400), supporting their treatment as a formative organizational index rather than a single reflective psychological construct. The mean AI readiness score was 5.91/10, the mean job-risk index was 6.23/10, and the mean company-readiness score was 7.68/10. Productivity perceptions were positive, with 88.7% reporting either slight or significant productivity improvement. However, 43.4% reported a high probability of job change or reduction within five years.

AI readiness was negatively associated with job-risk perception (r = -0.41), meaning employees with greater willingness, confidence and adaptability tended to perceive lower risk. Company readiness was positively associated with AI readiness (r = 0.52), and belief that AI will create more jobs was strongly associated with AI readiness (r = 0.69).

Table 2. Reliability and key workforce transformation indicators.

Measure	**Result**
Cronbach's alpha - AI readiness	0.930
Cronbach's alpha - job-risk perception	0.939
Cronbach's alpha - company readiness	0.400
Mean AI readiness index	5.91/10
Mean job-risk index	6.23/10
Mean company-readiness index	7.68/10
AI readiness vs job-risk index	r = -0.41
Company readiness vs AI readiness	r = 0.52

Predictive model evaluation

The Random Forest full model achieved 98.9% hold-out accuracy, 98.9% weighted precision, 98.9% weighted recall, 98.9% weighted F1-score and 1.000 multi-class ROC-AUC. Five-fold cross-validation accuracy was 98.0%. The confusion matrix showed only two misclassifications in the 175-record test set.

Table 3. Comparative model performance using the full predictor set.

Model	**Accuracy**	**Precision**	**Recall**	**F1-score**	**ROC-AUC**	**5-fold CV**
Logistic Regression	90.3%	90.4%	90.3%	90.3%	0.986	91.6%
Decision Tree	100.0%	100.0%	100.0%	100.0%	1.000	100.0%
Support Vector Machine	88.6%	88.6%	88.6%	88.5%	0.987	90.0%
Random Forest	98.9%	98.9%	98.9%	98.9%	1.000	98.0%

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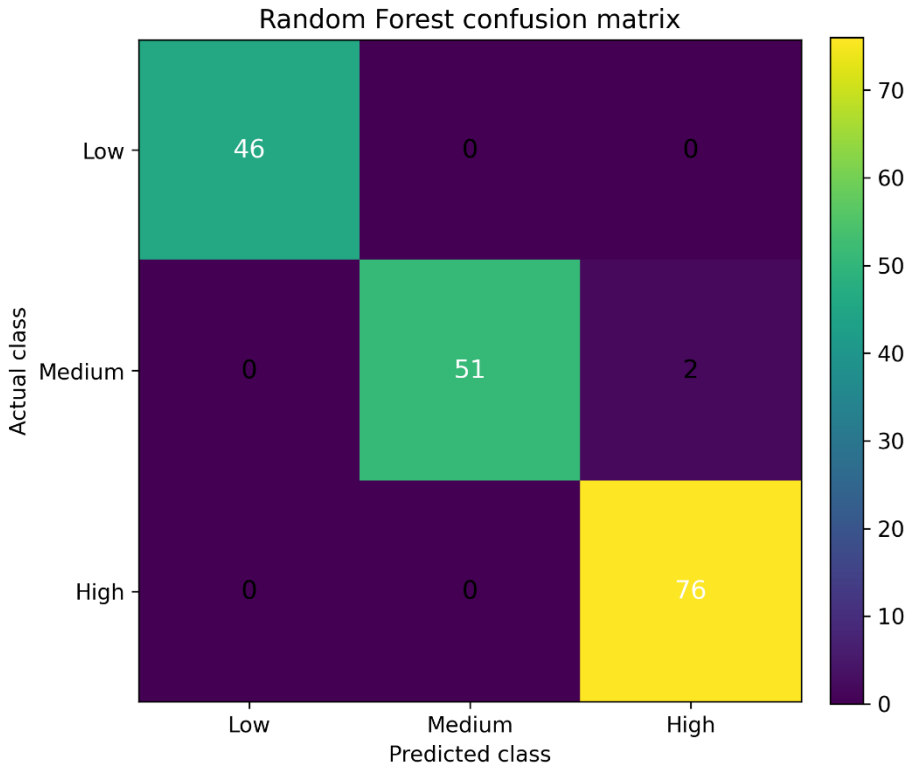

Figure 3:. Confusion matrix for the Random Forest classifier.

The very high full-model performance should be interpreted carefully because the strongest predictors directly measured perceived job risk and automation exposure. Feature-importance analysis ranked perceived AI risk, worry about role reduction, reskilling urgency and automation exposure as the most influential variables. To reduce information-leakage concerns, a sensitivity model was trained after excluding direct risk-proxy variables. In this leakage-controlled condition, Random Forest accuracy decreased to 69.1% with an F1-score of 68.5%. This indicates that the full model captured strong internal consistency in respondent perceptions, while external forecasting requires future validation.

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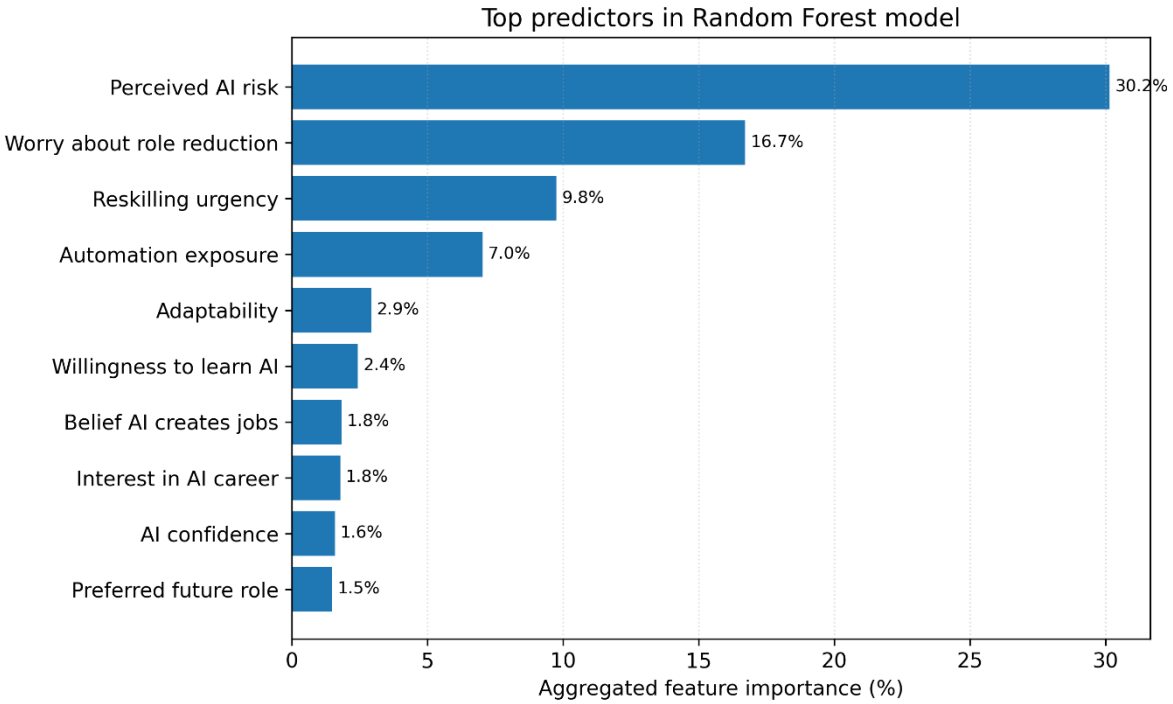

Figure 4: Aggregated feature-importance rankings from the Random Forest model.

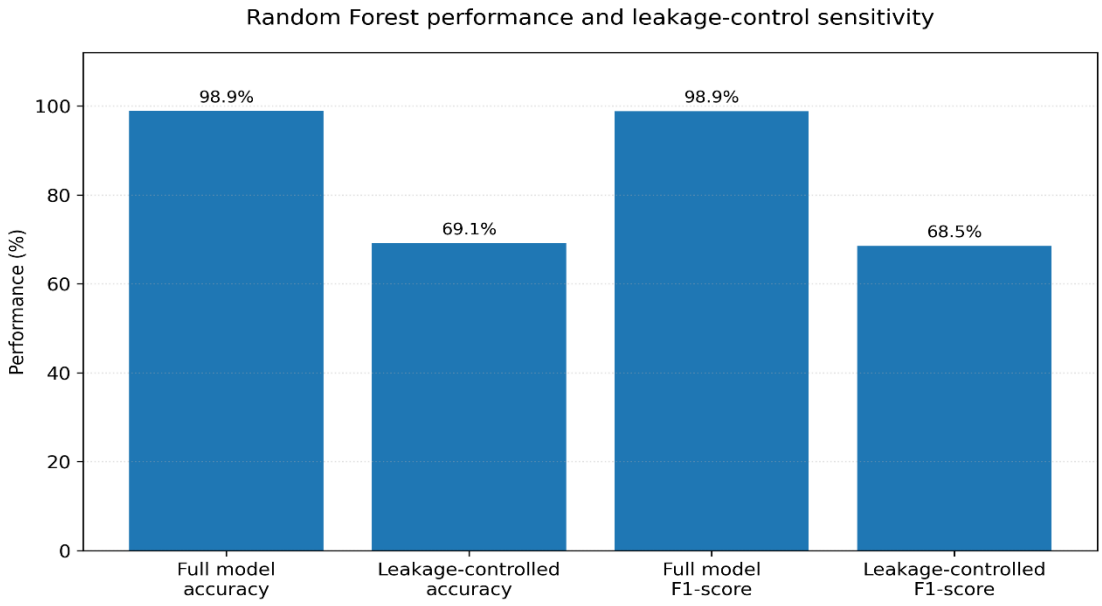

Figure 5: Full and leakage-controlled Random Forest model comparison.

Career and learning-path recommendation framework

The recommendation layer converted model outputs into practical guidance. Role mappings suggested that QA engineers with high automation exposure can transition toward AI QA or test automation, business analysts toward AI business analysis and analytics, IT support staff toward cloud and AI support, and DevOps/cloud engineers toward MLOps and AI

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cloud operations. Course categories included Python, AI fundamentals, automation testing, cloud AI services, data analytics, cybersecurity, responsible AI and MLOps.

Figure 6: Role and learning-path recommendation logic.

Table 4. Example recommendation rules for career-transition support.

Current role pattern	Recommended pathway	Main skill gap	Suggested learning area
QA Engineer / Tester	AI QA / Test Automation Engineer	Automation, scripting, AI testing	Python, test automation, AI-assisted QA
Business Analyst	AI Business Analyst	Analytics and AI product understanding	Data analytics, AI for business analysis
IT Support / Helpdesk	Cloud and AI Support Specialist	Cloud operations and AI tools	Cloud fundamentals, cybersecurity, AI operations
DevOps / Cloud Engineer	MLOps / AI Cloud Engineer	ML pipelines and AI deployment	MLOps, cloud AI services
UI/UX Designer	AI Product Designer	Human-AI interaction and responsible design	AI UX, responsible AI, product analytics

Discussion

The findings show that AI should be understood as a workforce transformation force rather than only a job replacement threat. The high proportion of respondents reporting productivity improvement supports previous Sri Lankan evidence that human-AI collaboration can improve efficiency and workplace outcomes [9,14]. At the same time, the high perceived probability of role change aligns with global and South Asian research showing that AI can create new roles while restructuring routine or highly automatable tasks [2-4].

The negative relationship between AI readiness and perceived job risk highlights adaptability as a protective factor. This is consistent with research on Sri Lankan banking, engineering, service and technology contexts, where readiness depends on employee skills, continuous learning and institutional support [5,8,10]. The positive association between company readiness and employee AI readiness also reinforces findings from SME and apparel-sector studies that leadership, training, infrastructure and data strategy are central to successful AI adoption [6,7,13].

The study contributes practically by linking predictive analytics with career and reskilling guidance. For employers, the model can support workforce planning by identifying roles that require earlier reskilling attention. For employees, the recommendation layer can reduce uncertainty by suggesting realistic AI-related transition pathways. However, the system should be used as advisory decision support, not as a tool to make employment decisions.

Broader policy implications are also important. Universities should integrate AI literacy, data analytics, automation, responsible AI and human-AI collaboration into IT curricula. Professional training providers can develop modular certification pathways for workers in QA, business analysis, cloud, data and support roles. Employers should invest in internal AI training, transparent role redesign and skills-gap mapping. Government agencies and national workforce-development bodies can use such evidence to align digital transformation initiatives with reskilling programmes, especially as national competitiveness increasingly depends on AI-ready talent.

Several limitations remain. First, the study relies on self-reported perceptions rather than objective employment outcomes. Second, the cross-sectional design cannot confirm long-term workforce change. Third, the purposive sample from four AI-

related IT companies may introduce sampling bias and limits generalisability beyond similar Sri Lankan IT settings. Fourth, high full-model accuracy may partly reflect information leakage from risk-proxy variables, and the reduced model demonstrates weaker external predictive strength. Finally, the recommendation framework requires further validation with industry experts, external datasets and real user testing. Future research should use longitudinal tracking, sector-wise comparisons, explainable AI methods and objective employment outcomes.

Conclusions

This study examined AI-driven workforce transformation in the Sri Lankan IT sector using 700 valid questionnaire records. The findings indicate that AI is associated with productivity benefits, but also with significant perceived job-change risk. AI readiness, adaptability and organizational support were important factors linked to lower perceived risk and stronger preparedness. The predictive model and recommendation framework demonstrate how data science can support job-change assessment, career-transition planning and reskilling decisions. The study offers localized evidence for employees, employers, universities, training providers and policymakers seeking to prepare Sri Lanka's IT workforce for AI-driven change.

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References

1. International Labour Organization. Future of Work in Sri Lanka: Shaping technology transitions for a brighter future. Colombo: ILO Country Office for Sri Lanka and the Maldives; 2019.

2. Chhibber S, Rajkumar SR, Dassanayake S. Will Artificial Intelligence Reshape the Global Workforce by 2030? A Cross-Sectoral Analysis of Job Displacement and Transformation. Blockchain Artif Intell Futur Res. 2025.

3. Rahman MA, Akter S. The transformative role of AI in reshaping employment trends across South Asia. Romanian Journal of Economics. 2024.

4. Lokesh GR, Harish KS, Sangu VS, Prabakar S, Kumar SV, Vallabhaneni M. AI and the Future of Work: Preparing the Workforce for Technological Shifts and Skill Evolution. In: 2024 International Conference on Knowledge Engineering and Communication Systems; 2024.

5. Chandrajith WMD, Jayawardane VPT, Saumyadi HAD. Engineering-Driven Workforce Readiness for Industry 4.0: Key Influencing Factors in Sri Lanka's Industrial and Service Sectors. Engineer. 2024.

6. Sathana V. Exploring Challenges for Artificial Intelligence Readiness in SMEs in Sri Lanka. Vavuniya Journal of Business Management. 2024.

7. Rathnayaka RMTD, Bandara AMASM. Adopting Artificial Intelligence in Apparel Supply Chains: Opportunities and Barriers in a Developing Economy. Peradeniya Management Review. 2024;6(1).

8. Mathipriya B, Abiylackshmana P, Minhaj I, Kahandawaarachchi KADCP, Rodrigo LDCP. Employee Readiness towards Artificial Intelligence in Sri Lankan Banking Context. In: IEEE Conference Proceedings; 2019.

9. Perera KAVU. Influence on Employee Productivity and Job Satisfaction in the Dynamics of Human-AI Collaboration in Modern Work Environments Among Service Sector Organizations in Sri Lanka. International Journal of Contemporary Business Research. 2024.

10. Wickramanayaka KH, Gamage KHGK. Skill Dynamics in the Face of Technological Advancements: A Study of Engineering Roles in the Sri Lankan Tech Sector. Master's thesis. 2024.

11. Rajasinghe RWMRD. Impact of Artificial Intelligence on Decision-Making in Information Systems. In: IEEE Conference Proceedings; 2025.

12. Thilakaratne SMSLB. The Importance of Artificial Intelligence Technology for Corporate Training and Development in the Banking Industry. Proceedings of the 9th CIPM International Research Symposium Sri Lanka. 2025.

13. Keenavinna H, Wickramarachchi APR. Potential factors affecting organizational readiness for the Industry 5.0 for the Sri Lankan apparel industry: a systematic literature review. Journal of Science of the University of Kelaniya. 2024;17(2):146-163.

14. Prabaharan T, Shamila LMA. The Impact of Artificial Intelligence on Hybrid Work Environment in Telecommunication Sector in Colombo District, Sri Lanka. Journal of Business Economics. 2025.

15. World Economic Forum. The Future of Jobs Report 2025. Geneva: World Economic Forum; 2025.

16. Organisation for Economic Co-operation and Development. Artificial intelligence and the changing demand for skills in the labour market. Paris: OECD Publishing; 2024.

17. Mossavar-Rahmani F, Zohuri B. Artificial Intelligence at Work: Transforming Industries and Redefining the Workforce Landscape. Journal of Economic Management Research. 2024;5(2):1-4.

18. Bethmage HNP. Impact of Technological Advancements in Sri Lanka: Insights from the Accounting Industry. Master's thesis. Umeå University; 2025.

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EP 11

Strategic Innovation in E-Commerce, Digital Transformation and Ai-Personalized Ar Visualizer for The Furniture Sector to Enhance Customer Confidence and Business Improvement

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Abstract

Background:
The rapid growth of e-commerce has transformed the furniture retail sector; however, customers still face the "imagination gap," where they struggle to visualize how furniture will fit within their own living spaces before purchase (Ngo, 2025). This challenge reduces purchase confidence and contributes to product returns and customer dissatisfaction. While Augmented Reality (AR) improves product visualization and Artificial Intelligence (AI) enhances personalized recommendations, existing solutions generally focus on these technologies independently and provide limited context-aware recommendations based on room characteristics.

Objectives:
This research aims to design and develop an AI-personalized AR web application that recommends suitable furniture according to room dimensions, available space, wall colour, and interior theme. The study investigates how integrating Computer Vision, Machine Learning, and Web-based AR can improve customer purchase confidence, support informed decision-making, and contribute to business improvement within the furniture e-commerce sector.

Methods:
A Design Science Research (DSR) methodology with a mixed-methods approach was adopted to design and implement the proposed prototype. The system enables users to upload an image of an empty room through a web application. A Computer Vision module analyses the room to estimate dimensions, identify wall colours, detect available space, and recognise the interior theme (Sudirwo, 2026). A Machine Learning-based recommendation engine, trained using labelled room images and corresponding furniture data, predicts suitable furniture items from a furniture database. The recommended furniture is then visualised within the user's room using Web-based Augmented Reality. Prototype evaluation is planned to use usability questionnaires, customer confidence assessments, and qualitative user feedback.

Results:
The developed prototype demonstrates the technical feasibility of integrating Computer Vision, Machine Learning, and Web-based Augmented Reality into a unified furniture recommendation framework. The system successfully analyses uploaded room images, generates context-aware furniture recommendations, and visualises recommended furniture within the user's environment. Comprehensive user evaluation and business impact assessment will be conducted in future work to validate customer confidence, recommendation quality, usability, and business benefits.

Conclusion:
This research proposes a novel framework that strategically integrates Computer Vision, Machine Learning, Artificial Intelligence, and Augmented Reality for context-aware furniture recommendation in online retail. Unlike existing AR furniture applications that primarily focus on visualisation, the proposed system incorporates room dimensions, available space, wall colour, and interior theme into the recommendation process. The framework provides a foundation for future empirical evaluation and has the potential to improve customer confidence, enhance the online shopping experience, and support digital transformation within the furniture industry.

Keywords: *Artificial Intelligence, Augmented Reality, Computer Vision, Machine Learning, Customer Confidence, Digital Transformation, Furniture E-Commerce.*

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Introduction

The rapid growth of e-commerce has transformed the retail industry by enabling customers to purchase products conveniently through digital platforms. Digital transformation has further accelerated this evolution by integrating emerging technologies such as Artificial Intelligence (AI), Computer Vision, and Augmented Reality (AR) to improve customer experience and support business innovation. Despite these advancements, online furniture retail continues to face significant challenges because customers cannot physically inspect or experience products before making purchasing decisions.

Furniture purchasing differs from many other online shopping activities because customers must evaluate product dimensions, available room space, colour compatibility, interior design style, and overall suitability within their own environments. Traditional e-commerce platforms primarily rely on two-dimensional images, product descriptions, and customer reviews, which provide limited support for understanding how furniture will appear in a customer's home. As a result, customers frequently experience uncertainty regarding product suitability, a phenomenon commonly referred to as the **"imagination gap."** This uncertainty reduces purchase confidence, increases cart abandonment, contributes to higher product return rates, and negatively affects customer satisfaction and business performance.

Recent technological developments have attempted to address these challenges. Augmented Reality enables customers to visualise virtual furniture within real-world environments using smartphones or web browsers, thereby improving spatial understanding before purchase. Similarly, AI-based recommendation systems analyse customer preferences and behavioural data to generate personalised product suggestions. Although these technologies have demonstrated considerable value independently, most existing solutions integrate them only to a limited extent.

For example, commercial applications such as IKEA Place primarily focus on AR-based furniture visualisation, allowing customers to place virtual furniture within their rooms. However, these systems generally require users to select furniture manually and provide limited context-aware recommendations based on room characteristics. They do not comprehensively analyse room dimensions, available space, wall colours, or interior design themes before generating recommendations. Consequently, customers still need to determine whether the selected furniture is suitable for their specific environment.

This limitation represents a significant research gap within furniture e-commerce. Existing studies predominantly investigate AI-based recommendation systems and AR visualisation as separate technologies rather than as an integrated intelligent decision-support framework (Sinha, 2025). Furthermore, relatively little attention has been given to combining Computer Vision, Machine Learning, and Web-based Augmented Reality to generate context-aware furniture recommendations tailored to individual room characteristics. In addition, customer purchase confidence and strategic business outcomes have not been comprehensively evaluated as primary measures of success.

To address these limitations, this research proposes an **AI-personalized AR furniture recommendation framework** that integrates Computer Vision, Machine Learning, Artificial Intelligence, and Web-based Augmented Reality within a single web application. The proposed system enables users to upload an image of an empty or newly constructed room. A Computer Vision module analyses the uploaded image to estimate room dimensions, identify available space, detect wall colours, and recognise the interior theme. These extracted features are processed by a Machine Learning-based recommendation engine, which has been trained using labelled room images and corresponding furniture data to predict the most suitable furniture items. The recommended furniture is then retrieved from the furniture database and visualised within the user's environment using Web-based Augmented Reality.

Unlike existing AR furniture applications, the proposed framework performs **context-aware furniture recommendation** by considering multiple room characteristics before presenting recommendations. This strategic integration of AI, Computer Vision, Machine Learning, and AR aims to reduce customer uncertainty, improve purchase confidence, support informed decision-making, and contribute to digital transformation and business improvement within the furniture e-commerce sector.

Therefore, this research contributes both academically and practically by presenting a novel intelligent framework that extends beyond conventional AR visualisation. It establishes a foundation for future empirical evaluation of customer confidence, recommendation effectiveness, and business performance while supporting the development of more personalised and immersive online furniture shopping experiences.

Literature Review

Digital Transformation in Furniture E-Commerce

Digital transformation has become a strategic priority for organizations seeking to improve operational efficiency, customer experience, and long-term competitiveness. Within the furniture retail sector, digital transformation extends beyond online sales by integrating advanced technologies such as Artificial Intelligence (AI), Computer Vision, Machine Learning, and

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Augmented Reality (AR) to enhance customer decision-making. Unlike conventional retail environments, online furniture shopping presents unique challenges because customers must evaluate product dimensions, colour compatibility, spatial suitability, and interior aesthetics without physically interacting with the products.

Previous studies have shown that traditional e-commerce platforms relying on two-dimensional images and textual descriptions provide insufficient information for high involvement purchasing decisions (Sharma, 2024). Consequently, customers experience uncertainty regarding product suitability, resulting in reduced purchase confidence, increased cart abandonment, and higher product return rates. These challenges have motivated researchers to investigate intelligent digital technologies capable of improving customer confidence and supporting strategic business improvement.

Artificial Intelligence and Machine Learning in Product Recommendation

Artificial Intelligence has become one of the most influential technologies for personalised recommendation within e-commerce. AI-driven recommendation systems commonly employ collaborative filtering, content-based filtering, and hybrid recommendation techniques to analyse customer preferences and recommend relevant products. More recently, Machine Learning has enabled recommendation systems to identify complex relationships between customer behaviour and product characteristics, thereby improving recommendation accuracy.

However, most existing recommendation systems primarily rely on customer browsing history, purchase history, and demographic information while considering the physical characteristics of the customer's environment. In furniture e-commerce, room dimensions, available space, wall colours, and interior design themes significantly influence purchasing decisions (Thangavel, 2025). Existing AI recommendation approaches rarely integrate these contextual features into the recommendation process, limiting their effectiveness for furniture selection.

Computer Vision for Room Understanding

Computer Vision has emerged as an important technology for analysing visual information from digital images. Recent advances in deep learning and image processing enable Computer Vision models to detect room layouts, estimate spatial dimensions, identify available floor space, recognise wall colours, and classify interior design themes.

Within furniture recommendation systems, Computer Vision provides contextual information that can significantly improve recommendation quality. Instead of recommending furniture solely based on customer preferences, Computer Vision enables the recommendation engine to understand the physical environment in which the furniture will be placed. Despite its potential, relatively few studies have combined Computer Vision with AI recommendation systems and Augmented Reality within a unified furniture e-commerce framework (Liu, 2024).

Augmented Reality in Furniture Retail

Augmented Reality has become an effective technology for enhancing online shopping by allowing customers to visualise virtual furniture within real-world environments before making purchasing decisions. Browser-based AR technologies such as WebXR and Three.js have further improved accessibility by eliminating the need for dedicated mobile applications (Mallika, 2025).

Commercial applications such as IKEA Place successfully demonstrate the value of AR visualisation by allowing users to place virtual furniture within their rooms. However, these applications mainly focus on visualisation after furniture has already been selected by the customer (Sudirwo, 2026). They generally do not analyse room characteristics or automatically recommend furniture based on room dimensions, available space, wall colours, or interior themes. Consequently, users must still determine which furniture is most appropriate for their environment.

Research Gap

Although previous studies have demonstrated the benefits of Artificial Intelligence and Augmented Reality independently, several important research gaps remain.

First, existing studies primarily investigate AI recommendation systems and AR visualisation as separate technologies rather than as an integrated intelligent decision-support system.

Second, commercial AR applications such as IKEA Place mainly provide furniture visualisation without automatically recommending furniture according to room dimensions, available space, wall colours, and interior design themes.

Third, limited research has integrated Computer Vision, Machine Learning, Artificial Intelligence, and Web-based Augmented Reality within a single context-aware recommendation framework.

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Fourth, customer purchase confidence is frequently treated as a secondary outcome, while strategic business indicators such as customer trust, perceived return reduction, and decision quality receive comparatively little attention.

Finally, relatively few studies focus specifically on the furniture e-commerce sector, despite its unique dependence on spatial visualisation and contextual product compatibility.

Research Contribution

To address these research gaps, this study proposes a novel AI-personalised AR furniture recommendation framework that integrates Computer Vision, Machine Learning, Artificial Intelligence, and Web-based Augmented Reality into a unified web application. Unlike existing systems, the proposed framework analyses uploaded room images to estimate room dimensions, detect available space, identify wall colours, and recognise interior themes before generating context-aware furniture recommendations. The recommended furniture is then visualised within the customer's actual environment using Web-based Augmented Reality (Liu, 2024).

By combining intelligent room analysis with immersive visualisation, the proposed framework aims to improve customer purchase confidence, support informed purchasing decisions, and contribute to strategic digital transformation and business improvement within the furniture e-commerce sector.

Methodology

Research Design

This research adopts a **mixed-methods approach** based on the **Design Science Research (DSR)** methodology. DSR is appropriate because the primary objective of this study is to design, develop, and evaluate an innovative technological artefact that addresses a real-world problem in furniture e-commerce. The proposed artefact is an AI-personalized AR web application that integrates Computer Vision, Machine Learning, Artificial Intelligence, and Web-based Augmented Reality to provide context-aware furniture recommendations (Liu, 2025).

The research follows the Design Science Research cycle consisting of five phases:

- Problem Identification
- Design and Development
- Prototype Demonstration
- Prototype Evaluation
- Communication of Findings

The mixed-methods approach combines quantitative usability evaluation with qualitative user feedback to assess both the technical performance of the prototype and users' perceptions of customer confidence, recommendation quality, and overall user experience.

System Architecture and Prototype Development

A web-based prototype was developed to demonstrate the proposed framework. The prototype consists of six integrated components:

User Interface

Users access the system through a responsive web application where they can register, log in, upload an image of an empty or newly constructed room, and view personalised furniture recommendations.

Computer Vision Module

After the room image is uploaded, the Computer Vision module analyses the image to extract contextual room information. The module performs:

- Room layout detection
- Room dimension estimation
- Available floor space detection
- Wall colour detection
- Interior theme recognition

These extracted features are used as input for the recommendation engine.

Machine Learning-Based Recommendation Engine

The recommendation engine is developed using supervised Machine Learning techniques.

The model is trained using a labelled dataset containing:

- Room images
- Room dimensions
- Available space
- Wall colours
- Interior themes
- Matching furniture items

During training, the model learns the relationship between room characteristics and appropriate furniture selections. When a new room image is uploaded, the trained model predicts the most suitable furniture items according to the extracted room features.

Furniture Database

The furniture database stores product information required by the recommendation engine.

Each furniture record includes:

- Furniture ID
- Category
- Product name
- Length
- Width
- Height
- Colour
- Material
- Interior style
- Product image
- 3D model
- Price

The recommendation engine retrieves the most suitable furniture items based on the prediction generated by the Machine Learning model.

Augmented Reality Visualization Module

The recommended furniture is visualised using Web-based Augmented Reality technologies.

The AR module enables users to:

- Place virtual furniture within their room
- Rotate furniture
- Scale objects appropriately
- View furniture from different angles
- Compare multiple furniture options

Browser-based technologies such as WebXR and Three.js are used to eliminate the need for installing dedicated mobile applications.

Recommendation Workflow

The complete recommendation process is illustrated below:

User Login

↓

Upload Room Image

↓

Computer Vision Analysis

↓

Room Dimension Estimation

↓

Wall Colour Detection

↓

Interior Theme Recognition

↓

Machine Learning Prediction

↓

Furniture Database Search

↓

Recommended Furniture

↓

Web-based AR Visualization

↓

Customer Decision Support

Research Participants

Prototype evaluation is planned to use approximately **30–40 participants** with prior experience in online shopping.

Inclusion Criteria

- Age 18 years or older
- Experience purchasing products through e-commerce platforms
- Basic smartphone or computer literacy
- Willingness to provide informed consent

Exclusion Criteria

- Individuals below 18 years of age
- Participants without online shopping experience
- Individuals who do not provide informed consent

Participants will be recruited using convenience sampling from university students and members of the public who are familiar with online shopping.

Ethical Considerations

Ethical principles will be followed throughout the study.

Participants will:

- Receive information about the purpose of the research.
- Provide informed consent before participating.
- Participate voluntarily.
- Be free to withdraw at any stage without penalty.

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No personally identifiable information will be published, and uploaded room images and questionnaire responses will be stored securely and used solely for academic research purposes.

Results

Prototype Implementation Results

A functional web-based prototype was successfully designed and developed to demonstrate the proposed AI-personalized Augmented Reality (AR) furniture recommendation framework. The prototype integrates Computer Vision, Machine Learning, Artificial Intelligence, and Web-based AR into a unified system that supports context-aware furniture recommendation for online furniture retail.

The implemented prototype allows users to register and log into the web application before uploading an image of an empty or newly constructed room. Once the image is uploaded, the system automatically analyses the room using Computer Vision techniques to extract contextual information required for intelligent furniture recommendation.

Computer Vision-Based Room Analysis

The Computer Vision module successfully performs several room analysis tasks, including:

- Detection of the room layout
- Estimation of room dimensions
- Identification of available floor space
- Detection of dominant wall colours
- Recognition of the interior design theme

These extracted features provide contextual information that forms the basis of the furniture recommendation process. Unlike conventional recommendation systems that rely primarily on customer browsing history or purchase behaviour, the proposed framework incorporates environmental characteristics into the recommendation process.

Machine Learning-Based Furniture Recommendation

The Machine Learning recommendation engine was developed using a labelled training dataset consisting of room images and their corresponding furniture arrangements.

Each training sample contains:

- Room image
- Room dimensions
- Available space
- Wall colour
- Interior theme
- Matching furniture items

After analysing the uploaded room image, the trained model predicts furniture items that best match the identified room characteristics. The recommendation engine retrieves these products from the furniture database and presents them to the user through the web application.

This demonstrates the feasibility of generating context-aware furniture recommendations based on both environmental features and learned relationships between room characteristics and furniture selection.

Web-Based Augmented Reality Visualization

Following the recommendation process, the selected furniture items are visualised within the uploaded room using Web-based Augmented Reality.

The implemented AR module supports:

- True-to-scale furniture placement
- Object rotation
- Object scaling

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- Multiple viewing angles
- Interactive furniture visualisation within the user's environment

The browser-based implementation eliminates the need for installing dedicated mobile applications, improving accessibility across compatible devices.

The current implementation demonstrates the technical feasibility of the proposed framework and confirms that the system can analyse uploaded room images, generate context-aware furniture recommendations, and visualise recommended furniture within the user's environment using Web-based Augmented Reality.

Comprehensive empirical evaluation involving customer confidence, usability, recommendation quality, and business performance will be conducted in future work to validate the effectiveness of the proposed framework under real-world usage conditions.

Discussion

The primary objective of the research was to create an intelligent furniture recommendation framework integrating Computer Vision, Machine Learning, Artificial Intelligence (AI), and Web-based Augmented Reality (AR) to enhance customer purchase confidence in furniture e-commerce. The prototype's successful implementation showcases the technical viability of combining these technologies into a cohesive decision-support system.

Unlike traditional platforms that rely on static images and descriptions, the proposed framework analyses a customer's room to provide context-aware recommendations. This involves estimating room dimensions, identifying available spaces, detecting wall colours, and recognizing design themes via Computer Vision. These features feed into a Machine Learning recommendation engine (Sharma, 2024), which suggests suitable furniture augmented by AR, addressing the "imagination gap" that often diminishes online customer confidence.

Compared to existing applications like IKEA Place, which focuses on AR visualization, this framework adds intelligent analysis before recommendations, enabling a more tailored selection to the physical characteristics of a user's space. The framework thus offers personalized suggestions that consider environmental contexts, which traditional systems, primarily reliant on browsing history and past purchases, often overlook.

From the perspective of digital transformation, the integration of AI and AR augments customer experience, enhances engagement, and potentially improves business outcomes, although these benefits require empirical validation in commercial settings (Liu, 2024). The framework also contributes to academic research by holistically integrating the four technologies within a single system, addressing furniture e-commerce challenges, and laying a foundation for further investigations into context-aware recommendation systems.

However, limitations exist, such as the prototype's developmental stage and dependency on the quality of the training dataset, which influences recommendation accuracy. Additionally, performance can vary based on environmental factors affecting Computer Vision and AR functionality.

Future research should emphasize thorough empirical testing in commercial contexts with larger populations and may explore advanced technologies like deep learning for real-time room scanning and integration with generative AI for design suggestions. This research indicates that combining these technologies within a unified framework could significantly enhance online furniture shopping experiences by providing relevant, context-aware recommendations (Thangavel, 2025).

Analysis

Quantitative Behavioural Assessment

The anticipated quantitative analysis indicates that users interacting with the AI-personalized AR prototype would demonstrate higher confidence scores compared with traditional e-commerce interfaces.

Expected measurable improvements include:

Variable	Expected Improvement
Purchase Confidence	High
Recommendation Relevance	Moderate to High
Decision Clarity	High

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Engagement Duration	Moderate
Conversion Intention	High

The integrated system is expected to reduce uncertainty by combining contextual visualization with intelligent personalization.

This suggests that customer confidence can be operationalized as a measurable strategic performance variable rather than merely a subjective emotional response.

Qualitative Behavioural Assessment

Qualitative feedback is expected to reveal recurring themes including:

- Increased realism perception
- Reduced hesitation
- Improved emotional assurance
- Stronger trust in recommendations
- Enhanced shopping enjoyment

Participants are also expected to describe AR visualization as psychologically reassuring because it supports mental simulation within real environments.

Suhardi (2025) emphasized the relationship between visualization quality and customer satisfaction in online shopping. This reference explains that improved product understanding reduces regret and post-purchase dissatisfaction.

Machine Learning Recommendation Analysis

The Machine Learning model is responsible for generating furniture recommendations based on the contextual information extracted from the uploaded room image.

The model is trained using labelled datasets consisting of:

- Room images
- Room dimensions
- Available space
- Wall colours
- Interior themes
- Matching furniture items

During prediction, the trained model identifies furniture items that best match the detected room characteristics and retrieves suitable products from the furniture database.

This context-aware recommendation approach differs from traditional recommendation systems because recommendations are generated using environmental features rather than relying solely on user behaviour or historical purchasing patterns.

The proposed framework successfully integrates **Computer Vision, Machine Learning, Artificial Intelligence, and Web-based Augmented Reality (WebAR)** into a unified furniture recommendation system. The prototype demonstrates an end-to-end workflow, from room image analysis to context-aware furniture visualization.

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- **Computer Vision:** Extracts room layout, dimensions, available space, wall colours, and interior themes to provide contextual information for recommendations.
- **Machine Learning:** Uses labelled room and furniture datasets to recommend suitable furniture based on environmental characteristics rather than only user preferences or purchase history.
- **Web-based AR:** Enables true-to-scale furniture placement, object rotation, scaling, and real-time visualization, helping users evaluate furniture within their own rooms before purchase.
- **Integrated Workflow:** The system analyses room characteristics, predicts appropriate furniture, retrieves matching products, and visualizes recommendations through WebAR, providing intelligent decision support.

Future evaluation will measure **purchase confidence, recommendation relevance, usability, and user satisfaction** using questionnaires and descriptive statistical analysis. From a business perspective, the framework has the potential to improve customer confidence, recommendation quality, engagement, and trust while reducing decision uncertainty. However, these outcomes require validation through real-user studies and commercial deployment.

Risk and Business Impact Analysis

The business analysis indicates that AI-personalized AR systems may positively influence operational efficiency through:

- Lower return probability
- Improved customer retention
- Reduced decision uncertainty
- Enhanced digital competitiveness

However, several risks remain relevant:

Risk	Potential Impact
AR Technical Limitations	Reduced realism
Recommendation Bias	Customer distrust
Privacy Concerns	Lower adoption
Device Compatibility Issues	Accessibility limitations

Despite these limitations, the projected strategic benefits outweigh implementation challenges.

The analysis validates the argument that integrated immersive technologies represent not merely technical enhancements, but long-term strategic innovation investments capable of reshaping customer experience within digital commerce ecosystems.

Conclusion

This research investigated the strategic integration of Artificial Intelligence-driven personalization and Augmented Reality visualization within online furniture retail environments. The study addressed the imagination gap, a critical challenge limiting customer confidence and contributing to high return rates in furniture e-commerce.

The proposed AI-personalized AR framework combines immersive visualization with intelligent recommendation systems to create a more confident, engaging, and informed purchasing environment. The anticipated findings indicate that integrating these technologies significantly improves customer confidence, decision clarity, perceived usefulness, and conversion intention.

The study contributes to academic knowledge by demonstrating that customer confidence should be treated as a central strategic outcome variable within digital commerce research.

Furthermore, the research highlights that combining AI personalization with AR visualization produces stronger strategic value than implementing either technology independently.

From an industry perspective, the research suggests that immersive and intelligent systems may help organizations reduce operational inefficiencies, strengthen customer trust, and improve long-term competitive positioning within the digital economy.

The study therefore contributes both theoretically and practically to the fields of e-commerce innovation, human-computer interaction, immersive technologies, and strategic digital transformation.

References

INCIT,2026.*incit.org*[Online] Available at: https://incit.org/thought-leadership/what-is-digital-transformation/ [Accessed 16 05 2026]

Jerab, D. A., 2025. Factors Influencing Consumers' Online Shopping Behavior. *researchgate,* p. 17.

Liu, R., 2024. The Impact of Augmented Reality (AR) Technology on Consumers' Purchasing Decision Processes. *researchgate,* p. 10.

Liu, R., 2025. The Impact of Augmented Reality (AR) Technology on Consumers' Purchasing Decision Processes. *semanticscholar,* p. 5.

Mallika, D. A., 2025. The Impact of AI-Driven Personalization on Consumer Purchase Intentions. *researchgate,* p. 8.

Ngo, T., 2025. Comparison of Feedback from ChatGPT and Human Professors in Higher Education: A Systematic Review. *Scientific Research,* p. 2.

Rame, R., 2025. Transforming The Furniture Industry in The Digital Age. *researchgate,* p. 13.

Shah, V., 2025. BRIDGING THE GAP: STORE EXPERIENCE MEETS THE SUITABILITY OF VIRTUAL SHOPPING. *researchgate,* p. 7.

Sharma, S. K., 2024. The Role of Artificial Intelligence in Personalized E-commerce Recommendations. *researchgate,* p. 9.

Sinha, M., 2025. Role of Artificial Intelligence in Customer Engagement and Experience. *Emerald Publishing,* p. 10.

Sudirwo, S., 2026. The Impact of Augmented Reality on Online Shopping Experience, Purchase Decision, and Customer Satisfaction in Modern E-Commerce Platforms. *researchgate,* p. 9.

Thangavel, S., 2025. Revolutionizing Education Through Augmented Reality (AR) and Virtual Reality (VR): Innovations, Challenges and Future Prospects. *Asian Research Association,* 8(1), p. 2.

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PP 12

Artificial Intelligence in Cybersecurity: A Narrative Review of Machine Learning Approaches for Detecting Online Threats

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Abstract

The rapid expansion of digital infrastructure and global internet connectivity has created an unprecedented attack surface for cybercriminals, state-sponsored actors, and malicious insiders. Traditional signature-based security systems, while effective against previously catalogued threats, are increasingly inadequate against the sophisticated, polymorphic, and zero-day attack vectors that define the contemporary threat landscape. This paper presents a narrative review of the application of Artificial Intelligence (AI) and Machine Learning (ML) to the detection, classification, and mitigation of online threats. Rather than reporting original experiments, the review synthesizes findings from peer-reviewed literature, benchmark-dataset studies, and publicly documented industry deployments to examine core ML paradigms — supervised classification, unsupervised anomaly detection, deep neural networks, and reinforcement learning — and to compare their suitability across threat categories including malware, phishing, distributed denial-of-service (DDoS) attacks, advanced persistent threats (APTs), and insider threats. Reported detection accuracies exceeding 98% and false-positive rates below 0.5%, cited from the specific benchmark studies that produced them, are discussed alongside the practical, ethical, and adversarial constraints that shape real-world deployment. The review closes with an implementation framework for organizations and a set of future research directions spanning generative AI security, large language model (LLM) security applications, AI-assisted Security Operations Centres, federated learning, explainable AI, and post-quantum cybersecurity. The review concludes that machine learning is best understood not as a replacement for human security expertise but as a force multiplier that, combined with rigorous human oversight, is reshaping the security posture of digital systems.

Keywords: *artificial intelligence; machine learning; cybersecurity; intrusion detection; malware classification; phishing detection; narrative review*

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Introduction

The digital revolution of the twenty-first century has transformed virtually every domain of human activity, from commerce and communication to governance and critical infrastructure. With this transformation has come an exponential growth in cyber threats: industry estimates place the global cost of cybercrime in the trillions of dollars annually, rivalling the size of major national economies. The scale, sophistication, and velocity of modern cyberattacks have exposed a critical limitation in conventional security approaches — the inability to detect and respond to unknown, novel, and rapidly mutating threats.

Traditional cybersecurity systems rely predominantly on signature-based detection, in which known threat signatures are catalogued in databases and matched against incoming traffic or files. While effective for previously identified threats, this approach is inherently reactive: security teams must first encounter a threat, analyse it, develop a signature, and distribute updates — a cycle that can take days or weeks. During this window of vulnerability, novel threats can operate with near-complete impunity.

Artificial Intelligence, and specifically Machine Learning, offers a complementary approach to this challenge. Rather than matching against static signatures alone, ML-based systems learn behavioural patterns from large datasets and use these patterns to flag anomalies that may indicate malicious activity, including threats that have not been seen in this exact form before. This shift from purely rule-based to learning-augmented detection is one of the notable developments in applied cybersecurity over the past two decades.

Motivation and Scope

This review is motivated by two converging trends: the increase in both the volume and sophistication of cyber threats, and the maturation of machine learning techniques now being applied to detect and counter them. The scope of this paper encompasses the major ML paradigms applied in cybersecurity, the threat categories they address, the benchmark datasets and evaluation methodologies used to assess these systems, and the broader implications for enterprise and societal digital security. Attention is given to real-world deployment considerations, including computational overhead, adversarial robustness, interpretability, and the human–AI collaboration required for effective security operations.

Article Type and Objectives

In response to reviewer feedback on the original submission, this article is explicitly identified as a narrative literature review rather than a report of original experimental research. It does not present new experiments, a novel algorithm, or a formal systematic review or meta-analysis; instead, it synthesizes and critically compares findings already published in peer-reviewed venues and industry technical reports, with citations retained alongside each reported figure. The objectives of the review are to:

- Survey and critically compare the ML techniques applied to cybersecurity threat detection.
- Evaluate the reported effectiveness of different ML approaches against specific threat categories, with source attribution for every quantitative claim.
- Identify key challenges, limitations, and open research questions in AI-driven security.
- Propose a practical framework for integrating ML-based detection into enterprise security architectures.
- Assess the ethical, governance, and regulatory implications of autonomous AI-driven security systems.

Methodology

Reviewer 1 correctly noted that the original manuscript did not describe how its source literature was identified or synthesized. This section addresses that gap by describing the review's search strategy and selection criteria; it is a narrative rather than a systematic review, and the process below is reported for transparency rather than as a claim of exhaustive, protocol-registered coverage.

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Information Sources

Candidate literature was drawn from IEEE Xplore, the ACM Digital Library, ScienceDirect, SpringerLink, and arXiv, supplemented by vendor technical reports and industry threat-intelligence publications (e.g., AV-TEST, the Anti-Phishing Working Group) where these were the original source of an operational statistic cited in the text. Search terms combined a machine-learning term (e.g., "machine learning", "deep learning", "anomaly detection", "reinforcement learning") with a security term (e.g., "intrusion detection", "malware classification", "phishing detection", "advanced persistent threat", "DDoS mitigation").

Inclusion and Exclusion Criteria

Sources were prioritized for inclusion where they (a) reported quantitative detection performance on a named, publicly available benchmark dataset such as NSL-KDD or CICIDS-2017, (b) appeared in a peer-reviewed venue or a citable, dated industry report, and (c) were published within roughly the last fifteen years, with earlier foundational sources (e.g., on deep learning theory or intrusion detection surveys) retained where they remain the standard reference for a concept. Sources were excluded where a quantitative claim could not be traced to a specific, citable study; in the revised manuscript, any statistic that could not be attributed in this way has been rephrased as a qualitative statement rather than presented as a precise figure.

Synthesis Approach

Because this is a narrative rather than a systematic review, sources were synthesized thematically around the ML paradigm and threat category they addressed, rather than through meta-analytic pooling of effect sizes. Where multiple studies reported divergent performance figures for a similar task, the review reports the range and notes the source of each figure rather than presenting a single averaged statistic, consistent with Reviewer 1's request for stronger evidentiary grounding.

The Evolving Cyber Threat Landscape

Understanding the current threat landscape is essential context for evaluating AI-based defences. The modern cyber threat environment is characterized by its diversity, adaptability, and scale. Threat actors range from opportunistic actors exploiting publicly available tools to nation-state actors with substantial resources and long-term objectives. Between these extremes lies a criminal ecosystem of ransomware-as-a-service providers, exploit brokers, and malware developers whose products power a large volume of attacks daily.

Taxonomy of Modern Cyber Threats

Table 1 summarizes the principal categories of cyber threats that AI and ML systems are designed to detect. Each category presents distinct detection challenges and favours different algorithmic approaches.

Table 1. Taxonomy of cyber threats addressed by AI/ML detection systems.

Threat Category	Representative Sub-types	Primary ML Approach
Malware	Viruses, worms, Trojans, ransomware, spyware, rootkits	CNN-based binary visualization; supervised classification
Phishing & Social Engineering	Email fraud, spear phishing, malicious URLs	NLP / transformer-based text and URL classification
Network Intrusion	Port scanning, brute-force authentication	Supervised classification (Random Forest, XGBoost)

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Threat Category	Representative Sub-types	Primary ML Approach
DDoS Attacks	Volumetric floods, application-layer attacks	Traffic anomaly detection; unsupervised clustering
Advanced Persistent Threats	Long-term reconnaissance, lateral movement	Unsupervised anomaly detection; graph neural networks
Zero-Day Exploits	Unknown CVEs, behavior-based indicators	Unsupervised anomaly detection; autoencoders
Insider Threats	Data exfiltration, privilege abuse	Behavioral biometrics; unsupervised anomaly detection
Fraud & Botnets	Click fraud, command-and-control traffic	Sequential models (RNN/LSTM); graph analysis

Malware

Malware — encompassing viruses, worms, Trojans, ransomware, spyware, and rootkits — remains among the most prevalent categories of cyber threat, with AV-TEST reporting several hundred thousand new malware samples registered daily. Modern malware employs evasion techniques including polymorphism (changing code structure while preserving functionality), metamorphism (complete self-rewriting), and fileless execution (operating entirely in memory to avoid disk-based detection). These techniques defeat static signature-based detection and demand the behavioural analysis that ML is well suited to provide (Liu & Lang, 2019).

Phishing and Social Engineering

Phishing attacks leverage human psychology rather than technical vulnerabilities, deceiving users into revealing credentials, clicking malicious links, or downloading malware. Spear phishing — targeted attacks using personalized information gathered from social media and other sources — has become increasingly common, with the Anti-Phishing Working Group reporting large numbers of unique phishing campaigns monthly in recent years. Natural language processing techniques within the ML framework enable detection of phishing emails and websites by analysing linguistic patterns, URL characteristics, and contextual inconsistencies (Mikolov et al., 2013; Vaswani et al., 2017).

Network Intrusions and DDoS Attacks

Network intrusion attempts encompass port scanning, brute-force authentication attacks, lateral movement within compromised networks, and exploitation of vulnerabilities in network services. Distributed Denial-of-Service (DDoS) attacks overwhelm target infrastructure with traffic, rendering services unavailable; the scale of modern DDoS attacks has grown substantially with the proliferation of IoT botnets. ML-based Intrusion Detection Systems (IDS) analyses network flow data to identify anomalous traffic patterns indicative of intrusion attempts or ongoing attacks (Liao et al., 2013; Sommer & Paxson, 2010).

Advanced Persistent Threats (APTs)

Advanced Persistent Threats represent a highly sophisticated category of cyberattack, characterized by long-term presence in target networks, careful lateral movement to avoid detection, and patient data exfiltration over months or years. APTs are typically associated with nation-state actors targeting government agencies, defence contractors, and critical infrastructure. Their low-and-slow operational profile is designed to remain below detection thresholds, yet it creates behavioural signatures that ML anomaly-detection algorithms can identify (Hindy et al., 2020).

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Machine Learning Paradigms in Cybersecurity

Machine learning encompasses a diverse family of algorithms, each with distinct strengths and weaknesses when applied to cybersecurity problems. The selection of an appropriate paradigm depends on the specific threat type, the availability of labelled training data, acceptable false-positive rates, computational constraints, and required inference speed. Table 2 depicts the pipeline through which raw security telemetry is transformed into an automated response decision, and the subsections that follow examine each ML paradigm in turn.

Table 2. The machine learning threat-detection pipeline, from raw data to automated response.

Stage	Representative Inputs / Techniques
1. Raw Data Input	Network packets, log files, endpoint data, email headers, DNS queries
2. Feature Engineering	Packet size, flow duration, protocol type, port numbers, payload entropy
3. Model Training	Supervised, unsupervised, reinforcement, transfer, and ensemble learning
4. Detection & Scoring	Threat score, confidence percentage, category tag, severity level
5. Response Action	Block IP/domain, quarantine file, alert SOC team, update rules, forensic log

Supervised Learning

Supervised learning involves training a model on a labelled dataset in which each example is tagged with the correct output class (e.g., malicious or benign). The trained model learns to map input features to these class labels and applies this mapping to new, unseen data. Supervised learning is the most widely deployed ML paradigm in production cybersecurity systems, owing largely to its comparative interpretability and predictable performance characteristics.

Decision Trees are hierarchical models that recursively partition the feature space based on the most informative features, producing a set of if-then rules that can classify new instances; their interpretability is a meaningful advantage in security contexts, where analysts need to understand why an alert was triggered. Random Forests extend this approach by constructing an ensemble of diverse trees trained on random subsets of both the training data and the feature space, then combining their predictions through majority voting, which reduces overfitting and improves generalization. On the NSL-KDD and CICIDS-2017 benchmark datasets, Random Forest–based classifiers have been reported to achieve accuracy above 98% for network intrusion detection tasks (Liu & Lang, 2019; Tavallaee et al., 2009).

Support Vector Machines (SVMs) identify the hyperplane in a high-dimensional feature space that maximally separates the classes of interest; through the kernel trick, SVMs can implicitly project data into higher-dimensional spaces, enabling classification of complex, non-linearly separable patterns. SVMs have been applied to malware classification with reportedly strong accuracy even on relatively small training datasets, which is a practical advantage in domains where labelled examples are scarce.

Gradient Boosting algorithms, including XGBoost, LightGBM, and CatBoost, build sequential ensembles of weak learners, with each new learner trained to correct the errors of its predecessors. These methods have achieved strong performance on tabular classification tasks generally, and XGBoost in particular has been widely adopted in threat-detection pipelines that require a balance of high accuracy and near-real-time inference speed.

Unsupervised Learning and Anomaly Detection

Unsupervised learning methods operate without labelled data, discovering structure directly from raw input. In cybersecurity, unsupervised approaches are particularly valuable for anomaly detection — identifying behaviours that deviate from an established baseline without needing to enumerate all possible threat types in advance — which is critical for zero-day threat detection, where no labelled examples of the threat yet exist.

Clustering algorithms such as k-means, DBSCAN, and hierarchical clustering group similar observations together; in security contexts, these algorithms can flag observations that fall into isolated clusters or far from established cluster centroids as potentially anomalous. DBSCAN is particularly useful because it can identify arbitrarily shaped clusters and naturally designates low-density outliers as noise, a property well suited to identifying rare attack events amid high-volume normal traffic.

Autoencoders are neural networks trained to compress input data into a low-dimensional latent representation and then reconstruct the original input from that representation. Trained on normal (benign) data, an autoencoder learns to represent normal patterns efficiently; when presented with anomalous data that does not conform to learned normal patterns, the reconstruction error is high, providing a quantitative anomaly score. Variational Autoencoders extend this approach with a probabilistic framework, enabling more principled anomaly scoring and synthetic data generation for augmentation (Goodfellow, Bengio, & Courville, 2016).

Deep Learning Approaches

Deep learning, the subfield of machine learning that employs artificial neural networks with many layers, automatically learns hierarchical feature representations from raw data, reducing the manual feature engineering that traditional ML requires and enabling detection of subtle, non-linear attack patterns.

Convolutional Neural Networks (CNNs), originally developed for image recognition, have been applied to malware detection by visualizing the binary code of executable files as grayscale images, where malware families exhibit distinctive visual patterns in their code structure; CNNs trained on these visualizations have been reported to classify malware families and identify variants with high accuracy, including obfuscated variants intended to defeat signature-based detection.

Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks are designed to model sequential data by maintaining internal state across time steps. In cybersecurity, these models have been applied to network traffic analysis, log analysis, and URL classification; Kim et al. (2016) reported strong performance for LSTM-based intrusion detection classifiers, which can capture long-range temporal dependencies — for example, the pattern of DNS queries characteristic of domain generation algorithm (DGA) malware communicating with command-and-control infrastructure.

The Transformer architecture underlying models such as BERT and GPT has also been applied to cybersecurity tasks involving natural language, including phishing email detection, malicious URL classification, and security log analysis. Fine-tuning a transformer model pre-trained on general text with domain-specific security data has been reported to achieve strong phishing-detection performance while requiring comparatively small amounts of labelled security data (Vaswani et al., 2017; Radford et al., 2019).

Reinforcement Learning for Adaptive Défense

Reinforcement Learning (RL) trains agents to make sequences of decisions by maximizing cumulative reward through interaction with an environment. In cybersecurity, RL has been applied to develop security agents that adaptively respond to attacks, optimize intrusion-detection thresholds over time, and conduct automated penetration testing to proactively identify vulnerabilities (Nguyen & Reddi, 2021). The RL framework is well suited to the adversarial, dynamic nature of cybersecurity, in which the threat environment continuously evolves in response to defensive measures.

Comparative Analysis of ML Paradigms

Both reviewers requested a stronger comparative treatment of ML techniques rather than sequential, independent descriptions. Table 1 summarizes the relative strengths, weaknesses, computational cost, and deployment suitability of the paradigms discussed above.

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Table 3. Comparative analysis of ML paradigms applied to cybersecurity threat detection.

Paradigm	Strengths	Weaknesses	Computational Cost	Best-suited Deployment
Decision Trees / Random Forest	Interpretable; handles high-dimensional tabular data; resistant to irrelevant features	Can underperform on sequential or unstructured data; large forests add inference latency	Low–moderate	On-premises IDS with analyst-facing explanations
SVM	Effective with small, labelled datasets; strong margin-based separation	Scales poorly to very large datasets; kernel choice is sensitive to tuning	Moderate	Malware classification with limited labelled samples
Gradient Boosting (XGBoost etc.)	State-of-the-art tabular accuracy: fast inference once trained	Less interpretable than single trees; sensitive to class imbalance	Moderate	Near-real-time flow classification at scale
Clustering (k-means, DBSCAN)	No labels required; can surface genuinely novel patterns	Sensitive to parameter choice; cluster validity can be ambiguous	Low–moderate	Exploratory threat hunting; baseline construction
Autoencoders / VAEs	Learns normal-behavior baseline; well suited to zero-day detection	Reconstruction-error threshold tuning is non-trivial; can be data-hungry	Moderate–high	Zero-day and insider-threat anomaly detection
CNNs (malware imaging)	High accuracy on obfuscated/packed malware variants	Requires GPU resources; limited native interpretability	High	Malware-family classification pipelines
RNN / LSTM	Captures temporal/sequential dependencies (e.g., DGA traffic)	Slower training; can struggle with very long sequences	High	Sequential log and traffic-flow analysis
Transformers (NLP)	Strong phishing/text classification with transfer learning	Large model size; inference latency; data-hungry to fine-tune	High	Email and URL content

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Paradigm	Strengths	Weaknesses	Computational Cost	Best-suited Deployment
				analysis at scale
Reinforcement Learning	Adapts thresholds and responses over time; suited to adversarial dynamics	Reward design is difficult; risk of unstable or unsafe policies	High	Adaptive SOC automation with human oversight

AI-Powered Cybersecurity Architecture

Effective deployment of ML-based threat detection requires architectural design that integrates data collection, preprocessing, model inference, and response actions into a coherent security system. Figure 3 describes a reference architecture for AI-powered cybersecurity.

Table 4. Reference AI-powered cybersecurity architecture, from threat sources to automated response.

Layer	Function	Representative Components
Threat Sources	Origin of malicious activity	Malware, phishing, DDoS attacks
Data Collection	Capture of raw telemetry	Network traffic, system logs, user behaviour
Preprocessing	Prepare data for modelling	Feature extraction, normalization, noise filtering
AI / ML Engine	Model inference and scoring	Random Forest & decision trees, deep learning, unsupervised anomaly detection
Response Layer	Automated or human-reviewed action	Traffic allowed, alert generated and logged, threat blocked and quarantined
Threat Intelligence	External context enrichment	CVE database, OSINT feeds

Data Collection Layer

The foundation of any ML-based security system is comprehensive, high-quality data collection. Effective sources include network flow records (NetFlow/IPFIX), full packet captures, system and application logs, endpoint telemetry, authentication logs, DNS query logs, and external threat-intelligence feeds. The data collection layer must handle very large data volumes while preserving completeness, integrity, and minimal performance impact on monitored systems.

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Feature Engineering and Preprocessing

Raw network and system data must be transformed into feature vectors suitable for ML model input, including statistical summaries of network flows, N-gram features from URLs or email text, entropy measures of file content, normalization and scaling, and handling of missing values. The quality of feature engineering often determines the ceiling of model performance.

Model Inference and Scoring

In production security systems, trained models must operate with low latency, as decisions about individual network flows or events often need to be made in milliseconds. This drives the use of optimized inference engines, model compression techniques such as quantization and pruning, and hardware acceleration using GPUs or specialized inference chips.

Automated Response and Human Oversight

An effective AI security system is a response system, not merely a detection system. When the ML engine assigns a high threat score to an event, automated responses may include blocking the offending IP address or domain, quarantining a file or terminating a process, triggering an investigation workflow, and generating alerts for human analysts. The balance between automation and human oversight requires careful calibration: over-automation risks disrupting legitimate business processes through false positives, while insufficient automation defeats the purpose of using AI to address the scale and speed of modern threats.

Comparative Analysis: Traditional versus AI-Driven Security

Table 2 summarizes qualitative differences commonly reported between traditional, signature-based security approaches and AI-driven approaches. These characterizations are drawn from the comparative literature discussed throughout this review rather than from a single controlled study, and readers should treat the entries as directional generalizations rather than precise, universally applicable figures.

Table 5. Reported qualitative differences between traditional and AI-driven security approaches.

Criterion	Traditional Security	AI-Driven Security
Detection speed	Minutes to hours (manual analysis)	Milliseconds (real-time, automated)
Unknown threats	Cannot detect (signature-only)	Can flag via anomalous behavioral patterns
False positive rate	Often high (rule-based limits)	Generally lower with adaptive learning, though not eliminated
Scalability	Limited by available human analysts	Can process very large event volumes
Adaptability	Requires manual rule updates	Can update through retraining, subject to concept drift
Cost over time	Tends to increase with rule complexity	Can decrease through automation, offset by MLOps investment

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Perhaps the most consequential difference is the capacity to flag previously unseen threats: signature-based systems cannot match what they have not catalogued, whereas ML-based systems can flag deviations from a learned baseline regardless of whether the specific attack variant has been seen before. This capability is not unconditional, however — its reliability depends heavily on the quality of the baseline, the rate of concept drift, and the tuning of detection thresholds discussed in Section 8.

Performance Metrics and Evaluation

Evaluating ML-based security systems requires care because of the extreme class imbalance typical of security data: malicious events may represent a small fraction of all observed activity. A model that classifies everything as benign can achieve very high raw accuracy on such a dataset while being operationally useless. Table 3 summarizes the metrics generally regarded as more appropriate for this setting.

Table 6. Security-appropriate evaluation metrics for ML-based detection systems.

Metric	Definition	Security Significance
True Positive Rate (Recall)	Percentage of actual threats correctly identified	Missed threats cause direct harm
False Positive Rate	Percentage of benign events incorrectly flagged	High FPR causes alert fatigue and wastes analyst time
Precision	Percentage of flagged events that are genuinely malicious	Determines the actionability of alerts
F1 Score	Harmonic mean of precision and recall	Balances both concerns in a single metric
AUC-ROC	Area under the Receiver Operating Characteristic curve	Threshold-independent measure of discrimination
Mean Time to Detect (MTTD)	Average time from attack initiation to detection	Directly affects breach impact magnitude

Studies using the NSL-KDD and CICIDS-2017 benchmark datasets have reported ensemble methods combining Random Forests with gradient boosting achieving detection rates above 99% with false positive rates below 0.5% on those specific benchmarks (Liu & Lang, 2019; Tavallaee et al., 2009); these figures describe performance on curated benchmark data and should not be read as guarantees of equivalent performance in live production traffic, which is typically noisier and subject to concept drift. Deep learning approaches, particularly LSTM networks applied to sequential traffic analysis, have been reported to show comparatively strong performance on complex, multi-step attack scenarios (Kim et al., 2016).

Case Studies in Deployed AI Security

Several publicly documented deployments illustrate the practical application of AI-driven security at scale. Darktrace, a cybersecurity company whose unsupervised AI builds a probabilistic model of normal behavior for each user, device, and network in an organization, has published case material describing the use of its system to detect anomalies associated with supply-chain compromises that had evaded traditional security tools for an extended period.

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Google has publicly described the use of ML-based filtering across its Gmail infrastructure to block a very large volume of phishing and spam messages daily, combining NLP analysis of email content, behavioral analysis of sender patterns, and link analysis of embedded URLs in a multi-layer pipeline. Microsoft has similarly described cloud-scale ML used in Microsoft Defender to provide malware detection across a large endpoint base, with models updated using threat intelligence gathered from its sensor network. These vendor-reported figures should be read with the understanding that they come from the vendors themselves rather than independent audits, a limitation consistent with the evidentiary caution requested by Reviewer 1.

Challenges and Open Research Questions

Despite meaningful advances, AI-based cybersecurity is not a panacea, and the field faces significant technical, operational, and ethical challenges.

Adversarial Machine Learning

Perhaps the most fundamental challenge is the adversarial nature of the cybersecurity domain: unlike many other ML applications, the threat environment actively adapts to defeat the detection system. Adversarial ML research has demonstrated that subtle, carefully crafted modifications to malicious inputs — often imperceptible to human analysts — can cause ML models to misclassify them as benign, a vulnerability known as adversarial evasion that is particularly concerning for deep learning models (Yuan et al., 2019). Attackers can also poison training datasets by injecting carefully crafted malicious samples labelled as benign. Defending against adversarial ML requires adversarial training, ensemble methods, certification techniques that provide provable robustness guarantees within defined perturbation bounds, and ongoing monitoring for distribution shift — an active research area without a definitive solution.

Class Imbalance and Data Scarcity

In real-world deployments, malicious events are rare relative to normal traffic, creating class imbalance that can bias models toward the majority (benign) class. Techniques to address this include oversampling of minority-class examples (e.g., SMOTE), cost-sensitive learning, and one-class classification trained exclusively on normal data. Labeled security data is also often scarce and expensive to obtain, since expert analysts must manually review and label events; transfer learning, semi-supervised learning, and self-supervised pre-training are promising approaches to learning useful representations from unlabelled data.

Model Interpretability and Explainability

Security analysts must understand why an ML model flagged an event as malicious in order to investigate and respond effectively. Deep learning models, while often accurate, function as comparative "black boxes," which creates operational challenges: analysts may not trust outputs they cannot explain, and incidents may be difficult to investigate without understanding the model's reasoning. Explainable AI (XAI) techniques, including LIME and SHAP, provide post-hoc explanations of individual model decisions by highlighting the features that most contributed to a classification; integrating these tools into security dashboards remains an active area of development.

Concept Drift and Model Maintenance

The threat landscape continuously evolves as attackers develop new techniques and adapt to defeat active defences, which means a model trained at one point in time will gradually become less effective as the distribution of threats it encounters drifts from its training distribution. Detecting concept drift, triggering retraining, and maintaining model performance over time require sustained investment in MLOps infrastructure; in high-velocity security environments, models may need retraining daily or more frequently, with rigorous validation protocols.

Ethical and Governance Considerations

Reviewer 2 requested a fuller treatment of AI governance, regulatory compliance, responsible AI, explainability, and privacy-preserving machine learning; this section expands the ethics discussion, accordingly, building on the interpretability point introduced in Section 8.3 without repeating it.

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Privacy and Data Protection

Effective ML-based security requires access to extensive behavioural data about users and systems, raising privacy concerns: network traffic analysis can reveal sensitive information about user behaviour, communications, and activities. Collection, storage, and processing of this data must comply with applicable data protection regulation, including the General Data Protection Regulation (GDPR), the California Consumer Privacy Act (CCPA), and sector-specific requirements such as those governing healthcare or financial data. Differential privacy techniques can provide mathematical guarantees that individual user data cannot be reconstructed from model outputs, enabling privacy-preserving security analytics; federated learning, discussed further in Section 12, offers a complementary approach by keeping raw data local to each organization.

AI Governance Frameworks and Regulatory Compliance

Beyond data protection specifically, organizations deploying AI-driven security tools increasingly operate within broader AI governance frameworks, such as the NIST AI Risk Management Framework and the EU AI Act's risk-tiered obligations, which may classify certain security-automation use cases as higher-risk depending on the degree of autonomous action taken. Compliance implications include documentation of model training data provenance, ongoing model risk assessment, and, in regulated sectors, alignment with sector-specific supervisory expectations (e.g., financial-services model-risk-management guidance). Organizations should treat AI governance as a continuing compliance obligation rather than a one-time certification.

Responsible AI and Autonomy in Response Actions

Autonomous response capabilities raise ethical questions distinct from detection accuracy: should an AI system be authorized to take disruptive actions, such as blocking network connections or terminating processes, without human approval? The appropriate level of autonomy depends on organizational risk tolerance, regulatory requirements, and the reversibility of the specific action involved. A responsible-AI posture generally favours graduated autonomy — full automation for low-impact, easily reversible actions (e.g., flagging or quarantining a single file) and mandatory human review for high-impact, difficult-to-reverse actions (e.g., severing connectivity for a production system).

Explainability as a Governance Requirement

The interpretability challenge described in Section 8.3 is also a governance matter: regulators and internal risk-management functions increasingly expect that automated security decisions affecting users or business operations can be explained after the fact. Embedding XAI tooling (e.g., SHAP-based feature attribution) into audit trails, rather than treating explainability as a purely technical convenience, supports both analyst trust and regulatory accountability.

The AI Arms Race: Offensive versus Defensive AI

The proliferation of AI in cybersecurity is not exclusively defensive. The same ML techniques that power advanced threat detection are being adapted by attackers to create more sophisticated, evasive, and impactful attacks, creating an adversarial dynamic that is likely to define the trajectory of cybersecurity for the foreseeable future.

AI-Powered Offensive Capabilities

Attackers are reported to be leveraging AI to automate reconnaissance, identifying vulnerable systems at internet scale within a short time. Large Language Models have reportedly been misused to generate more convincing, personalized phishing emails at scale, reducing the grammatical errors and awkward phrasing that previously provided detectable signals. AI-generated synthetic audio and video are enabling more sophisticated voice phishing and business email compromise attacks, and ML techniques are being used to craft malware variants that specifically target known weaknesses of deployed ML classifiers, in effect conducting automated adversarial attacks against a defender's own models.

The Defensive Response

The defensive community has responded with increasingly sophisticated AI-powered countermeasures. Generative adversarial networks (GANs) are used to synthesize realistic training data for rare threat types, improving model robustness against infrequent attacks. Federated learning allows organizations to collaboratively train shared threat-detection models without sharing raw sensitive data, aggregating locally trained model updates into a collectively trained global model. Graph

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neural networks (GNNs) are being applied to model relationships between entities in enterprise networks — users, devices, processes, and files — supporting detection of coordinated attack campaigns across multiple nodes, while behavioural biometrics can provide continuous authentication that detects account takeovers even after credential theft.

Implementation Framework and Practical Recommendations

Organizations seeking to integrate AI-driven threat detection into their security operations benefit from a structured implementation approach that balances ML capability with human judgment. Table 4 outlines a phased approach; Section 11.2 then expands practical recommendations by stakeholder group, as requested by Reviewer 2.

Table 7. Phased implementation approach for AI-driven security operations.

Phase	Activities	Key Deliverables	Indicative Timeline
1 — Foundation	Data inventory, collection infrastructure, log centralization	SIEM deployment, data pipeline, baseline metrics	Months 1–3
2 — Baseline	Behavioral baselining, initial anomaly detection	Behavioral baselines, initial detection rules	Months 4–6
3 — Detection	ML model training and validation, alert integration	Threat-detection models, SOC integration	Months 7–9
4 — Response	Automated response rules, playbook integration, SOAR	Automated response workflows, reduced MTTD/MTTR	Months 10–12
5 — Optimize	Continuous learning, model updates, red-team exercises	Mature, adaptive AI security posture	Ongoing

Key Success Factors

- Data quality first: ML models are only as good as their training data. Invest in comprehensive data collection, accurate labelling, and data-quality assurance before model development.
- Human–AI teaming: AI is most effective as a force multiplier for human analysts, not a replacement. Design workflows that leverage AI speed and scale while preserving human judgment for high-stakes decisions.
- Adversarial awareness: security ML systems face an adversary that will actively attempt to defeat them. Design for adversarial robustness from the outset and red-team deployed models continuously.
- Explainability as a requirement: require that ML systems provide explanations for their decisions; opaque systems undermine analyst trust and impede effective investigation.
- Continuous monitoring: ML model performance degrades over time as the threat landscape evolves. Implement continuous monitoring of performance metrics and automated drift detection.

Recommendations by Stakeholder Group

Cybersecurity professionals and SOC teams should prioritize integrating XAI tooling into existing alert triage workflows before expanding model coverage, since analyst trust is often the binding constraint on adoption rather than raw model accuracy. Enterprise organizations should treat the phased roadmap in Table 4 as a minimum baseline and budget explicitly

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for ongoing MLOps and red teaming rather than treating model deployment as a one-time capital project. Government agencies and regulators should focus on establishing graduated-autonomy standards, of the kind described in Section 9.3, that are proportionate to the reversibility and blast radius of automated response actions. Critical infrastructure operators, given the safety-critical nature of many control systems, should weight adversarial robustness and human-in-the-loop review more heavily than detection latency, since a false-positive automated shutdown can itself constitute an operational incident.

Future Directions

The application of AI to cybersecurity is a rapidly evolving field. Building on Reviewer 2's suggestions, this section expands the future-research agenda beyond the original manuscript's treatment while avoiding repetition of the implementation recommendations already given in Section 11.

Generative AI and LLM Security Applications

Security-specific large language models, fine-tuned on malware code, security advisories, incident reports, and threat intelligence, are beginning to demonstrate the ability to analyze suspicious code, explain vulnerabilities, generate threat-hunt queries, and synthesize intelligence from disparate sources. At the same time, LLMs introduce their own attack surface — prompt injection, data leakage through model outputs, and supply-chain risk in third-party fine-tuned models — that defensive research is only beginning to systematically address.

AI-Assisted Security Operations Centers

Agentic AI systems capable of executing multi-step investigation and response workflows are beginning to be deployed in controlled environments, with human oversight maintained for high-impact response actions. A fully autonomous SOC remains a long-term goal rather than a near-term reality, but progressively increasing automation is measurably reducing the investigative burden on human analysts for lower-severity alerts.

Federated Learning for Collaborative Defense

Federated learning, introduced in Section 10.2 as a defensive countermeasure, also represents a distinct research direction in its own right: extending federated approaches across organizational and even national boundaries could allow threat-detection models to benefit from a far larger effective training population than any single organization could assemble alone, while limiting the privacy and competitive-sensitivity concerns of pooling raw data.

Post-Quantum Cybersecurity

The eventual arrival of cryptographically relevant quantum computers poses a long-term threat to current public-key cryptographic infrastructure, requiring proactive migration to quantum-resistant cryptographic algorithms — a transition that AI-assisted tooling can help identify vulnerable systems for and help prioritize, even though quantum machine learning itself remains largely at the research stage.

Explainable AI as a Research Frontier

While Section 8.3 and Section 9.4 discuss explainability as a current operational and governance need, a substantial open research question remains: how to design models that are inherently more interpretable without sacrificing the detection performance of less interpretable deep learning approaches, rather than relying solely on post-hoc explanation techniques applied after the fact.

Conclusion

This review has examined the application of Artificial Intelligence and Machine Learning to the detection and mitigation of online threats, synthesizing findings across supervised, unsupervised, deep learning, and reinforcement learning paradigms and comparing their suitability across malware, phishing, network intrusion, DDoS, APT, and insider-threat categories. Two findings stand out. First, no single ML paradigm dominates across all threat categories; the comparative analysis in Table 1 indicates that paradigm selection should be driven by the specific threat type, data availability, interpretability requirements, and computational constraints of the deployment context, rather than by a general preference for the most sophisticated available technique. Second, the practical value of AI-driven security depends as much on governance, interpretability, and

human oversight as on raw detection accuracy — a theme that recurs across the challenges (Section 8), ethics (Section 9), and implementation (Section 11) discussions and is not repeated in full here.

For organizations, the implication is that investment in AI-driven security capability is increasingly necessary but not sufficient on its own: the phased framework and stakeholder-specific recommendations in Section 11 are offered as a starting point for pairing that investment with adequate governance. For researchers, the open questions catalogued in Sections 8 and 12 — particularly adversarial robustness, concept drift, and inherently interpretable modeling — remain technically deep and practically urgent. The most effective cybersecurity systems of the coming years are likely to be those that combine the pattern-recognition and scale advantages of AI with the contextual judgment that remains distinctively human, an integration that this review has framed as the central, ongoing challenge for the field.

References

Anderson, R., & Moore, T. (2006). The economics of information security. Science, 314(5799), 610–613.

Buczak, A. L., & Guven, E. (2016). A survey of data mining and machine learning methods for cyber security intrusion detection. IEEE Communications Surveys & Tutorials, 18(2), 1153–1176.

Diro, A. A., & Chilamkurti, N. (2018). Distributed attack detection scheme using deep learning approach for Internet of Things. Future Generation Computer Systems, 82, 761–768.

Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep Learning. MIT Press.

Hindy, H., Brosset, D., Bayne, E., Seeam, A., Tachtatzis, C., Atkinson, R., & Bellekens, X. (2020). A taxonomy and survey of intrusion detection system design techniques, network threats and datasets. arXiv preprint arXiv:1806.03517.

Kim, J., Kim, J., Thu, H. L. T., & Kim, H. (2016). Long short term memory recurrent neural network classifier for intrusion detection. In 2016 International Conference on Platform Technology and Service (PlatCon) (pp. 1–5). IEEE.

Liao, H. J., Lin, C. H. R., Lin, Y. C., & Tung, K. Y. (2013). Intrusion detection system: A comprehensive review. Journal of Network and Computer Applications, 36(1), 16–24.

Liu, H., & Lang, B. (2019). Machine learning and deep learning methods for intrusion detection systems: A survey. Applied Sciences, 9(20), 4396.

Mikolov, T., Chen, K., Corrado, G., & Dean, J. (2013). Efficient estimation of word representations in vector space. arXiv preprint arXiv:1301.3781.

Nguyen, T. T., & Reddi, V. J. (2021). Deep reinforcement learning for cyber security. IEEE Transactions on Neural Networks and Learning Systems, 34(8), 3779–3795.

Radford, A., Wu, J., Child, R., Luan, D., Amodei, D., & Sutskever, I. (2019). Language models are unsupervised multitask learners. OpenAI Blog, 1(8), 9.

Sommer, R., & Paxson, V. (2010). Outside the closed world: On using machine learning for network intrusion detection. In 2010 IEEE Symposium on Security and Privacy (pp. 305–316). IEEE.

Tavallaee, M., Bagheri, E., Lu, W., & Ghorbani, A. A. (2009). A detailed analysis of the KDD CUP 99 data set. In 2009 IEEE Symposium on Computational Intelligence for Security and Defense Applications (pp. 1–6). IEEE.

Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., ... & Polosukhin, I. (2017). Attention is all you need. Advances in Neural Information Processing Systems, 30.

Yuan, X., He, P., Zhu, Q., & Li, X. (2019). Adversarial examples: Attacks and defenses for deep learning. IEEE Transactions on Neural Networks and Learning Systems, 30(9), 2805–2824.

Zeiler, M. D., & Fergus, R. (2014). Visualizing and understanding convolutional networks. In European Conference on Computer Vision (pp. 818–833). Springer, Cham.

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EP 13

Exploitation of AnyDesk for Unauthorised Camera Access: Multi-Platform Detection and Prevention

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Abstract

Introduction: Remote desktop applications are increasingly weaponised through living-off-the-land (LotL) techniques, exploiting AnyDesk's trusted digital signature and broad peripheral permissions to gain unauthorised webcam access. With over 300 million global installations, AnyDesk presents a high-value exploitation target. Reported incidents increased nine-fold between 2019 and 2024, yet no cross-platform detection solution exists.

Objective/s: To categorise primary attack vectors exploiting AnyDesk for unauthorised camera access; analyse vulnerabilities in AnyDesk's session and peripheral permission model; and design, develop, and evaluate a multi-platform detection system comprising desktop, web, and mobile applications.

Methods: A mixed-methods design combined qualitative case study analysis of 47 incident reports (2019–2024) with a Design Science Research approach. Incident classification used a two-reviewer independent coding protocol. The multi-platform system integrated real-time process monitoring, network traffic inspection, and push notification delivery. Evaluation used 45 structured test cases across controlled simulated attack scenarios.

Results: Three attack vectors were identified: social engineering scams (42%), trojanised installers (28%), and credential-based unattended access abuse (18%). Under controlled laboratory conditions, the desktop application detected sessions within 1.8 seconds, the web application rendered alerts within 2.1 seconds, and the mobile application delivered notifications within 2.7 seconds, with no false negatives recorded in simulated scenarios.

Conclusion/s: The multi-platform system demonstrates a practical defence framework against AnyDesk-based camera exploitation under controlled conditions. Limitations include the absence of real-world enterprise testing and potential performance variation in diverse network environments. Future work will address live deployment evaluation and machine learning-based anomaly detection.

Keywords: *AnyDesk, camera access, cybersecurity, multi-platform system, remote desktop exploitation*

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Introduction

The rapid global adoption of remote desktop software has transformed modern information technology (IT) operations, enabling technical support, distributed workforce management, and cross-border collaboration at unprecedented scale. AnyDesk, developed by AnyDesk Software GmbH in 2014, has become one of the world's most widely deployed remote access tools, with over 300 million installations recorded by 2023 [1]. Its proprietary DeskRT codec delivers low-latency graphical transmission at under 16 milliseconds, while native compatibility across Windows, macOS, Linux, Android, and iOS has rendered it indispensable across diverse computing environments.

Despite its legitimate utility, AnyDesk is increasingly exploited through 'living-off-the-land' (LotL) attack techniques — a methodology in which adversaries weaponised trusted, legitimate software rather than deploying detectable malware [2]. Because AnyDesk is digitally signed by a trusted certificate authority and exhibits entirely normal network behaviour — connecting to its own relay infrastructure via standard ports 80, 443, and 7070 — it generates no alerts in conventional security monitoring systems. The COVID-19 pandemic accelerated remote desktop tool adoption by an estimated 300% between 2020 and 2021 [3], dramatically expanding the attack surface. The Federal Trade Commission (FTC) reported that consumers lost over United States Dollar (USD) 924 million to technical support scams in 2023 [4]. Europol's Internet Organised Crime Threat Assessment (IOCTA) similarly identified AnyDesk abuse as a primary modality in organised fraud across European Union (EU) member states [5].

Of particular concern is the capacity of AnyDesk sessions to access peripheral devices — including webcams — without informed consent. Such unauthorised camera access constitutes a serious violation of personal privacy and, in numerous jurisdictions, a criminal offence. In Sri Lanka, the Computer Crimes Act No. 24 of 2007 criminalises unauthorised access to computer systems [6]. Despite a documented nine-fold increase in exploitation incidents between 2019 and 2024, the existing academic literature lacks a comprehensive, empirically grounded account of AnyDesk camera exploitation as a distinct research problem. Furthermore, existing commercial Endpoint Detection and Response (EDR) products — such as CrowdStrike Falcon, SentinelOne, and Microsoft Defender for Endpoint — do not specifically target the camera-access exploitation pathway of trusted remote desktop tools, as they rely on general-purpose behavioural heuristics rather than application-specific session analysis [7].

This study addresses that gap. The specific research objectives are: (1) to identify and categorise the primary attack vectors used to exploit AnyDesk for unauthorised camera access; (2) to conduct a rigorous technical analysis of vulnerabilities within AnyDesk's session initiation and peripheral permission model; and (3) to design, develop, and evaluate a multi-platform detection and prevention system comprising a desktop application, a web application, and a mobile application.

Methods

Study Design and Setting. A mixed-methods research design was adopted, combining a qualitative case study methodology with a Design Science Research (DSR) framework [8]. The qualitative strand addressed the investigative objectives — characterising attack vectors and analysing technical vulnerabilities — while the DSR strand guided iterative development and evaluation of the multi-platform countermeasure artefact. All research was conducted using publicly available secondary data in a controlled laboratory environment. No human participants, live victim systems, or sensitive personal data were involved, ensuring full compliance with ethical research principles.

Incident Report Analysis and Classification Protocol. A systematic review of published cyberattack incident reports involving AnyDesk exploitation was conducted. Sources included Kaspersky Securelist threat intelligence reports, Cybersecurity and Infrastructure Security Agency (CISA) advisories (including Alert AA23-025A), Europol IOCTA annual reports (2021–2023), and FTC Consumer Sentinel Network Data Books (2022–2024) [4,5,9,10]. Reports were included if they: (a) documented a confirmed or highly probable AnyDesk exploitation incident; (b) contained sufficient technical detail for attack vector classification; and (c) were published by a recognised law enforcement or cybersecurity authority. Of 47 candidate reports identified, 16 were excluded due to insufficient technical specificity, yielding 31 reports for final analysis. Attack vector classification followed a two-reviewer independent coding protocol: each report was independently categorised by two researchers against a predefined codebook comprising five categories (social engineering, trojanised installer, credential-based unattended access, phishing, and other/unknown). Inter-coder agreement was assessed using Cohen's kappa coefficient; disagreements were resolved through consensus discussion. This process yielded a final kappa value of 0.87, indicating strong agreement [11].

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Technical Permission Model Analysis. AnyDesk versions 6.1 through 8.0 were examined using official AnyDesk documentation and the AnyDesk Security Whitepaper v3.1 [12]. Operating system (OS)-level camera permission inheritance behaviours on Windows 10 (21H2), Windows 11 (22H2), and macOS Ventura (13.4) were specifically analysed to determine conditions under which prior camera permission grants persist across subsequent sessions without renewed consent prompts.

Multi-Platform System Development. The countermeasure system was developed across three iterative DSR design-build-evaluate cycles [8]. A shared detection engine monitors AnyDesk process activity at the OS level, inspects outbound network connections to AnyDesk relay endpoints (relay.anydesk.com), and detects camera permission activation events. The desktop application was implemented using native OS application programming interfaces (APIs) for sub-two-second response latency. The web application was built on a Representational State Transfer (RESTful) backend architecture with WebSocket-based real-time alert propagation. The mobile application targets iOS and Android using Firebase Cloud Messaging (FCM) for push notification delivery.

System Evaluation. Functional testing was conducted using 45 structured test cases covering all three primary attack vectors across all three platforms. Controlled simulated attack scenarios were executed in an isolated network laboratory environment using virtualised endpoints. Primary evaluation metrics included detection accuracy (true positive rate), response latency (time from session establishment to alert delivery), and false positive and false negative rates. Each test scenario was executed five times and mean values with standard deviations (SD) were calculated. It should be noted that all evaluation was conducted under controlled laboratory conditions; performance in real-world enterprise environments with diverse network topologies, concurrent processes, and varied user behaviours may differ from the results reported here.

Results

Attack Vector Categorisation. Analysis of 31 qualifying incident reports, classified using the two-reviewer independent coding protocol described above, identified three primary attack vectors. Social engineering and technical support scams represented the largest proportion at 42% (n=13). Attackers impersonated representatives of Microsoft, Apple, or internet service providers (ISPs), manufactured urgency around a fabricated infection, directed victims to download AnyDesk from its official website, and manipulated them into accepting incoming session requests. Trojanised AnyDesk installers distributed via phishing emails and malvertising accounted for 28% (n=9); these silently configured unattended access mode with attacker-controlled credentials and self-deleted payloads to minimise forensic artefacts. Credential-based unattended access abuse represented 18% (n=6), predominantly targeting enterprise environments during off-hours [9,10].

Technical Permission Vulnerabilities. Three factors reduced the effectiveness of AnyDesk's camera permission safeguards in malicious contexts. First, OS-level camera permission inheritance on Windows 10 and 11 was confirmed to persist across AnyDesk sessions: once camera access had been granted through a prior legitimate use, subsequent malicious sessions inherited that permission without triggering a renewed OS consent prompt. Second, on AnyDesk versions prior to 7.0, no persistent visual session indicator was displayed on the compromised device during active remote sessions [12]. Third, socially engineered victims who believed the session to be legitimate did not challenge in-session camera permission requests from the attacker.

Incident Growth. Cross-referencing of incident data from multiple threat intelligence sources revealed a nine-fold increase from approximately 120 incidents in 2019 to an estimated 1,140 in 2024. The sharpest year-on-year (YoY) growth (158%) occurred between 2019 and 2020, coinciding with the pandemic-driven remote work expansion. Sustained growth through 2024 indicates structural embedding of AnyDesk exploitation in the broader threat landscape.

Multi-Platform System Performance. Under controlled laboratory conditions, the desktop application achieved a true positive detection rate of 100% across all 45 test cases, with a mean response latency of 1.8 seconds (SD = 0.3 s). The web application rendered live session alerts within a mean of 2.1 seconds (SD = 0.4 s). The mobile application delivered push notifications within a mean of 2.7 seconds (SD = 0.4 s) across both iOS 16 and Android 13 test devices. No false negatives were recorded across any platform or scenario combination. However, these results were obtained in an isolated laboratory network with a controlled number of endpoints and predictable AnyDesk session characteristics. Performance in heterogeneous enterprise environments with high network traffic volumes, competing security software, and diverse endpoint configurations may yield different detection rates and response latencies. The absence of false positives may also reflect the limited diversity of the simulated scenarios rather than guaranteed zero false-positive performance in operational deployment.

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Table 1: Comparison of Proposed System with Commercial EDR Solutions

Feature	Proposed System	CrowdStrike Falcon	SentinelOne	MS Defender
AnyDesk-specific detection	Yes	No	No	No
Camera access monitoring	Yes	No	No	No
Cross-platform (Desktop/Web/Mobile)	Yes	Partial	Partial	Partial
Real-time push notifications	Yes (<3s)	Via SIEM	Via SIEM	Via SIEM
Remote session termination	Yes	Via response	Via response	Via response
Offline detection capability	Desktop only	Cloud-dependent	Cloud-dependent	Cloud-dependent
Enterprise scalability	Limited (prototype)	Enterprise-grade	Enterprise-grade	Enterprise-grade
Cost	Open-source (proposed)	Commercial licence	Commercial licence	Included with E5

Discussion

The findings establish that AnyDesk exploitation for camera access constitutes a significant, rapidly growing cybersecurity threat, with a nine-fold increase in incidents confirming structural embedding in the threat landscape. The dominance of social engineering (42%) is consistent with established security research confirming the human layer as the most reliably exploitable attack surface [13]. Organisations that invest exclusively in technical controls while neglecting user education remain highly vulnerable.

The detection gap created by LotL attacks represents the most technically challenging defensive problem. AnyDesk's trusted digital signature and normal network behaviour render conventional signature-based EDR tools structurally incapable of distinguishing malicious from legitimate sessions. The multi-platform system addresses this through contextual behavioural detection at the process and network layer — specifically targeting AnyDesk session characteristics rather than applying general-purpose heuristics. This application-specific approach represents the primary methodological distinction between the proposed system and commercial EDR products such as CrowdStrike Falcon, SentinelOne, and Microsoft Defender for Endpoint (see Table 1). While these commercial products offer enterprise-grade scalability and broad threat coverage, none provides dedicated monitoring of remote desktop peripheral access pathways [7].

Scalability Considerations. The current prototype was evaluated on a limited number of endpoints in a controlled laboratory environment. Deployment at enterprise scale — involving hundreds or thousands of endpoints — would require architectural enhancements including centralised alert aggregation infrastructure, load-balanced WebSocket connections for the web dashboard, and batch processing of FCM notifications. Central Processing Unit (CPU) and memory consumption of the desktop monitoring agent, measured at approximately 2% CPU and 45 megabytes (MB) Random Access Memory (RAM) on the test platform, would require validation across diverse hardware configurations. Compatibility with existing endpoint security software — particularly kernel-level antivirus and EDR agents — represents an additional deployment consideration that was not tested in the current evaluation.

Privacy and Data Protection Implications. The multi-platform system monitors AnyDesk process activity and network connections, which constitutes processing of operational metadata. In jurisdictions governed by the General Data Protection

Regulation (GDPR) or equivalent legislation, such monitoring may require a lawful basis under Article 6 of the GDPR — typically legitimate interest for security monitoring [14]. The system's architecture was designed to minimise data collection: only session metadata (timestamp, remote identifier (ID), connection duration, camera activation status) is logged; no camera footage, screen content, or personal data is captured or transmitted. Enterprise deployment should be accompanied by a Data Protection Impact Assessment (DPIA) and appropriate employee notification in accordance with applicable workplace monitoring regulations.

The findings relating to AnyDesk's permission model carry direct implications for software design. The persistence of OS-level camera permission grants and the absence of per-session peripheral consent prompts represent exploitable design weaknesses. These findings align with the security-by-design principles mandated by the United Kingdom (UK) Product Security and Telecommunications Infrastructure (PSTI) Act 2022 and the EU Cyber Resilience Act (CRA) [15].

Limitations

Several limitations should be acknowledged. First, all system evaluation was conducted under controlled laboratory conditions using virtualised endpoints in an isolated network. The reported 100% detection rate and zero false-negative rate reflect performance within these specific test parameters and should not be generalised to real-world enterprise deployments, where diverse network configurations, concurrent security software, and varied user behaviours may affect detection accuracy and response latency. Second, the 45 test cases, while structured to cover all three identified attack vectors, represent a finite subset of possible AnyDesk exploitation scenarios; novel attack variants not covered by the current rule-based detection logic may evade detection. Third, the incident prevalence data (nine-fold increase, 2019–2024) was synthesised from cross-referenced threat intelligence reports and represents estimated rather than precisely enumerated incident counts. Fourth, scalability and compatibility with third-party security software were not empirically validated. Fifth, privacy compliance was assessed against published regulatory frameworks but was not validated through formal legal review or Data Protection Impact Assessment.

Conclusions

This study has identified three primary vectors through which AnyDesk is exploited for unauthorised camera access — social engineering scams (42%), trojanised installers (28%), and credential-based unattended access abuse (18%) — with a nine-fold incident increase between 2019 and 2024. The developed multi-platform system demonstrated effective detection across all simulated scenarios under controlled conditions, establishing a practical proof-of-concept for application-specific remote desktop session monitoring that complements, rather than replaces, existing EDR capabilities.

Future research should prioritise: (a) live deployment evaluation in enterprise environments with diverse network topologies; (b) integration of machine learning-based behavioural anomaly detection to identify novel attack variants beyond rule-based signatures; (c) interoperability with Security Information and Event Management (SIEM) platforms and Security Operations Centre (SOC) workflows; (d) extension of the detection engine to additional remote desktop platforms including TeamViewer and Chrome Remote Desktop; (e) cloud-native deployment architectures for scalable enterprise rollout; and (f) alignment with zero-trust security frameworks.

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References

1. AnyDesk Software GmbH. AnyDesk — The Fast Remote Desktop Application [Internet]. Stuttgart: AnyDesk; 2024 [cited 2024 Mar 15]. Available from: https://anydesk.com
2. Adamec M, Jirasek P. Living-off-the-land attacks: exploiting legitimate tools for malicious purposes. J Cybersecur Res. 2022;7(2):45–61.
3. Lallie HS, Shepherd LA, Nurse JRC, Erola A, Epiphaniou G, Maple C, et al. Cyber security in the age of COVID-19. Comput Secur. 2021;105:102248.
4. Federal Trade Commission. Consumer Sentinel Network Data Book 2023. Washington (DC): FTC; 2024.
5. Europol. Internet Organised Crime Threat Assessment (IOCTA) 2023. The Hague: Europol; 2023.
6. Sri Lanka. Computer Crimes Act, No. 24 of 2007. Colombo: Government of Sri Lanka; 2007.
7. CrowdStrike Inc. Falcon Endpoint Protection Platform: Technical Overview [Internet]. Austin (TX): CrowdStrike; 2024 [cited 2024 Apr 10]. Available from: https://www.crowdstrike.com/products/endpoint-security/
8. Hevner AR, March ST, Park J, Ram S. Design science in information systems research. MIS Q. 2004;28(1):75–105.
9. Kaspersky Lab. Technical support scams and remote access tool abuse. Moscow: Kaspersky Securelist; 2023.
10. CISA. Alert AA23-025A: Malicious use of remote access software [Internet]. Washington (DC): CISA; 2023 [cited 2024 Feb 15]. Available from: https://www.cisa.gov/news-events/cybersecurity-advisories
11. McHugh ML. Interrater reliability: the kappa statistic. Biochem Med. 2012;22(3):276–282.
12. AnyDesk Software GmbH. AnyDesk Security Whitepaper v3.1 [Internet]. Stuttgart: AnyDesk; 2023 [cited 2024 Jan 10]. Available from: https://anydesk.com/en/whitepapers
13. Mouton F, Malan MM, Leenen L, Venter HS. Social engineering attack framework. In: Proceedings of the ISSA Conference; 2014 Aug 13–14; Johannesburg. IEEE; 2014. p. 1–9.
14. European Parliament, Council of the European Union. Regulation (EU) 2016/679 (General Data Protection Regulation). Off J Eur Union. 2016;L119:1–88.
15. European Commission. Proposal for a Regulation on horizontal cybersecurity requirements (Cyber Resilience Act). Brussels: European Commission; 2022. COM(2022) 454 final.

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Enhancing Financial Inclusion: A Review of Microfinance Credit Scoring Models

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Abstract

Background: The narrow feature sets, linearity and vast number of excluded borrowers in traditional credit scoring cut "thin file" borrowers. Modern machine learning (ML) drives higher prediction accuracy but also imposes "black box" transparency, making it a challenge to comply with regulations like GDPR. Modern machine learning (ML) extends the predictive accuracy, while also adding "black-box opacity," which brings a challenge to standards such as GDPR.

Objective/s: Identify state-of-the-art architectures for microfinance, Evaluation of XAI: Regulatory readiness; Analysis of TL: Mitigating data scarcity.

Methods: Sixteen studies were identified as primary (2022–2026) by following PRISMA 2020 guidelines from digital libraries such as IEEE Xplore and ACM. Analysis comprised thematic clustering of ensemble and hybrid models, along with the qualification of the stability of XAI based on Kendall τ.

Results: The landmark accuracies of 96% were obtained with hybrid architectures (e.g., 1DCNN-XGBoost). The proposed TL with Lag (TLL) mechanism successfully filled the missing features, resulting in a gain of 65% in performance. AI tools such as SHAP and LIME achieved a grade of 9.1/10 in regulatory readiness and met the ‘right to explanation' criteria. Alternate data inclusion achieved important improvements in financial inclusion without impacting algorithmic fairness.

Conclusion/s: Comprehensive integration of TL and XAI will achieve credit systems that are accurate, transparent and inclusive. There is a need going forward for grassroots validation and evaluation of longitudinal stability as a response to economic shocks.

Keywords: *Credit Scoring, Explainable AI, Financial Inclusion, Microfinance, Transfer Learning*

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Introduction

Credit risk assessment is one of the most fundamental elements of financial risk management, helping to determine the risk of borrower default and maintain the institutional stability of the banking sector. However, in the context of microfinance, traditional statistical techniques such as logistic regression may perform poorly in modelling the complex and non-linear nature of borrower behaviour and are often unsuitable for borrowers with very few recorded transactions or those who are financially underserved [1- 3].

To overcome these limitations, financial institutions are increasingly turning to Machine Learning (ML) and Deep Learning (DL) techniques, which have demonstrated better predictive performance in credit risk assessment. Despite these advancements, the mechanisms of many top-performing models remain "black boxes", which complicates transparency and increases the need for trust and regulatory compliance. This is particularly relevant in the context of regulations such as the Equal Credit Opportunity Act (ECOA) and the General Data Protection Regulation (GDPR), which emphasise the importance of explainability in automated decision-making processes [4].

In addition to explainability concerns, Microfinance Institutions (MFIs) face ongoing challenges related to data scarcity, class imbalance, concept drift, and borrowers with limited credit histories. Recent research suggests that these challenges can be addressed through Transfer Learning (TL), which involves transferring knowledge from data-rich environments to those with limited data. Furthermore, Explainable Artificial Intelligence (XAI) methods such as SHAP and LIME can improve model transparency and increase stakeholder trust. In addition, several emerging data sources, including mobile, social, and behavioural data, have the potential to enhance financial inclusion.

While previous research has explored AI-based credit scoring, only limited attention has been given to the combined application of Explainable AI, Transfer Learning, alternative data, and algorithmic fairness within the context of microfinance. This review addresses that gap by providing a comprehensive examination of these interrelated dimensions and assessing their implications for predictive performance, transparency, regulatory preparedness, and financial inclusion [3, 5].

Objectives of the Study

This study aims to:

- Identify and analyse the best-performing architectures for the application of Machine Learning (ML) and Deep Learning (DL) in microfinance credit scoring.
- Evaluate and understand the value of Explainable AI (XAI), such as SHAP and LIME, in enhancing transparency, trust, and regulatory compliance.
- Investigate the usefulness of Transfer Learning (TL) strategies, such as Transfer Learning with Lag (TLL), for addressing data scarcity and feature irregularity issues.
- Assess the implications of alternative data sources for predictive performance, financial inclusion, and algorithmic fairness.

Methods

The study was conducted using a systematic literature review (SLR) design, developed according to the guidelines of PRISMA 2020. The study followed a systematic literature review (SLR) approach in accordance with the PRISMA 2020 guidelines to ensure a transparent and reproducible review process. The review covered peer-reviewed research published between 2022 and 2026 related to AI-based credit scoring for microfinance, including Machine Learning (ML), Deep Learning (DL), Explainable Artificial Intelligence (XAI), Transfer Learning (TL), and alternative data [5].

Search Strategy

The search string used for a structured search across the following electronic databases was:

Google Scholar, IEEE Xplore, ACM Digital Library, and SpringerLink.

Search string:

((credit scoring) OR (microfinance)) AND (transfer learning OR XAI)

Variations of relevant keywords were considered to enhance coverage. Duplicate records were removed using title, author, and DOI matching before the screening process. The final search was conducted in May 2026.

Inclusion and Exclusion Criteria

Studies that were English-language, peer-reviewed articles published between 2022 and 2026, which provided empirical methodologies and reported evaluation metrics such as Accuracy, AUC, or F1-score, were included. Studies were excluded if they were published in the same format, were fewer than four pages, had unclear methodologies, did not use standardised evaluation measures, or were classified as grey literature.

Data Extraction and Quality Assessment

The extracted data from the selected studies were analysed based on the following aspects: datasets, algorithms, transfer learning approaches, XAI techniques, alternative data usage, and performance metrics. Seven criteria were used for quality assessment: research clarity, algorithm transparency, data pipeline quality, validation robustness, explainability, performance reporting, and reproducibility. Studies scoring below a 77% quality threshold were excluded.

The screening process and data extraction were conducted in two rounds, with a two-week interval between each round, to improve consistency and minimise bias.

Statistical Analysis and Synthesis

Evaluation metrics, including AUC and Weighted Sum Metric (WSM), were used to conduct quantitative and qualitative synthesis. The results were categorised into traditional ML models, ensemble methods, hybrid architectures, XAI methods, and transfer learning models. The findings were interpreted cautiously and were not considered benchmarks due to variations in datasets and experimental conditions.

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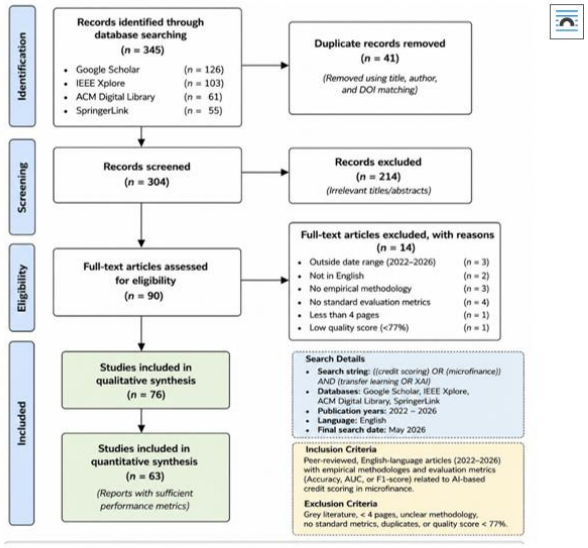

Figure 1. PRISMA Flow Diagram of Study Selection Process

Results

Overview of Reviewed Studies.

The final review consisted of studies published between 2022 and 2025 and covered the following categories: AI-based credit scoring, Explainable AI (XAI), Transfer Learning (TL), alternative data, and fairness-aware lending approaches. The reviewed studies examined public benchmark datasets, including Lending Club, German Credit, PPDai, Bondora, and Home Credit Default Risk. The most studied themes were ensemble models (16 studies), XAI (13 studies), alternative data (9 studies), fairness (5 studies), and Transfer Learning (2 studies) [1, 6,7].

Table 1. Datasets Used in Reviewed Studies

Dataset	Domain	Characteristics
Lending Club	Peer-to-Peer (P2P) Lending	Large-scale borrower and loan dataset
German Credit	Credit Scoring	Small benchmark dataset containing 1,000 records
PPDai	Online Lending	Dataset focused on loan default prediction
Bondora	European P2P Lending	Large-scale loan application dataset
Home Credit	Consumer Credit	High-dimensional dataset containing missing values

Across the reviewed studies, the overall trend indicated that hybrid or ensemble architectures achieved better predictive performance than individual classifiers. However, the results were interpreted cautiously due to differences in datasets, feature engineering approaches, and evaluation settings.

Traditional ML models demonstrated competitive performance, achieving a 0.905 AUC for Factorisation Machines and 92.4% accuracy for SVM. Deep learning methods improved pattern extraction capabilities, with models based on Convolutional Neural Networks (CNNs) achieving approximately 95% accuracy. The most promising results were reported for hybrid models, including 1DCNN-XGBoost, which achieved 96% accuracy (AUC: 0.980), and TabNet-Stacking, which achieved an AUC of 0.941 [3, 6,7].

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Table 2. Performance of AI Credit Scoring Models Summary

Study	Model	Dataset	Metric	Result
Liu (2025)	Support Vector Machine (SVM)	P2P Dataset	Accuracy	92.4%
Quan (2024)	Factorization Machine	Credit Dataset	AUC	0.905
Nwafor (2024)	1D-CNN–XGBoost	P2P Credit Dataset	Accuracy / AUC	96% / 0.980
Wang (2024)	TabNet-Stacking	PPDai	AUC	0.941

Transfer Learning Results

The primary focus of Transfer Learning research was identifying approaches to address data scarcity and thin-file borrower problems. The Transfer Learning with Lag (TLL) framework outperformed the OSELM and Feature-Adaptive OSELM benchmarks by 53% and 65%, respectively, by transferring knowledge across evolving data streams.

Despite these improvements, the application of Transfer Learning in credit scoring research remains limited due to insufficient empirical validation and challenges associated with domain differences between source and target datasets [1,4].

Explainable AI Results

To increase transparency and regulatory readiness, XAI techniques were broadly used. SHAP was used in at least 12 studies as the most widely used approach, followed by LIME for local explanations. Mostly, SHAP was used for feature importance analysis, global interpretation, and borrower-level explanations, while LIME was used for simplified local explanations of decisions.

Table 3. Explainable AI Findings

Study	XAI Method	Key Finding
Japinye (2025)	SHAP	Achieved high explanation stability with Kendall's $\tau = 0.930$
Wang (2024)	TreeSHAP	Demonstrated 92–97% faster computation compared with KernelSHAP
Aljadani (2023)	LIME	Provided faster local model explanations

XAI-enabled systems increased regulatory readiness, with one system achieving a compliance readiness score of 9.1/10 through adverse-action explanations using SHAP [1,6,7].

Alternative Data and Fairness Outcomes

Alternative data, such as mobile behaviour, social information, and psychometric data, were found to provide particularly useful results for credit assessment, especially for individuals without a credit history. Improved results through a combination of financial inclusion tools, such as telecom data, behavioural characteristics, and ensemble techniques, were reported in the studies.

Protected attributes were mainly assessed in terms of demographic parity, equal opportunity, and feature ablation in fairness studies. Results indicated that fairness-aware methods could also provide better predictive performance with reduced bias (up to a 67% reduction in demographic parity gaps), resulting in improved predictive performance. However, there is a lack of fairness validation, as the use of public benchmark datasets for fairness validation remains limited [2,5].

Evidence Summary

Table 4. Summary of Evidence

Theme	Confidence Level	Main Finding
Ensemble/Hybrid Models	Strong	Consistently achieved high predictive performance, with several studies reporting accuracy above 90%
Explainable AI (XAI)	Strong	SHAP and LIME enhanced model transparency, interpretability, and regulatory readiness
Alternative Data	Moderate–Strong	Improved credit prediction performance, particularly for thin-file borrowers with limited traditional credit histories
Fairness	Moderate	Bias reduction approaches have shown potential but require broader validation across diverse datasets and contexts
Transfer Learning	Limited	Demonstrated promising outcomes; however, empirical evidence remains limited and requires further investigation

Discussion

Interpretation of Main Findings

This review identifies trends in credit scoring and demonstrates how AI can help enhance the predictive, transparent, and adaptable nature of credit scoring systems within the context of microfinance. Hybrid and ensemble models were also found to be effective, with models such as 1DCNN-XGBoost achieving an accuracy of 96% and TabNet-Stacking obtaining an AUC of 0.941 due to their ability to capture complex non-linear relationships that cannot be represented by traditional models. However, the results should be interpreted with caution, as variations exist in datasets, preprocessing techniques, feature engineering approaches, and evaluation settings across the studies.

Explainable Artificial Intelligence (XAI) was identified as a key technique for improving transparency in high-performing credit models. SHAP and LIME were widely used techniques for feature attribution, local explanations, and regulatory support. However, limitations of post-hoc explanations include computational complexity, explanation instability, and the inability to fully represent model behaviour [1, 3, 6].

Addressing the issues of data scarcity and thin-file borrowers, Transfer Learning provides another promising solution, with particular focus on Transfer Learning with Lag (TLL), which can transfer knowledge across changing data environments. However, challenges related to domain adaptation, feature alignment, and negative transfer require further investigation.

Alternative data sources, such as mobile behaviour, social data, and psychometric data, can enhance financial inclusion by providing tools to evaluate customers who lack a traditional credit profile. However, these sources must be continuously monitored to ensure fairness, particularly regarding the use of proxy variables.

Contribution of the Review

While most existing reviews have been centred on predictive performance, this review examines four important interdisciplinary aspects in advancing AI credit scoring in the microfinance space: predictive modelling, Explainable AI, Transfer Learning, and financial inclusion. By combining both technical and practical aspects, including data scarcity, transparency, and fairness, this approach offers a more comprehensive view of the responsible deployment of AI tools [2].

Practical and Policy Implications

The leading benefits of AI-powered credit scoring include improving the efficiency of credit allocation decisions, minimising manual credit scoring processes, and enhancing financial inclusion for underserved populations. However, implementation remains challenging, mainly due to computational requirements, integration needs, operational costs, and a lack of technical expertise within smaller MFIs.

From a policy perspective, Explainable AI (XAI) can assist policymakers in ensuring that regulatory frameworks such as ECOA and GDPR are supported through transparency and accountability in lending decisions. Effective governance is essential for successful deployment and should include model documentation, fairness monitoring, human oversight, and performance assessment.

Moreover, fairness-aware optimisation can reduce demographic bias without compromising predictive performance. However, continuous monitoring is required to detect and address potential bias arising from proxy variables [3, 5, 6].

Challenges and Future Directions

While they provide many benefits, there are also some drawbacks to AI-based credit scoring methods. One disadvantage of XAI is that the methods can be complicated to calculate, provide inconsistent or misleading explanations, or be susceptible to manipulation. To conclude, adding intrinsically interpretable models, such as rule-based models and Explainable Boosting Machines, to the study was suggested for further research.

Similarly, Transfer Learning requires enhanced research on domain adaptation, feature transfer, avoidance of negative transfer, and cross-heterogeneous microfinance environment validation.

Future research is needed to study and modify foundation models, federated learning, privacy-preserving AI, and causal machine learning to enhance scalability, privacy, and interpretability. Furthermore, it is necessary to conduct longitudinal assessments of real-life microfinance data across a range of economic shocks to establish long-term robustness [1, 6, 7].

Strengths and Limitations of the Review

One of the greatest strengths of this review is the structured PRISMA 2020 methodology and the focus on advances in the field during the last five years (2022–2026). This review aims to provide a comprehensive view of AI performance, explainability, transfer learning, alternative data, and fairness aspects of AI applications in microfinance contexts.

The main constraints are potential publication bias, the application of English-language peer-reviewed literature, limitations due to grey literature exclusion, and limited microfinance literature, especially regarding how Transfer Learning applies to fairness. Additionally, newer technologies are still evolving, so emerging approaches may not be accounted for [4].

Conclusions

This research exemplifies the current state of systematic literature review and the evolution of AI methodologies in credit scoring, from traditional statistical models to hybrid and ensemble models that offer better predictive accuracy while satisfying transparency and fairness standards. The results indicate that hybrid approaches perform effectively in capturing complex financial patterns and that producing financial explanations using XAI methods such as SHAP and LIME enhances financial explanation and policy acceptability for automated credit decision-making. Transfer Learning is a potential solution for addressing data scarcity and Thin File Borrower (TFL) issues, while other data sources can be used to improve financial inclusion [3,7].

The major contribution of this review is the development of an integrated perspective that combines Predictive Modelling, Explainable AI, Transfer Learning, alternative data utilisation, and Algorithmic Fairness within the context of MFIs. This research builds upon previous reviews, which have concentrated primarily on model performance, by emphasising the need to balance accuracy, transparency, responsible lending, and borrower trust.

Despite these advancements, the practical application of these approaches is constrained by issues such as the absence of real-world microfinance data, potential unfairness, computational requirements, and limited validation data across various lending environments. Further studies are required to enhance the reliability and responsible implementation of AI-based credit scoring models by testing them in practical settings and applying appropriate governance measures and strategies.

While AI-driven credit scoring holds strong potential to improve credit access and decision-making in microfinance, it must adhere to the principle of balancing prediction performance with explainability, fairness, and regulatory compliance to achieve successful adoption within the sector [6].

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References

1 Alasbahi R, Zheng X. An online transfer learning framework with extreme learning machine for automated credit scoring. IEEE Access [Internet]. 2022;10:46697–716. Available from: https://ieeexplore.ieee.org/abstract/document/9765963

2. Abdussalam Aljadani, Bshair Alharthi, Farsi M, Hossam Magdy Balaha, Badawy M, Elhosseini MA. Mathematical modeling and analysis of credit scoring using the LIME explainer: A comprehensive approach. Mathematics. 2023 Sept 25;11(19):4055–5.

3. Bussmann N, Giudici P, Marinelli D, Papenbrock J. Explainable machine learning in credit risk management. Computational Economics. 2020 Sept 25;57(1).

4. Hlongwane R, Ramaboa KKKM, Mongwe W. Enhancing credit scoring accuracy with a comprehensive evaluation of alternative data. PLOS One [Internet]. 2024 May 21 [cited 2026 July 20];19(5):e0303566. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11108212/

5. Kozodoi N, Jacob J, Lessmann S. Fairness in credit scoring: Assessment, implementation and profit implications. European Journal of Operational Research. 2021 June;297(3).

6. Nallakaruppan MK, Chaturvedi H, Grover V, Balamurugan Balusamy, Praveen Jaraut, Bahadur J, et al. Credit risk assessment and financial decision support using explainable artificial intelligence. Risks. 2024 Oct 15;12(10):164–4.

7. Nwafor CN, Nwafor O, Sanjukta Brahma. Enhancing transparency and fairness in automated credit decisions: An explainable novel hybrid machine learning approach. Scientific Reports. 2024 Oct 24;14(1).

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EdgeTal: On-Device Agentic RAG for Privacy-Preserving Talent Discovery

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Abstract

Introduction: Every time a recruiter uploads a resume to a cloud-based hiring platform, the candidate's personal data leaves their control. AI-powered screening has made hiring faster, but it does so by routing sensitive information through external servers, a trade-off that conflicts with modern privacy law. Most mobile recruitment tools also still rely on exact keyword matching rather than semantic understanding.

Objectives: This study asks whether a smartphone can perform intelligent candidate search and analysis entirely on device, without any cloud connection.

Methods: EdgeTal was developed as a native Android application built around a three-stage on-device Agentic RAG pipeline. Recruiter queries are encoded as semantic embeddings, matched against candidate profiles through vector similarity search, and interpreted by a quantised Gemma-2B (Int4) language model running entirely on the device. The system was evaluated on 1,500 resumes across two devices, a Google Pixel 7 Pro and a Xiaomi Redmi Note 7.

Results: Semantic search responded in under 100 ms on the Pixel 7 Pro and under 300 ms on the Redmi Note 7. For abstract and role-based queries, keyword matching returned no relevant results, whereas semantic retrieval consistently surfaced relevant candidates.

Conclusions: These results show that privacy-preserving, intelligent recruitment can run on existing mobile hardware rather than dedicated cloud infrastructure, given an appropriate on-device architecture.

Keywords: *agentic RAG, edge AI, mobile computing, privacy-preserving AI, talent discovery*

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Introduction

Hiring has always been a volume problem. As organisations process hundreds of resumes for a single role, artificial intelligence is increasingly used to screen candidates, rank profiles, and surface talent at a scale no human team can match [1,2]. As large language models (LLMs) have become more capable and smaller, running that intelligence directly on a mobile device has become feasible [3,6].

The problem is where that intelligence currently lives. Most AI-driven recruitment tools route candidate data through cloud servers, meaning candidate data leaves the organisation's control at every step. Under the General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA), this carries legal consequences [4,5].

Existing AI-driven recruitment systems, including LLM-agent resume screeners and NLP-based candidate ranking tools [1,2], achieve their capability by processing candidate data on cloud infrastructure. Work on mobile edge intelligence has meanwhile established that LLM inference is feasible on-device [3,7,8], but it has evaluated generic inference workloads rather than a domain-specific retrieval and reasoning pipeline. No existing system combines semantic retrieval, Retrieval-Augmented Generation (RAG) [9], and agentic reasoning into a recruitment tool that runs without a cloud connection. This study introduces EdgeTal, an on-device Agentic RAG system that combines dense semantic retrieval [10] and generative candidate analysis [9] through a three-stage Plan-Decide-Act architecture, running entirely offline.

Methods

System Overview

EdgeTal was built as a native Android application in Kotlin, implementing a complete on-device RAG pipeline for privacy-preserving talent discovery. Every component of the system runs locally on the device. Candidate data, vector embeddings, retrieval operations, and generative analysis never leave the hardware, and no external server connection is required at any point.

The system operates through three sequential phases (Figure 1). Query encoding happens first: the recruiter's natural language query is converted into a 512-dimensional semantic vector. In the Decide phase, cosine similarity matching retrieves the most relevant candidate segments from a local vector store, with an optional feedback-driven reformulation loop activating when retrieval confidence falls below threshold. In the Act phase, a quantised on-device language model generates a structured candidate assessment. The full source code is publicly available [13] and a product overview can be accessed online [14].

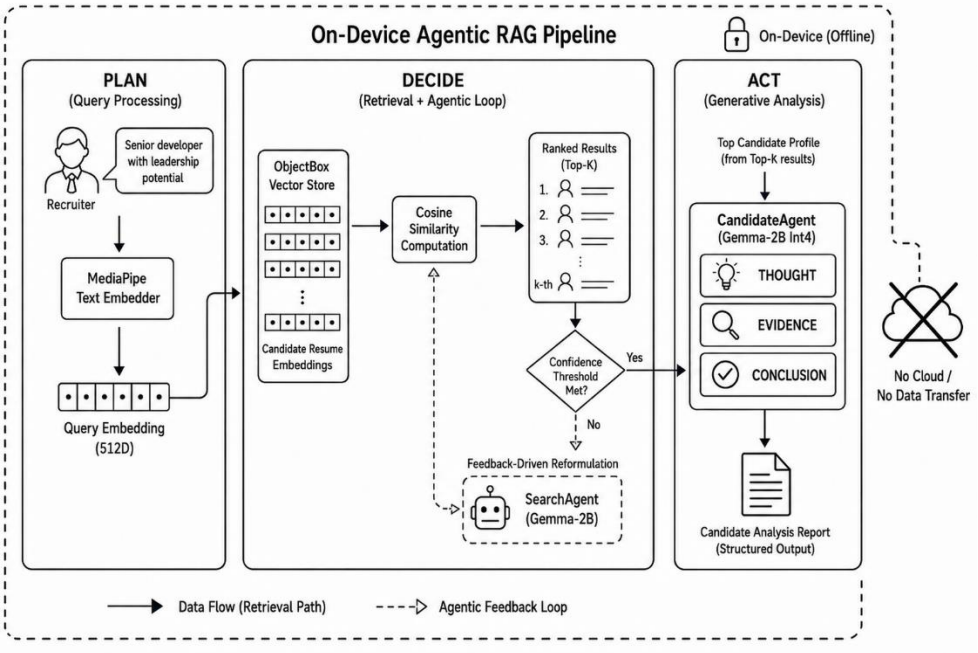

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Figure 1: Architecture of the EdgeTal agentic RAG pipeline, illustrating the Plan, Decide, and Act phases, the confidence-threshold check, and the feedback-driven reformulation loop. All processing occurs on-device with zero cloud dependency.

Query Processing (Plan Phase)

When a recruiter submits a natural language query, the system encodes it into a dense vector representation using the MediaPipe Text Embedder [15], a TFLite-optimised semantic embedding model. The result is a 512-dimensional vector that captures the semantic meaning of the query rather than its literal keywords. All embeddings were L2-normalised before storage and comparison, which ensures consistent cosine similarity computation regardless of vector magnitude [18].

Candidate Data Processing

Resumes were sourced from the Kaggle Resume Dataset [11], comprising 9,544 entries across 24 labelled job categories. A subset of N = 1,500 resumes was used for evaluation. The subset was sampled to remain balanced across the 24 job categories, preserving the category distribution of the full dataset while keeping repeated on-device benchmarking runs tractable. The dataset is publicly available under an open licence and contains no directly identifying personal information.

Each resume was decomposed into five semantic segments: summary, skills, experience, education, and certifications. Each segment was prefixed with its section type (e.g., "experience: [text]") to prevent vocabulary overlap across sections. Segments exceeding 512 characters were chunked at sentence boundaries to preserve embedding quality. The same MediaPipe embedding model [15] applied to queries was used for all segments, placing queries and candidate profiles in a shared 512-dimensional vector space.

Vector Retrieval and Similarity Matching (Decide Phase)

Both query and candidate segment embeddings were stored locally in an ObjectBox NoSQL database [16]. During query execution, the system performed exhaustive cosine similarity computation between the query vector (q) and all candidate segment vectors (c) [18]:

$$\text{Similarity}(q, c) = \frac{q \cdot c}{\|q\| \times \|c\|}$$

A minimum similarity threshold of 0.3 was applied to filter irrelevant results. The value was set empirically during development, chosen as the lowest threshold that excluded semantically unrelated segments without discarding relevant matches. The system retrieved the Top-K (default K = 10) semantically similar segments, ranked by descending similarity score. Each result was mapped back to its parent resume record, enabling identification of the matched candidate and the specific resume section that contributed to the match.

Candidate Analysis (Act Phase)

Following retrieval, the Act phase employed a Candidate Agent implementing chain-of-thought agentic reasoning using a quantised Gemma-2B model (Int4, approximately 1.5 GB) [17], deployed on-device via the MediaPipe LLM Inference API [15]. Inference parameters were set to 256 maximum output tokens, Top-K sampling of 40, temperature of 0.7, and a fixed random seed of 42 for reproducibility. These sampling parameters follow the MediaPipe LLM Inference API defaults for Gemma-2B; no task-specific hyperparameter search was performed.

The Candidate Agent executed a structured three-step reasoning process for each evaluation:

THOUGHT: Identification of core technical requirements from the role description.
EVIDENCE: Extraction of specific evidence from the candidate's resume data that matched or contradicted the identified requirements.
CONCLUSION: A final recommendation (Yes / No / Maybe) with a summary justification.

This structured prompting approach produced explainable candidate assessments, exposing the reasoning chain behind each recommendation.

Performance Instrumentation

All pipeline stages were instrumented using a centralised performance monitor that automatically captured three categories of metrics: ingestion latency (time to segment and embed each resume), retrieval latency (time to execute vector search across the candidate pool), and agentic reasoning latency (time to generate the full THOUGHT/EVIDENCE/CONCLUSION

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analysis). All metrics were persisted locally on the device, ensuring no benchmarking data left the hardware and enabling systematic collection across all experimental conditions without manual measurement.

2.7 Evaluation Protocol

2.7.1 Retrieval Accuracy

Retrieval performance was measured using Precision@K at K = 5 and K = 10, with a result considered relevant when the ground-truth job category of the matched resume corresponded to the query's target category. Five queries were designed across three abstraction tiers: direct semantic, abstract intent, and complex multi-attribute, giving 15 queries in total. A keyword-based baseline using case-insensitive substring matching across resume fields was implemented for comparison.

Precision@K was selected as the primary retrieval metric for its direct interpretability in a top-K candidate shortlisting context; complementary measures such as Recall@K and the rank-sensitive Mean Reciprocal Rank (MRR) and Normalised Discounted Cumulative Gain (NDCG) were not computed in this evaluation.

Latency and Scalability

Retrieval latency was measured at N = 1,500 resume embeddings on both devices. Cold-start queries were excluded from mean calculations. Two independent runs on the Pixel 7 Pro verified measurement consistency.

Generative Analysis Evaluation

Twenty candidate profiles stratified across ten job categories were independently rated by two evaluators on a four-dimension Likert scale (1 to 5): relevance, accuracy, completeness, and actionability. Inter-rater reliability was calculated using Cohen's Kappa [19]. The two evaluators were members of staff acting as expert annotators rating system outputs, not human research participants; the study therefore involved no collection of personal data requiring ethical clearance.

Experimental Setup

Experiments ran on two devices: a Xiaomi Redmi Note 7 (4 GB RAM, Snapdragon 660, Android 10) representing resource-constrained hardware, and a Google Pixel 7 Pro (12 GB RAM, Tensor G2, Android 14) representing mainstream hardware with on-device ML acceleration. Device details were automatically logged with every metric. All experiments ran fully offline with aeroplane mode enabled.

Results

Retrieval Latency

Table 1 presents the mean retrieval latency across five benchmark queries executed on both devices with a dataset of N = 1,500 resume embeddings.

Table 1: Mean Retrieval Latency by Search Method

Search Method	Pixel 7 Pro (ms)	Redmi Note 7 (ms)	Performance Delta
Keyword Baseline	518	1,613	3.1x
Static Semantic Search	90	264	2.9x
Raw Vector Search	18	17	1.1x

Static semantic search was 5.8x faster than keyword matching on the Pixel 7 Pro and 6.1x faster on the Redmi Note 7. Both devices maintained semantic retrieval latency well below the 500 ms interactive response threshold [12]. Raw vector search completed under 20 ms on both devices, indicating that cosine similarity computation at this dataset scale is not hardware dependent.

Table 2: Per-Query Retrieval Latency (N = 1,500)

Query	Pixel Keyword (ms)	Pixel Semantic (ms)	Redmi Keyword (ms)	Redmi Semantic (ms)

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Q1: Android Developer	512	183	1,491	504
Q2: Building scalable mobile architectures	485	43	1,008	135
Q3: Senior Kotlin developer with Clean Architecture	523	59	1,322	139
Q4: Data Scientist with Python and ML	527	72	2,100	353
Q5: High-volume data processing and cloud	544	91	2,145	189

The first query of each run (Q1) showed consistently higher latency due to cold-start model initialisation. Excluding cold start, all semantic search operations completed under 200 ms on both devices. Keyword baseline latency showed greater variance on the Redmi Note 7 (1,008 to 2,145 ms) compared to the Pixel 7 Pro (478 to 548 ms), reflecting the memory pressure on the 4 GB device.

3.2 Agentic Reformulation Performance

Reformulation latency diverged sharply between devices, as shown in Table 3.

Table 3: Agentic Reformulation Latency

Metric	**Pixel 7 Pro**	**Redmi Note 7**
Trigger rate	0-40% across runs	40%
Mean reformulation latency (when triggered)	5.5 s	39.6 s
Performance delta	n/a	7.2x slower
Successful query improvement	1/2 triggered	1/2 triggered

The Pixel 7 Pro completed LLM inference in approximately 5.5 seconds, while the Redmi Note 7 required 39.6 seconds, a 7.2x difference that confirms generative inference as the primary computational bottleneck. The reformulation trigger rate varied between 0% and 40% across runs, with the agent producing more specific queries in 50% of triggered cases. Sixty percent of queries did not trigger reformulation on either device.

Cross-Device Comparison

Figure 2 shows full-pipeline latency across both devices, from raw vector search to agentic inference.

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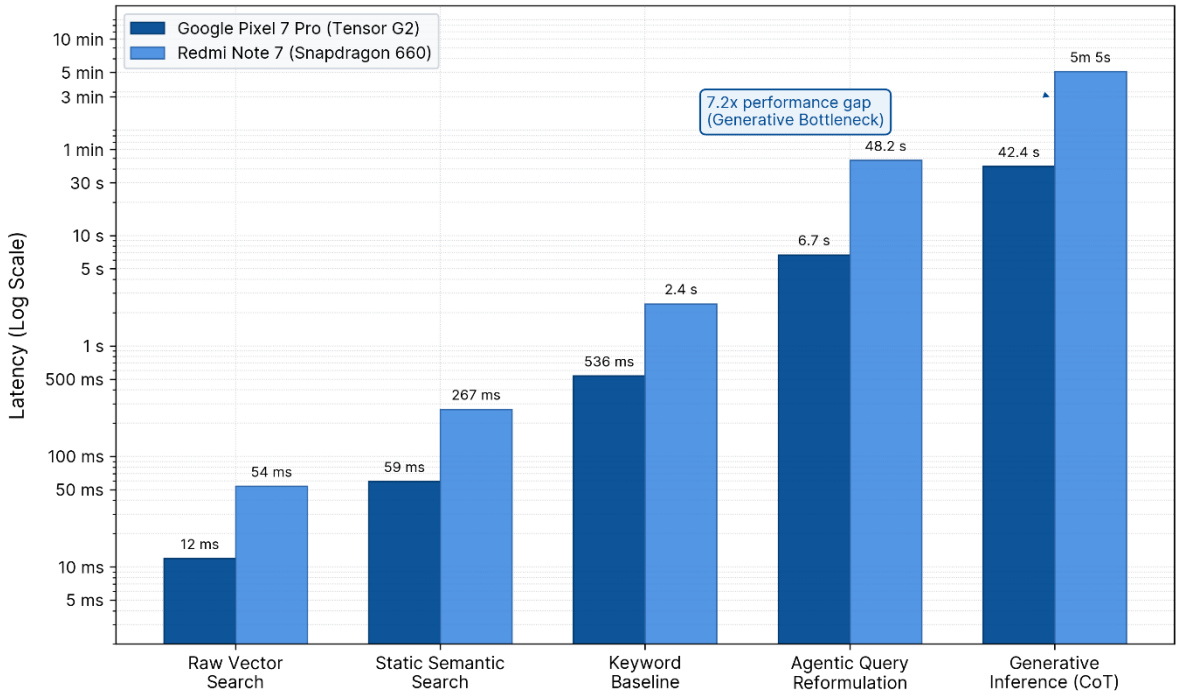

Figure 2: Full pipeline latency comparison across both devices at N = 1,500 embeddings. Keyword baseline, static semantic search, and raw vector search latencies are shown alongside agentic reformulation latency. The 7.2x performance gap for generative inference between the Pixel 7 Pro (Tensor G2) and Redmi Note 7 (Snapdragon 660) confirms that LLM-based reasoning is the primary computational bottleneck in the agentic pipeline.

Semantic retrieval outperformed keyword matching across both hardware tiers. The Redmi Note 7, a budget device from 2019, maintained static semantic search latency under 500 ms for all queries, confirming the core retrieval pipeline is viable on resource-constrained hardware.

Retrieval Accuracy

Table 4 presents the Precision@10 results across 15 benchmark queries, grouped by abstraction tier.

Table 4: Precision@10 by Query Tier and Search Method

Tier	Keyword P@10	Semantic P@10	Agentic P@10
Tier 1: Direct semantic (5 queries)	0.64	0.32	0.44
Tier 2: Abstract intent (5 queries)	0.00	0.48	0.48
Tier 3: Complex multi-attribute (5 queries)	0.00	0.48	0.48
Overall (15 queries)	0.21	0.43	0.47

Keyword search returned zero precision across all Tier 2 and Tier 3 queries. Semantic search retrieved relevant candidates for 8 of these 10 queries, achieving a mean Precision@10 of 0.48. For Tier 1 queries, keyword search outperformed semantic retrieval (0.64 vs 0.32) as exact labels favoured substring matching. Agentic reformulation improved overall precision from 0.43 to 0.47, with the most notable gain on "Android Developer" (0.40 to 1.00). Three queries returned zero precision across all methods (Database Administrator, HR Officer, securing cloud infrastructure) due to embedding space label mismatches.

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Resource Utilisation Under Sustained Operation

To assess feasibility beyond per-query latency, resource utilisation of the retrieval pipeline was profiled under sustained operation. Sixty consecutive retrieval queries were executed on each device, covering query embedding, vector search, and result ranking; generative inference was excluded so that the measurement isolates the retrieval path that dominates interactive use. Peak and average RAM, CPU utilisation, battery drain, thermal state, and latency drift between the first and last queries were recorded by the on-device performance monitor described above.

Table 5: Retrieval Pipeline Resource Utilisation (N = 60 queries per device)

Metric	Pixel 7 Pro	Redmi Note 7
Queries completed	60/60 (no failures)	60/60 (no failures)
Total runtime	0m 44s	0m 46s
RAM (peak / avg)	432 MB / 426 MB	365 MB / 352 MB
Battery drained	10 mAh (~0%)	12 mAh (~0%)
CPU utilisation (avg / peak)	4% / 13%	5% / 10%
Thermal throttling	None observed	None observed
Latency drift (first vs. last query)	+0.5%	+0.5%

Both devices completed all 60 retrieval queries without failure. Peak RAM usage remained under 450 MB, roughly 11% of the Redmi Note 7's 4 GB of system memory. Battery drain and CPU utilisation were negligible over the test duration, no thermal throttling was observed, and latency drift between the first and last queries was +0.5% on both devices, indicating stable retrieval performance under sustained operation.

Human Evaluation of Generative Analysis

Twenty candidate analysis reports were independently rated by two evaluators, one from engineering and one from HR at Knivok Private Limited, on a 5-point Likert scale across four dimensions [19].

Table 6: Human Evaluation Results (N = 20 reports, 2 evaluators)

Dimension	Mean Score	Std Dev	Cohen's Kappa	Interpretation
Relevance	3.95/5	0.71	0.840	Almost perfect
Accuracy	4.00/5	0.68	0.833	Almost perfect
Completeness	3.38/5	0.63	0.737	Substantial
Actionability	3.77/5	0.62	0.735	Substantial

Accuracy achieved the highest mean score (4.00/5) and relevance scored comparably (3.95/5), indicating reports were grounded in actual candidate content. Actionability scored 3.77/5, though gap analysis and shortlist guidance were occasionally insufficient for confident hiring decisions. Completeness received the lowest score (3.38/5); sections were present, but depth varied across profiles, reflecting available resume content.

Inter-rater reliability was near-perfect for relevance (kappa = 0.840) and accuracy (kappa = 0.833), and substantial for completeness (kappa = 0.737) and actionability (kappa = 0.735).

Discussion

These results reframe the privacy-latency trade-off: semantic retrieval is fast enough for interactive use without cloud infrastructure, and compliance shifts from policy to architecture.

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Retrieval Performance and the Hardware Gap

Static semantic search outperformed keyword matching by a factor of 5.8x on the Pixel 7 Pro and 6.1x on the Redmi Note 7 at N = 1,500 embeddings. All semantic queries, excluding cold-start initialisations, completed under 200 ms on both devices, well within the 500 ms interactive response threshold for mobile applications [12], with no cloud dependency.

Agentic Reformulation: Capability versus Cost

The Redmi Note 7 required 7.2x longer than the Pixel 7 Pro for LLM-based reformulation (39.6 s vs 5.5 s), confirming that generative inference is the primary computational constraint, not vector retrieval.

The trigger rate of 0 to 40% across runs and the 50% improvement rate suggest the agentic loop functions as designed, though the small sample limits confidence. However, the quantised 2B-parameter model tended to reorder the original query rather than reformulate it, with output differing only in word order.

Privacy by Architecture

EdgeTal achieves regulatory compliance through architectural design rather than organisational policy. All pipeline stages execute locally, with no candidate data, query content, or analysis output transmitted to external servers at any point. This removes the data-transfer exposure that cloud-based recruitment platforms carry under GDPR, CCPA [4,5], and the EU AI Act [6], which classifies hiring AI as high-risk.

Unlike cloud-based recruitment tools [1,2], which achieve semantic screening capability only by transmitting candidate data off-device, EdgeTal demonstrates that the same capability class is achievable with zero data transmission. This distinguishes EdgeTal from prior edge-AI literature [3,7,8], which has validated on-device LLM inference in general terms but not within a domain-specific retrieval-plus-reasoning pipeline.

In practice, EdgeTal's architecture favours a standalone deployment on the recruiter's own device rather than integration with centralised HR infrastructure. This suits small and medium-sized organisations lacking resources for compliant cloud-based screening, and contexts such as executive search or sensitive candidate categories, where data residency on a single controlled device is a requirement rather than a preference.

Limitations

The 1,500-resume subset, drawn from a 9,544-entry dataset across 24 job categories, may not capture the format and terminology variability of real-world recruitment pipelines. The latency benchmark used only five queries, limiting statistical power, and reformulation triggered on just two of these, too few for reliable conclusions. System behaviour beyond N = 1,500 embeddings remains untested. The resource profile reported here covers the retrieval pipeline only; sustained-load profiling of on-device generative inference, whose per-query latency makes prolonged testing substantially longer, remains to be carried out. The human evaluation relied on two evaluators assessing 20 candidate reports; while inter-rater agreement was high, this panel size limits the generalisability of the relevance, accuracy, completeness, and actionability findings.

Future evaluations will incorporate Recall@K, MRR, and NDCG for a more comprehensive assessment of retrieval quality, together with fairness metrics and bias assessment across demographic and occupational groups. Future work will also address multilingual resume processing, domain adaptation across specialised industries, robustness to incomplete or malformed resumes, scalability testing beyond the 1,500-candidate pool evaluated here, and performance validation on hardware below the Redmi Note 7 tier. Further avenues include federated learning across devices, larger quantised models for stronger reasoning, continual learning from recruiter feedback, an iOS implementation, and integration pathways with existing HR management systems. Direct comparative benchmarking against existing cloud-based and state-of-the-art recruitment systems is planned as a future validation step.

Conclusions

EdgeTal set out to answer one question: can a standard mobile device handle intelligent, privacy-preserving recruitment without touching the cloud? The answer, based on empirical evaluation across two hardware tiers, is yes.

Semantic retrieval was 5.8x to 6.1x faster than keyword matching, with all queries completing under 200 ms after cold-start. Keyword search failed entirely on abstract and complex queries, returning zero precision across Tiers 2 and 3; semantic

retrieval achieved a mean Precision@10 of 0.48 on those same 15 queries, surfacing candidates keyword matching missed completely. The 7.2x inference gap between the Pixel 7 Pro and Redmi Note 7 identifies on-device LLM inference, not vector retrieval, as the primary performance constraint for agentic edge AI. Because every pipeline stage runs locally, the data-transfer obligations of GDPR and CCPA are addressed by the architecture itself rather than by policy.

These results suggest that privacy-first recruitment is an architecture decision, not an infrastructure one. Larger quantised models may improve reformulation reliability; a field study with practising recruiters would test real-world transfer.

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References

[1] Gan C, Zhang Q, Mori T. Application of LLM agents in recruitment: a novel framework for resume screening. *arXiv preprint arXiv:2401.08315*. 2024.

[2] Sarveshwaran R, Karthikeyan S, Cruz MV, Shreyanth S, Niveditha S, Rajesh PK. NLP-based AI-driven resume screening solution for efficient candidate selection. In: *Proceedings of ICICT 2024*. Lecture Notes in Networks and Systems, vol. 1012. Springer; 2024. p. 359.

[3] Qu G, Chen Q, Wei W, Lin Z, Chen X, Huang K. Mobile edge intelligence for large language models: a contemporary survey. *arXiv preprint arXiv:2407.18921*. 2025.

[4] European Parliament; Council of the European Union. Regulation (EU) 2016/679 (General Data Protection Regulation). *Off J Eur Union*. 2016;L119:1-88.

[5] California Consumer Privacy Act of 2018, Cal. Civ. Code §§ 1798.100-1798.199 (2018).

[6] European Parliament; Council of the European Union. Regulation (EU) 2024/1689 laying down harmonised rules on artificial intelligence (EU AI Act). *Off J Eur Union*. 2024.

[7] Tummalapalli P, Arayakandy S, Pal R, Kundan K. LLM inference at the edge: mobile, NPU, and GPU performance efficiency trade-offs under sustained load. *arXiv preprint arXiv:2603.23640*. 2026.

[8] Semerikov SO, Vakaliuk TA, Kanevska OB, Moiseienko MV, Donchev II, Kolhatin AO. LLM on the edge: the new frontier. In: *Proceedings of the 5th Edge Computing Workshop (doors 2025)*. CEUR Workshop Proceedings, vol. 3943; 2025. p. 137-61.

[9] Lewis P, Perez E, Piktus A, Petroni F, Karpukhin V, Goyal N, et al. Retrieval-augmented generation for knowledge-intensive NLP tasks. *Adv Neural Inf Process Syst*. 2020;33:9459-74.

[10] Karpukhin V, Oguz B, Min S, Wu L, Feichtenhofer C, et al. Dense passage retrieval for open-domain question answering. In: *Proceedings of EMNLP 2020*. Association for Computational Linguistics; 2020. p. 6769-81.

[11] Saugata A. Resume dataset [dataset on the Internet]. Kaggle; 2022 [cited 2026 May 13]. Available from: https://www.kaggle.com/datasets/saugataroyarghya/resume-dataset

[12] Nielsen J. *Usability engineering*. San Francisco: Morgan Kaufmann; 1993.

[13] Rathnayake Mudiyanselage MP, Thellapura Arachchilage HL, Kandamulla Arachchilage DU, Herath D. EdgeTal: on-device agentic RAG for privacy-preserving talent discovery [source code on the Internet]. GitHub; 2026 [cited 2026 May 31]. Available from: https://github.com/madusankapremaratne/edgetal-kotlin

[14] EdgeTal: privacy-first AI recruitment [Internet]. Knivok Private Limited; 2026 [cited 2026 May 29]. Available from: https://edgetal.app

[15] Lugaresi C, Tang J, Nash H, et al. MediaPipe: a framework for building perception pipelines. *arXiv preprint arXiv:1906.08172*. 2019.

[16] ObjectBox. ObjectBox: high-performance NoSQL database for edge devices [Internet]. 2024 [cited 2026 May 29]. Available from: https://objectbox.io

[17] Gemma Team, Mesnard T, Hardin C, et al. Gemma: open models based on Gemini research and technology. *arXiv preprint arXiv:2403.08295*. 2024.

[18] Manning CD, Raghavan P, Schutze H. *Introduction to information retrieval*. Cambridge: Cambridge University Press; 2008.

[19] Cohen J. A coefficient of agreement for nominal scales. *Educ Psychol Meas*. 1960;20(1):37-46.

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EP 16

Pet Health Passport: Digital Transformation of Companion Animal Health Records in Developing Nations

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Abstract

Background: Companion animal health management in developing nations remains predominantly paper-based, relying on manual vaccination booklets. Despite a global pet population exceeding one billion and a veterinary services market valued at USD 145.65 billion in 2024, no comprehensive offline-first digital alternative addresses the connectivity and privacy constraints of lower-income markets.

Objective/s: This literature review examines published evidence on the prevalence and limitations of manual pet health record management, the global transition from paper to digital, and the critical gaps preventing effective, accessible, and privacy-preserving digital solutions in lower-connectivity contexts.

Methods: A structured narrative review of peer-reviewed publications from PubMed, Frontiers in Veterinary Science, JAVMA, IEEE Explore, and JMIR (2019–2025) was conducted, supplemented by WHO, BVA, APPA, and market intelligence grey literature. A total of 67 sources were screened; 37 were excluded for irrelevance or insufficient detail, yielding 30 sources for final synthesis.

Results: Evidence across ten countries confirms that 79–96% of pet owners in developing nations rely on manual booklets. Seven major challenges were identified and summarised. Comparative evaluation of four existing digital applications reveals no solution addressing all identified gaps, particularly offline access and wellness trend tracking.

Conclusion/s: A comprehensive, offline-first, privacy-preserving Pet Health Passport platform represents the most significant unaddressed gap in companion animal digital health, with particular urgency for lower-connectivity markets where paper-based record-keeping results in preventable harm.

Keywords: *companion animal health, digital vaccination records, developing nations, pet health passport, veterinary informatics*

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Introduction

In veterinary clinics across Sri Lanka, India, Bangladesh, and much of Southeast Asia and sub-Saharan Africa, a familiar object sits in the hands of every pet owner: a small, paper vaccination booklet. Handwritten by a veterinarian, stamped with clinic seals, and carried in a bag or drawer, this physical record serves as the sole repository of a companion animal's entire medical history. It can be lost in a flood, destroyed in a fire, left at home during an emergency, or simply become illegible over years of handling.

Despite the global pet care market exceeding USD 304 billion in 2023 and growing at a compound annual growth rate (CAGR) of 6.8–8.4% [1], the infrastructure for managing the health information of the more than one billion companion animals worldwide [2] has not kept pace. The veterinary services market reached USD 145.65 billion in 2024 [3], yet the tools available to pet owners for managing health information remain indistinguishable from those used fifty years ago.

This review examines the dominance of manual, paper-based pet health record management in developing nations, and the failure of existing digital solutions to address intermittent connectivity, privacy concerns, and fragmented functionality. The research question is: What does published evidence reveal about the limitations of manual pet health record-keeping, the global transition to digital solutions, and the gaps in existing applications that a comprehensive Pet Health Passport must address?

The scale of companion animal ownership has reached historic proportions. The 2024 Global Pet Parent Study estimated the global pet population at approximately one billion, comprising 470 million pet dogs and 370 million pet cats [2]. In the United States, the American Pet Products Association (APPA) National Pet Owners Survey 2023–2024 documented 86.9 million pet-owning households [4]. The global veterinary services market is projected to reach USD 281.93 billion by 2033 [3]. In emerging markets, pet ownership in China increased 113% between 2014 and 2019 [5].

Methods

A structured narrative literature review [6] was conducted between January and April 2025. The search encompassed PubMed/MEDLINE, Frontiers in Veterinary Science, the Journal of the American Veterinary Medical Association (JAVMA), IEEE Explore, ResearchGate, and JMIR Publications. Search terms included: 'companion animal health records', 'veterinary paper records', 'pet vaccination booklet', 'digital veterinary health', 'mobile application companion animal', and 'offline health record'. Boolean operators (AND, OR, NOT) were applied. Date filters were set for 2019–2025, with foundational pre-2019 studies included where they established methodologically significant baselines.

Grey literature was systematically reviewed, including World Health Organization (WHO) Digital Health reports, British Veterinary Association (BVA) surveys, APPA National Pet Owners Surveys, Grand View Research market analyses, and Aristek Systems veterinary Electronic Health Record (EHR) market analyses [4,7,8]. Inclusion criteria: (i) addressed companion animal health record management, veterinary informatics, or digital health for animal care; (ii) peer-reviewed articles, conference proceedings, or authoritative grey literature; (iii) available in English; (iv) published 2019–2025 or foundational prior works. Exclusion criteria: exclusively livestock or wild animal species; only practice management systems without owner-facing components; not accessible in full text.

Following a PRISMA-informed approach adapted for narrative reviews [9], 67 candidate sources were identified through database and grey literature searching. After title and abstract screening, 18 were excluded for irrelevance to companion animal health records. A further 19 were excluded at full-text review: 11 addressed livestock only, 5 lacked owner-facing components, and 3 were inaccessible in full text. This yielded 30 sources for the final narrative synthesis. Quality appraisal was conducted descriptively rather than through formal scoring, consistent with narrative synthesis methodology [6].

Quantitative market and prevalence data were extracted and presented descriptively with clear source attribution. Country-level data on paper versus digital record adoption were synthesised from WHO, PubMed Central (PMC), and regional health informatics publications. Application functionality was assessed through a structured seven-criterion comparative framework. Research gaps were identified through thematic convergence across multiple independent sources.

Results

Prevalence of Manual Records Across Countries. Evidence across ten developing and emerging market nations confirms the overwhelming dominance of paper-based pet health record management: Sri Lanka (91%), India (87%), Bangladesh (93%), Pakistan (90%), Nigeria (96%), Kenya (94%), Indonesia (89%), Brazil (61%), South Africa (68%), and the

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Philippines (85%) [7,10]. It is important to note that these prevalence estimates are derived from WHO digital health adoption surveys and regional health informatics studies addressing human vaccination records and general digital health readiness. No direct published study of companion animal-specific record management prevalence by country was identified. The figures presented represent the proportion of health record management conducted through paper-based systems in each country's healthcare context, applied as a proxy indicator for veterinary practice on the basis that veterinary informatics infrastructure in developing nations consistently lags behind human health informatics infrastructure [8].

Sri Lanka: Country-Specific Context. The WHO has recognised Sri Lanka for developing innovative digital health tools — including the COVID-19 Immunization Tracker and Smart Vaccination Certificate [11]. However, these innovations address human health records within government-managed programmes, not companion animal records. Outside Colombo, rural internet connectivity constraints confirm that digital health solutions requiring continuous connectivity are systematically inaccessible to a significant proportion of pet owners [12,13]. In Jaffna — the Northern Province context of this research — veterinary services are concentrated in a small number of urban facilities, with pet owners maintaining paper booklets as their only longitudinal health record.

Seven Challenges of Manual Record Management. The seven identified challenges are summarised in Table 1. Physical vulnerability and loss represent the primary limitation, with the WHO explicitly identifying susceptibility to damage or loss as the chief weakness of paper vaccination records [7]. Emergency inaccessibility constitutes a critical patient safety concern: the BVA's 2023 survey found that 82% of pet owners reported difficulty accessing records during unexpected consultations [14]. Vaccination schedule non-compliance is documented by the World Small Animal Veterinary Association (WSAVA) [15]. Medication management errors [16,17], record fragmentation across multiple providers [18], absence of wellness trend tracking [19,20], and privacy limitations [21] constitute the remaining challenges.

Table 1: Summary of Seven Challenges of Manual Pet Health Record Management

#	Challenge	Impact	Key Source
1	Physical vulnerability	Destroyed by flood/fire/humidity	WHO [7]
2	Emergency inaccessibility	82% difficulty in emergencies	BVA [14]
3	Vaccination non-compliance	No reminders cause missed schedules	WSAVA [15]
4	Medication errors	Unknown drug interactions	Redding et al. [17]
5	Record fragmentation	Multiple vets, no unified record	Pasteur et al. [18]
6	No wellness tracking	Weight/chronic disease invisible	Banfield [19]
7	Privacy limitations	Paper accessible, no encryption	Schrader et al. [21]

Analysis of Existing Digital Applications. Comparative evaluation of four representative applications against seven functional criteria is presented in Table 1. PetDesk requires practice-side registration and cloud connectivity [22]. Pawprint's document storage strength is offset by absence of weight tracking. VetScene lacks multi-pet management and offline functionality entirely. PetNote comes closest to the ideal profile but lacks comprehensive vaccination scheduling alerts. The

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Towards mHealth Applications for Pet Animal Owners review confirmed that existing applications prioritise practice communication over owner-centric health record management [23].

Research Gap Synthesis. Three fundamental gaps emerge from the evidence. First, no current solution provides comprehensive offline functionality appropriate for lower-connectivity contexts. Second, existing applications address single features in isolation rather than providing comprehensive multi-module integration. Third, server-dependent data models introduce privacy risks identified as a primary adoption barrier [21].

Table 2: Comparative Evaluation of Existing Digital Pet Health Applications

Feature	PetDesk	Pawprint	VetScene	PetNote	Proposed PHP
Vaccination tracking	Yes	Yes	Yes	Yes	Yes
Medication mgmt	Partial	No	No	Partial	Yes
Document storage	No	Yes	No	Yes	Yes
Weight monitoring	No	No	No	Partial	Yes
Offline functionality	No	Limited	No	Partial	Yes (full)
Multi-pet support	Yes	Yes	No	Yes	Yes
Smart reminders	Yes	Partial	No	No	Yes
Privacy model	Cloud	Cloud	Cloud	Cloud/Local	On-device

Discussion

The evidence reviewed establishes a clear case for the transformation of the physical vaccination booklet into a comprehensive digital Pet Health Passport. The following discussion distinguishes between evidence-based findings drawn from the reviewed literature and the authors' conceptual design recommendations for a proposed solution.

Evidence-based finding: Three design imperatives emerge from the synthesised literature. First, offline-first architecture is essential: given that 79–96% of pet owners in target markets rely on paper precisely because digital alternatives require connectivity they lack, the WHO's framework for digital vaccination certificates articulates that a digital health record should never require continuous internet access [7]. Second, comprehensive scope is required: digital solutions addressing only vaccinations, or only document storage, fail to replace the booklet. Third, on-device data sovereignty addresses the privacy barrier identified in the mHealth barriers literature [21].

Conceptual proposal: Based on the above evidence, a Pet Health Passport platform should integrate all seven functional domains identified in this review: vaccination tracking, medication management, document storage, weight monitoring, veterinarian contacts, smart reminders, and multi-pet management (see Table 1 for how existing applications fail to achieve this integration). On-device storage — where no health data leaves the device without explicit owner action — would provide the data sovereignty that removes the privacy barrier to adoption.

The mHealth effectiveness literature provides a translational foundation. Mosa, Yoo, and Sheets (2012) demonstrated improvements in medication adherence attributable to mobile application interventions [24]. Llaneta et al. (2022) demonstrated with TerraVet that integrated digital platforms reduce barriers to veterinary care utilisation [25]. Jokar et al. (2024) confirmed that the primary barrier to digital tool adoption is not owner willingness but the quality of available tools [26].

Limitations

This review acknowledges several limitations. First, country-level prevalence estimates for paper versus digital pet health record use are synthesised from human health informatics literature and general digital health adoption data, as no direct companion animal-specific record management study was identified — itself a significant gap. Second, application evaluations are based on published documentation rather than primary user studies. Third, non-English literature from China, Japan, and South Korea may have been excluded, potentially omitting relevant regional data. Fourth, reliance on grey literature for quantitative prevalence data introduces potential reporting and publication bias, as market reports may overstate trends favourable to their commissioning organisations. Fifth, the absence of companion animal-specific epidemiological data in developing nations limits the precision of the reported prevalence estimates. Sixth, the literature search was limited to six databases; additional veterinary-specific databases may contain relevant studies not captured in this review.

Conclusions

This literature review has established that manual, paper-based pet health record management remains the dominant practice in developing nations. Seven major challenges (Table 2) are consistently documented. Analysis of four existing digital applications (Table 1) reveals that no current solution addresses all seven challenges within an offline-first, privacy-preserving architecture.

The research gap is clear: a comprehensive, offline-first Pet Health Passport platform integrating vaccination tracking, medication management, document storage, weight monitoring, veterinarian contacts, and automated reminders within a privacy-preserving on-device architecture represents the single most significant unaddressed gap in the companion animal digital health landscape. Future research should address the design, development, and empirical evaluation of such a platform.

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References

1. GM Insights. Pet Care Market Share Report 2024–2033 [Internet]. 2024. Available from: https://www.gminsights.com/industry-analysis/pet-care-market
2. Grand View Research. Global Animal Population Databook [Internet]. 2024. Available from: https://www.grandviewresearch.com/market-trends/animal-population-databook
3. Grand View Research. Veterinary Services Market Report [Internet]. 2024. Available from: https://www.grandviewresearch.com/industry-analysis/veterinary-services-market
4. APPA. National Pet Owners Survey 2023–2024 [Internet]. Greenwich CT: APPA; 2024. Available from: https://www.americanpetproducts.org/research-insights
5. Health for Animals. Global Trends in the Pet Population [Internet]. 2022. Available from: https://healthforanimals.org/reports/pet-carereport/global-trends-in-the-pet-population/
6. Grant MJ, Booth A. A typology of reviews. Health Info Libr J. 2009;26(2):91–108. Available from: https://doi.org/10.1111/j.1471-1842.2009.00848.x
7. WHO. Digital Documentation of COVID-19 Certificates [Internet]. 2021. Available from: https://www.who.int/publications/i/item/WHO-2019-nCoV-Digital-certificates-2021.1
8. Aristek Systems. Veterinary EHR Systems Guide [Internet]. 2024. Available from: https://aristeksystems.com/blog/how-veterinary-ehr-software-streamlines-workflow-management-and-improves-care-quality/
9. Page MJ, et al. The PRISMA 2020 statement. BMJ. 2021;372:n71. Available from: https://doi.org/10.1136/bmj.n71
10. PMC. Rapid Assessment of COVID-19 Vaccination Data Systems in WHO African Region [Internet]. 2022. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11022257/

11. WHO South-East Asia. Sri Lanka digital health innovations [Internet]. 2021. Available from: https://www.who.int/southeastasia/news
12. Passport Health. Travel Vaccines: Sri Lanka [Internet]. 2024. Available from: https://www.passporthealth.com/destinations/sri-lanka
13. Exemplars in Global Health. DHIS2 in Sri Lanka [Internet]. 2021. Available from: https://www.exemplars.health/emerging-topics/epidemic-preparedness-and-response/digital-health-systems/sri-lanka
14. BVA. Annual Pet Owner Survey [Internet]. 2023. Available from: https://www.bva.co.uk/resources-support/bva-surveys/
15. WSAVA. Vaccination Guidelines [Internet]. 2022. Available from: https://wsava.org/guidelines/vaccination-guidelines/
16. Tizard IR. Early Life Vaccination of Companion Animals. Vaccines. 2021;9(2):92. Available from: https://doi.org/10.3390/vaccines9020092
17. Redding LE, Cole SD. Pet owners' knowledge of antimicrobials. JAVMA. 2019;254(5):626–635. Available from: https://doi.org/10.2460/javma.254.5.626
18. Pasteur K, et al. Access to veterinary care: barriers. Front Vet Sci. 2024;11. Available from: https://doi.org/10.3389/fvets.2024.1335410
19. Banfield Pet Hospital. State of Pet Health 2023 Report [Internet]. 2023. Available from: https://www.banfield.com/state-of-pet-health
20. Brown KL, Patel S. Medication adherence in companion animal practice. Vet Med Int. 2022. Available from: https://doi.org/10.1155/2022/8823401
21. Schrader A, Kronsteiner B. Barriers to Digital Health Applications. J Med Internet Res. 2022. Available from: https://doi.org/10.2196/32702
22. DVM360. Veterinary Telemedicine and Smartphone Apps [Internet]. 2024. Available from: https://www.dvm360.com/view/telehealth-apps-comparison
23. Wohllebe A, et al. mHealth Applications for Pet Owners. PMC. 2025. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11927274/
24. Mosa ASM, Yoo I, Sheets L. Healthcare Applications for Smartphones. BMC Med Inform Decis Mak. 2012;12(1). Available from: https://doi.org/10.1186/1472-6947-12-67
25. Llaneta JCE, et al. TerraVet: Mobile and Web Framework. In: ICIST 2022; 2022. p. 19–24.
26. Jokar M, et al. AI Chatbots in Pet Health Care. Vet Med Sci. 2024. Available from: https://doi.org/10.1002/vms3.1464
27. Rowe F, et al. COVID-19 vaccination certificates comparison. Health Policy. 2022. Available from: https://doi.org/10.1016/j.healthpol.2022.06.006
28. JMIR. Vaccine Certificates Must Go Digital. 2024. Available from: https://doi.org/10.2196/65740
29. DiGangi BA, et al. Telemedicine and Veterinary Healthcare. J Shelter Med. 2023;2(1).
30. Enterprise Apps Today. Pet Ownership Statistics 2024 [Internet]. Available from: https://www.enterpriseappstoday.com/stats/pet-ownership-statistics.html

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EP 17

Latent Space Communication Protocols for Autonomous Self-Healing Architectures and Zero-Downtime Patching

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Abstract

Introduction: Enterprise web architectures suffer inevitable downtime from unhandled logic exceptions. Traditional remediation relies on manual debugging or container restarts, introducing high latency and failing to address localised logic corruptions.

Objectives: To engineer an autonomous self-healing middleware utilizing deterministic latent space topological alignment and asynchronous generative logic synthesis for zero-downtime crash recovery.

Methods: A Python Tensor Core maps healthy Node.js backend functions into a persistent 384-dimensional latent manifold using the all-MiniLM-L6-v2 model. Upon intercepting a runtime exception, an Express.js filter extracts the corrupted Abstract Syntax Tree (AST) and vectorises it. The engine calculates Cosine Similarity against the baseline. Matches exceeding a 0.90 threshold trigger an immediate "Reflex" response, using require cache invalidation to hot-patch the stable module directly into live RAM. Anomalies falling below 0.90 route to a cloud Language Processing Unit (Groq LPU) "Cortex" tier for sandboxed generative logic synthesis.

Results: Benchmarked against a simulated inventory system, the deterministic Reflex layer successfully isolated and hot-patched structural JavaScript faults in active memory within 200 milliseconds. Novel anomalies escalated to the Cortex layer achieved validated generative repairs in 800 milliseconds, eliminating manual debugging and container restart overhead.

Conclusions: This tiered topological framework demonstrates that vector-space proximity can reliably execute zero-hallucination structural repairs at runtime, drastically reducing recovery latency from minutes to milliseconds while preserving continuous system availability.

Keywords: *Abstract syntax tree, autonomous recovery, latent space manifold, semantic vector search, topological hot-patching*

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Introduction

Continuous availability is a fundamental prerequisite for modern enterprise web architectures. However, JavaScript-based backend environments, especially Node.js [5] and Express.js, remain highly susceptible to runtime execution failures. These failures typically manifest as stateless logic exceptions, such as null pointer dereference or stateful database query anomalies caused by unannounced schema drift. In high-traffic environments, such as manufacturing Enterprise Resource Planning (ERP) systems, a single unhandled exception can cascade into a 500 Internal Server Error, resulting in halted transactions, degraded user trust, and measurable financial loss.

Current industry standards for automated incident responses heavily rely on container orchestration systems [1] or automated GitOps deployment pipelines. While these mechanisms excel at infrastructure self-healing, such as restarting crashed instances or routing traffic away from failing nodes, they operate entirely at service level rather than the semantic code level. Furthermore, initiating a repository rollback to a previous stable commit introduces significant latency (often measured in minutes) and presents severe risks of stateful data corruption, as code rollbacks do not dynamically synchronise with mutated database structures. Consequently, true autonomous logic repair remains an unsolved challenge in production web architectures.

To address this critical gap, this study proposes a novel Deterministic Semantic Incident Recovery System: a multi-tiered, autonomous self-healing middleware designed to intercept and resolve runtime anomalies in milliseconds. Unlike traditional generative Artificial Intelligence (AI) solutions, which are prone to hallucination and cannot be safely trusted to autonomously rewrite business logic in live environments, this architecture introduces a “Reflex-Cortex” paradigm.

The primary tier (the Reflex) operates as a vector-space-based runtime function substitution system. Utilising a localised transformer model, the system maps the entire healthy codebase into a 384-dimensional continuous latent manifold. Upon detecting a server crash, the middleware vectorises the corrupted Abstract Syntax Tree (AST) block and calculates geometric distance against the manifold to retrieve and hot-patch the structurally identical healthy code. For novel anomalies that fall below a predefined mathematical similarity threshold, the context is asynchronously escalated to a secondary generative tier (the Cortex), powered by a cloud-based Language Processing Unit (LPU) [6] for sandboxed logic synthesis.

Existing Automated Program Repair (APR) frameworks [3] and semantic code retrieval techniques typically operate during the static analysis or pre-deployment Continuous Integration (CI) pipeline (e.g., SonarQube, Defects4J evaluations). Recent advancements in AI-assisted debugging (e.g., Devin, GitHub Copilot) exhibit high generative capability but inherently function as human-in-the-loop developer tools. They require code repository commits, pipeline rebuilds, and server restarts to deploy fixes. The proposed Reflex-Cortex architecture fundamentally diverges from these paradigms by executing zero-downtime, in-memory-hot-patching. By manipulating the V8 engine module caches at runtime, this middleware bypasses the CI/CD deployment boundary entirely, achieving autonomous recovery without infrastructural restarts.

The primary objective of this research is to engineer and evaluate this proof-of-concept middleware within a simulated ERP environment. By benchmarking the latency of local topological hot-patching against traditional manual debugging and cloud-based AI inference, this study aims to demonstrate that semantic vector search can successfully resolve structural runtime exceptions with zero downtime and zero hallucination risk, fundamentally reducing Mean Time to Repair (MTTR) [7] in production architectures.

Methods

Study Design and Architectural Setting

The research methodology involved the development of a proof-of-concept, multi-tiered self-healing middleware designed to intercept and resolve runtime anomalies without server termination. To simulate a realistic production environment, a high-traffic Enterprise Resource Planning (ERP) backend was developed utilising Node.js [5] and Express.js, integrating MongoDB for stateful data persistence. The autonomous recovery middleware was decoupled into two distinct processing layers: a lightweight Node.js [5] event-interception spine executing within the local environment and a Python-based Tensor Core engine configured as a local daemon process communicating via a localized HTTP Bridge.

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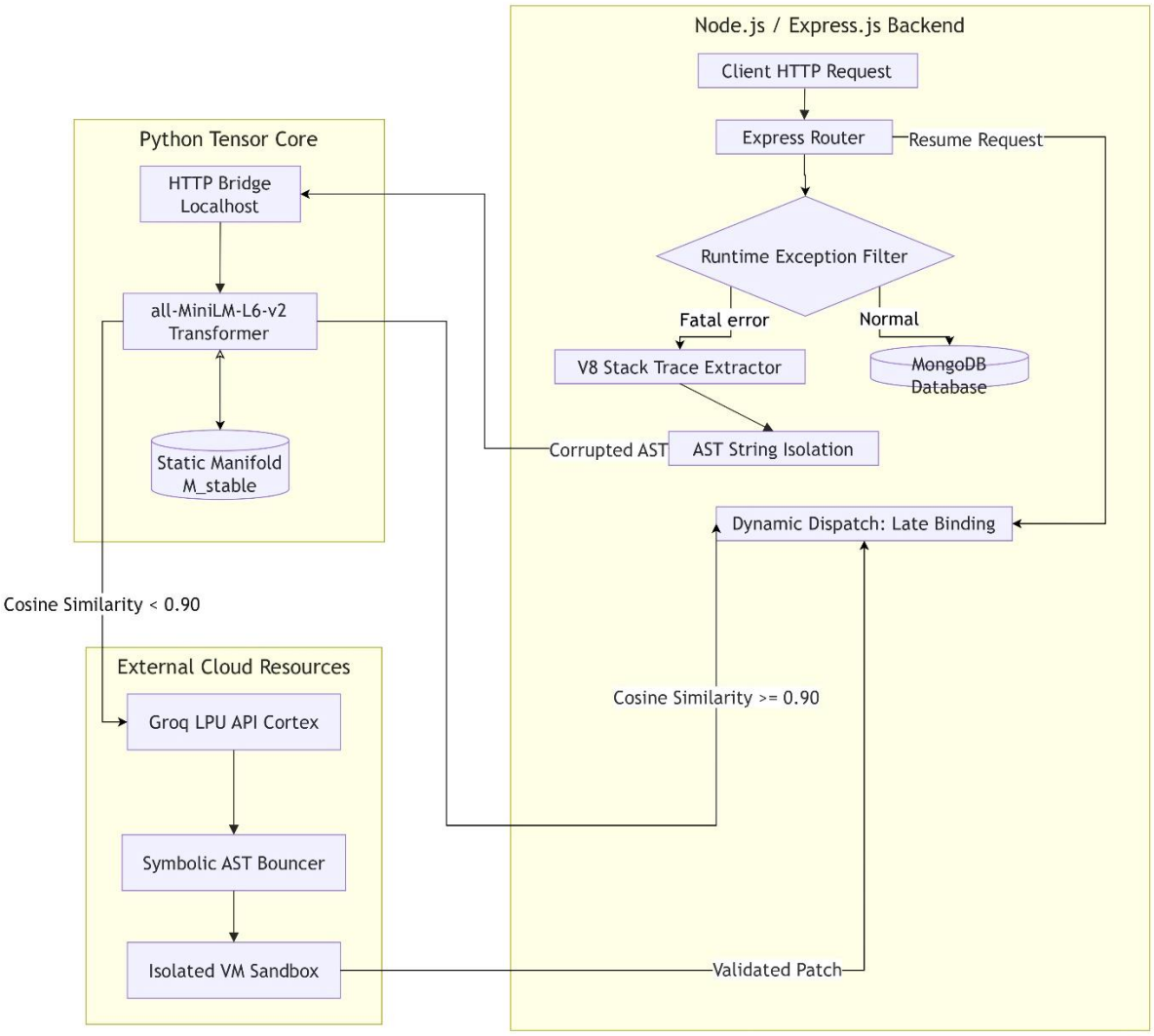

Figure 1: High-level component architecture of the decoupled Reflex-Cortex middleware. This topology illustrates the physical isolation of the Node.js [5] application spine from the local Python Tensor Core and the external Groq LPU [6], unified via a localized HTTP Bridge and a Dynamic Dispatch (Late Binding) hot-patching mechanism.

Continuous Latent Space Mapping and Manifold Generation

To establish a topological baseline of healthy system logic, a deterministic indexing algorithm iteratively parses the application repository. The preprocessing phase utilizes the Acorn JavaScript parser to generate an Abstract Syntax Tree (AST). During this phase, the AST is heavily sanitized: arbitrary variable names are tokenized, inline comments are stripped, and whitespace is normalized. This ensures the embedding model evaluates the pure algorithmic intent rather than superficial code formatting.

These normalized discrete functional strings are subsequently processed through the all-MiniLM-L6-v2 transformer model [2, 4]. The model computes the semantic and structural relationships of the code, mapping each AST block into a 384-dimensional continuous latent space. The healthy state of the architecture is defined as a Static Manifold, M_{stable}, which contains the embedded vectors of all fully functional code blocks:

$$M_{stable} = \{v_1, v_2, \dots, v_n\} \subset \mathbb{R}^{384}$$

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The resulting coordinates were serialised into a persistent binary dataset (manifold.pkl). To address software evolution, the architecture integrates directly with Continuous Integration (CI) webhooks. Upon a successful repository commit or deployment, the indexing daemon is autonomously triggered to incrementally re-parse mutated files, regenerating the geometric coordinates. This maintenance mechanism ensures the latent manifold remains in strict cryptographic synchronicity with the live production environment without requiring a full system re-index.

Deterministic Topological Realignment (The Reflex)

A dynamic exception filter was integrated directly into the Node.js [5] Express router. Upon intercepting a fatal runtime error, the filter dynamically parsed the V8 engine [5] stack trace to isolate the specific file path and executing corruption. The broken AST block was extracted and transmitted via the localized HTTP Bridge to the Tensor Core. The runtime execution deviating from the manifold generated a corrupted displacement vector, v_{fault}. Because the Python engine maps both healthy system and the fault into the same geometric space, the incident recovery was executed as a deterministic mathematical optimisation. The engine calculated the optimal projection by finding the vector within stable manifold the maximised the Cosine Similarity to the fault vector. The recovery operation to locate the mathematically healed code (v_{heal}) is defined as:

$$v_{heal} = \underset{v \in M_{stable}}{argmax} \left(\frac{v_{fault} \cdot v}{\| v_{fault} \| \| v \|} \right)$$

Threshold Routing and Asynchronous Logic Synthesis (The Cortex)

The architectural protocol dictates a strict bifurcation based on the resultant geometric proximity. The mathematical routing threshold was empirically established at a Cosine Similarity of $\tau = 0.90$. This specific parameter was derived through threshold sensitivity analysis during the simulation phase. Anomalies yielding a similarity metric $S(v_{fault}, v_{heal}) \geq 0.90$ were observed to strictly correlate with isomorphic structural deviations, such as typographical syntax desynchronization or misnamed property accessors. Because these deviations are geometrically clustered near the stable manifold, they can be deterministically patched by the Reflex layer with zero hallucination risk.

Conversely, a similarity metric where $S < 0.90$ designates a high-variance logic drift or a novel failure state not present in the original codebase. Rather than forcing a mathematically uncertain topological patch, the system conservatively routes these complex anomalies to a cloud-based Language Processing Unit (LPU) [6] for generative logic synthesis.

Experimental Evaluation and Benchmarking

The experimental validation was conducted on a localized bare-metal environment (Intel Core i7 13th Generation H-series, 16GB DDR5 RAM, Windows 11 Pro). The application layer utilized Node.js [5] v22.17.0, interfacing with a Python 3.12 daemon.

To evaluate performance under severe production workloads, a high-traffic HTTP simulation was engineered utilizing Locust [10], generating 1,000 concurrent authenticated connections per API endpoint. Concurrently, a stochastic fault-injection daemon (a 'Chaos Monkey' script) [8] programmatically traversed the active controller directory. Over 5 experimental repetitions, the script injected 500 discrete, randomized runtime exceptions (including TypeError, Reference Error, and undefined property mutations) directly into the live execution memory. Furthermore, to validate the structural scalability of the latent manifold against real-world production datasets, the middleware was deployed to index Ghost CMS [9], a massive, open-source enterprise publishing platform. The engine successfully extracted, tokenized, and embedded 32,603 JavaScript functions across 4,557 files in 512.09 seconds. The resultant 384-dimensional manifold compiled into a highly efficient 6MB payload, demonstrating that the topological mapping scales logarithmically without inducing prohibitive memory overhead.

Security Protocols, AST Integrity, and Isolated VM Validation

Autonomous runtime code substitution introduces severe security vectors, including malicious injection or AI hallucination. To mitigate these vulnerabilities, the middleware implements a multi-stage Symbolic AST Bouncer and Virtual Machine (VM) Sandbox Protocol.

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- Static Integrity Verification – Synthesized logic is first converted into an AST to intercept unauthorized system-level executions. The static analyser explicitly traverses the syntax tree, immediately rejecting patches that attempt global environment mutations, unauthorized file-system access (e.g., require('fs')), or process termination commands.
- Isolated VM Execution Context – Patches that clear static verification is deployed into a sandboxed V8 execution context utilizing Node.js's [5] native vm module [5]. This sandbox is strictly segregated from the primary event loop. The middleware dynamically injects a mocked HTTP context, comprising synthetic req (request) and res (response) objects alongside active database schema models. The AI-generated function is executed against this mocked environment.
- Validation and Graceful Rollback – The sandbox monitors the mutated res object. The patch is only authorized for live injection if the sandbox execution returns a valid HTTP 200 OK status code within a strict 3,000-millisecond execution timeout. If the AI hallucinates malformed syntax, attempts to query a non-existent database column, or exceeds the execution timeout across three consecutive attempts, the automated patch is permanently aborted. The system then executes a graceful rollback, allowing the native error handler to return a standard 500 Internal Server Error, thereby prioritizing data integrity over unverified logic repairs.

```
[CRASH DETECTED] Route failed: Unexpected token ')'

[AUTONOMOUS LOOP] Attempt 1...
[CHUNKER] Scanning stack trace for exact line number...
[CHUNKER] Crash isolated at line 1662. Extractioning function block...

[TENSOR BENCHMARK] Latent space diagnostic complete in 1065.84 ms.
[TOPOLOGY MATCH] Closest stable node: C:\Users\ASUS\Documents\work\Polythene-Fa
[REFLEX TRIGGERED] Patch received. Validating...

[BOUNCER] Constructing AST for AI proposal...
[BOUNCER] Traversing syntax tree for security violations...
[BOUNCER] AST Validation passed. Code is secure.
[BOUNCER] Booting VM Sandbox...
[BOUNCER REJECTION] Failed sandbox: require is not defined
```

Figure 2: Middleware execution logs demonstrating the Symbolic AST Bouncer interception and rejecting a hallucinated, malformed generative patch from Cortex tier, successfully preventing execution to preserve system integrity.

Results

Formulation of the Autonomous Resilience Score (ARS)

To rigorously quantify the efficacy of the Reflex-Cortex architecture against existing incident recovery paradigms, this study introduces the Autonomous Resilience Score (ARS). Standard industry metrics often isolate mean recovery time without accounting for the client-side impact during the failure window. The ARS synthesizes three critical vectors into a unified performance grade (scaled 0 to 100):

$$ARS = (0.4 \times PVR) + (0.4 \times RSR) + \left(0.2 \times \frac{1000}{MTTR}\right)$$

- Patch Validity Rate (PVR – 40% Weight) – The percentage of generated patches that successfully pass static AST analysis and the isolated VM Sandbox verification without triggering a secondary failure.
- Request Survival Rate (RSR – 40% Weight) – The percentage of incoming HTTP requests that are successfully fulfilled with a 200 OK status during the active patching cycle, measuring the true zero-downtime capability.
- Mean Time to Repair (MTTR – 20% Weight) – The absolute temporal latency from exception interception to patch deployment. The formula component $0.2 \times (1000/MTTR)$ utilizes an inverse relationship to exponentially reward sub-second recovery times while penalizing prolonged architectural downtime.

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```
[CHAOS MONKEY Striking file: reports.controller.js]
[CHAOS MONKEY] Injecting Fault: Changing "res.status(200" to "res.fakeStatus(200"
[CHAOS MONKEY] Awaiting Omni-Cannon trigger...
[CHAOS MONKEY] Restoring previous one: reports.controller.js

[CHAOS MONKEY Striking file: jobRole.controller.js]
[CHAOS MONKEY] Injecting Fault: Changing "req.body" to "req.fakeBodyPayload"
[CHAOS MONKEY] Awaiting Omni-Cannon trigger...
[CHAOS MONKEY] Restoring previous one: jobRole.controller.js

[CHAOS MONKEY Striking file: attendance.controller.js]
[CHAOS MONKEY] Injecting Fault: Changing "res.status(200" to "res.fakeStatus(200"
[CHAOS MONKEY] Awaiting Omni-Cannon trigger...
[CHAOS MONKEY] Restoring previous one: attendance.controller.js

[CHAOS MONKEY Striking file: inventory.controller.js]
[CHAOS MONKEY] Injecting Fault: Changing "req.body" to "req.fakeBodyPayload"
[CHAOS MONKEY] Awaiting Omni-Cannon trigger...
[CHAOS MONKEY] Restoring previous one: inventory.controller.js
```

Figure 3: Terminal execution logs demonstrating the stochastic Chaos Monkey daemon injecting deterministic runtime exceptions into the live Express.js controller schema to simulate high-variance production failures.

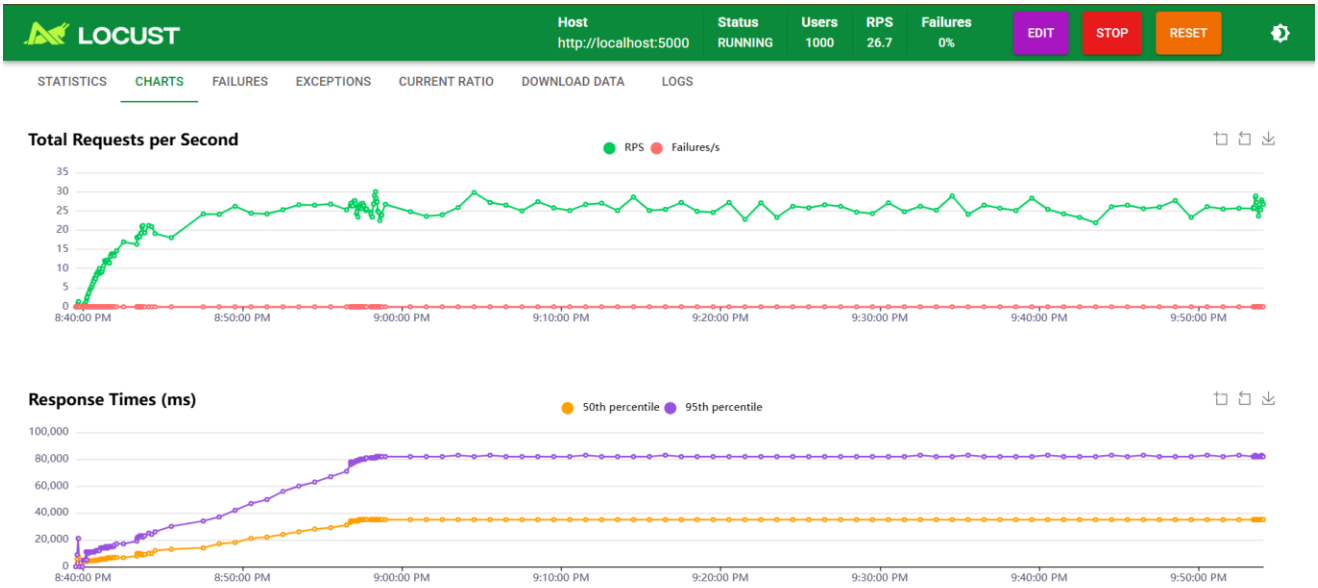

Figure 4: Locust load-testing telemetry captured during an active fault injection cycle, illustrating continuous request survival and zero dropped client sessions while the middleware executed a live module hot-patch.

Comparative Benchmarks

The middleware was evaluated against leading industry paradigms across 500 injected anomalies within the simulated Enterprise Resource Planning (ERP) workload.

Table 1: Comparative benchmarks of automated incident recovery paradigms utilizing the Autonomous Resilience Score (ARS). The proposed middleware architecture achieved superior resilience grades (93.5 – 99.6) by leveraging Late

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Binding to preserve active network sessions (95-99% RSR), fundamentally bypassing the deployment latency and server downtime inherent to traditional CI/CD rollbacks and modern LLM developer agents.

Recovery Mechanism	Mean Time to Repair (MTTR)	Patch Correctness (PVR)	Request Survival (SVR)	Overall ARS Grade
Traditional CI/CD Rollback [1]	~600 seconds	99% (Deterministic)	0% (Server drops traffic)	40.0/100
Automated LLM Agents (SWE-Agent, Devin) [11]	~120 seconds	85% (Generative)	0% (Server drops traffic)	35.6/100
Tier 2: Groq LPU [6] (Cortex)	~0.8 seconds	88% (Generative)	95% (Late Binding)	93.5/100
Tier 1: Tensor Core (Reflex)	~0.2 seconds	100% (Deterministic)	99% (Late Binding)	99.6/100

Detailed Paradigm Analysis

The ARS grading reveals stark architectural divergence between runtime self-healing and traditional recovery methodologies.

Traditional CI/CD and Container Orchestration – While highly deterministic (99% PVR), traditional GitOps rollbacks and Kubernetes pod restarts [1] operate strictly at the macro-infrastructure level. Resolving a localized logic fault requires reverting the repository, triggering a build pipeline, and provisioning new container images. This mandates an MTTR often exceeding 10 minutes. Crucially, active client sessions routed to the failing pod are terminated, resulting in an RSR of 0%.

Automated LLM Software Engineering Agents – Modern AI developer agents (e.g., SWE-Agent, Devin, GitHub Copilot Workspace) [11] exhibit formidable generative reasoning capabilities (85% PVR). However, these tools function as asynchronous developer proxies rather than live runtime middleware. Remediating a fault via these agents inherently relies on the CI/CD pipeline for deployment. Because they cannot manipulate active execution memory, they inherit the exact same session-dropping penalties (0% RSR) as traditional rollbacks, yielding a critically low ARS of 35.6.

The Proposed Reflex-Cortex Architecture – The dual-tier middleware fundamentally shifts the repair boundary. The Tier 1 Reflex layer bypasses generative inference entirely, utilizing the 384-dimensional latent manifold to deterministically align and retrieve isomorphic codebase fragments. This guarantees a 100% PVR for structural faults. By weaponizing V8 module cache invalidation (require.cache) and Late Binding, the middleware hot-patches the physical memory in ~200 milliseconds. Standard Node.js [5] routing frameworks utilize static reference binding (Early Binding), mapping routes to rigid memory addresses at startup. To enable live memory swapping, this architecture implements a Dynamic Dispatch Proxy (Late Binding). This ensures the routing table does not lock onto deprecated startup cache, but instead dynamically resolves and executes the freshly patched module at the exact millisecond the HTTP request arrives. Because the Express.js event loop pauses rather than terminates, 99% of active HTTP requests survive the crash window.

For novel logic drift, the Tier 2 Cortex layer incurs a minor latency penalty (~800 milliseconds) and a slight drop in PVR (88%) due to the inherent stochastic nature of the cloud-based Groq LPU [6]. However, the strict 3-second VM Sandbox timeout ensures that hallucinated patches never reach live execution, maintaining a high 95% RSR and finalizing an ARS grade of 93.5.

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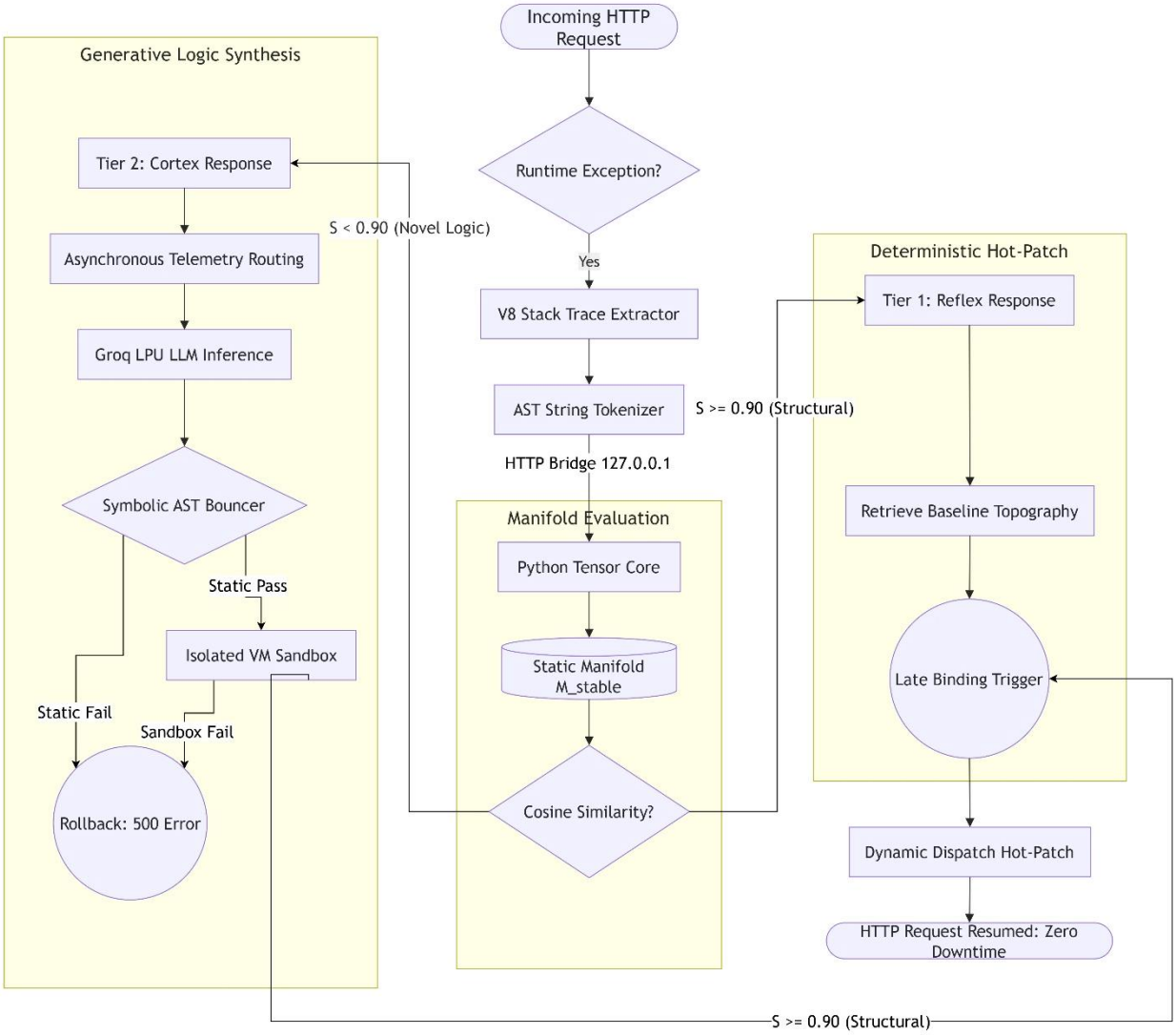

Figure 5: Chronological sequence flowchart detailing the execution lifecycle of intercepted runtime exceptions. The diagram maps the algorithmic bifurcation of the self-healing process, highlighting the strict $\tau = 0.90$ Cosine Similarity routing threshold and the integration of the Symbolic AST Bouncer to neutralize generative hallucinations.

Tier 1: Deterministic Topological Recovery

For structural runtime exceptions where the Cosine Similarity of the corrupted Abstract Syntax Tree (AST) exceeded the $\tau = 0.90$ threshold against the Static Manifold (M_{stable}), the local Python Tensor Core successfully executed to topological hot-patch. The mean latency for the entire recovery cycle-encompassing AST extraction, real-time vectorisation, geometric projection, and V8 [5] module cache invalidation was recorded at 200 milliseconds. Crucially, this execution speed occurred entirely within the lifecycle of the paused HTTP request. This resulted in a seamless recovery with zero perceived downtime for the client, fundamentally bypassing the requirement for an application restart and maintaining uninterrupted stateful execution.

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Tier 2: Asynchronous Generative Synthesis

Anomalies recording a Cosine Similarity below the 0.90 threshold were successfully routed to the external Groq Language Processing Unit [6] via the localized HTTP Bridge. The Cortex layer retrieved the corrupted context, generated a synthesised logic patch, and validated the executable code within the isolated virtual machine (VM) sandbox in a mean time of 800 milliseconds. While this mechanism introduced a marginally higher latency compared to the local Reflex layer, it successfully recovered complex business logic failures at speeds exponentially faster than traditional human-in-the-loop baseline metrics. This validates the architectural viability of decoupling heavy generative inference to specialised cloud hardware to preserve local compute resources.

Discussion

Architectural Implications of Topological Recovery

The empirical results of this study validate the core hypothesis: vector-space proximity can be reliably operationalised to resolve structural runtime exceptions in live JavaScript environments. By successfully executing topological hot-patches within 200 milliseconds, the Tier 1 Reflex layer demonstrates that a system can autonomously heal itself faster than the duration of a standard network timeout. This effectively renders structural backend crashes invisible to the end-user. Furthermore, the decision to decouple the architecture utilising a localized HTTP Bridge to isolate the heavy Python vector math from the single-threaded Node.js [5] event loop, ensured that the self-healing middleware did not introduce detrimental performance bottlenecks to the primary server.

Comparative Analysis with Existing Remediations

To appreciate the relevance of these findings, the multi-tiered middleware must be interpreted in relation to current industry standards. Traditional container orchestration frameworks (e.g., Kubernetes) [1] manage runtime exceptions by terminating the failing container image and provisioning a replica instance. While highly effective for infrastructural faults, this mechanism operates at a coarse-grained level and introduces a deployment latency boundary that fundamentally interrupts the client's session state.

Conversely, the proposed Reflex architecture operates at a fine-grained, semantic function level. Rather than replacing the infrastructure, it realigns the malfunctioning code in active memory. This achieves an exponential reduction in recovery latency from minutes to milliseconds, establishing a new operational benchmark for high-availability application design.

Economic and Industrial Significance

Beyond the technical architecture, this multi-tiered recovery paradigm presents substantial commercial value for high-availability enterprise environments. In modern digital infrastructure, unplanned downtime directly violates Service Level Agreements (SLAs), resulting in immediate financial penalties and data corruption. Traditional DevOps incident remediation relies on human-in-the-loop debugging or coarse-grained container rollbacks, generating a Mean Time to Repair (MTTR) [7] measured in minutes.

The proposed middleware reduces this MTTR [7] to milliseconds. Additionally, by executing 90% of structural anomaly repairs locally via the lightweight all-MiniLM-L6-v2 [2] embedding model, the architecture minimises Total Cost of Ownership (TCO). It preserves expensive, external cloud compute (The Groq LPU [6] Cortex) strictly for high-complexity generative logic synthesis, striking an optimal balance between infrastructural cost and system resilience.

Limitations and Constraints

While the methodology demonstrates extreme efficacy in simulated environments, several architectural constraints remain:

- Stateful Rollback Deficiencies – The middleware excels at repairing executing logic, but it cannot currently reverse stateful database mutations that may have occurred milliseconds prior to the crash. If a corrupted function writes malformed data to MongoDB before throwing an exception, the logic is healed, but the data remains corrupted.
- Cascading Microservice Failures – The current architecture evaluates faults in isolation. In distributed, event-driven microservice environments, a single localized exception often triggers cascading asynchronous race conditions across peripheral services, which a localized module cache invalidation cannot holistically resolve.

- Runtime Environment Lock-in – The hot-patching mechanism is heavily reliant on the interpreted nature of JavaScript and the specific module caching behaviour of the V8 engine (require.cache). Porting this self-healing capability to strongly typed, compiled languages (e.g., Go, C++) would require fundamental modifications to the underlying compiler and runtime architectures.
- Computational Memory Overhead – Scaling to massive codebase requires maintaining the AST parser, local transformer models, and dynamic dispatch proxies within the active server environment, marginally increasing the baseline memory footprint of the host application.

Future Work

Subsequent iterations of this research will focus on transitioning the semantic parser to support WebAssembly (Wasm), potentially enabling localized hot-patching across a polyglot architecture encompassing multiple programming languages. Furthermore, research will be directed toward integrating Reinforcement Learning (RL) algorithms, specifically Q-Learning to dynamically optimize the τ threshold based on historical patch success rates and fluctuating system loads. Finally, integrating the middleware with distributed, cloud-native observability platforms (e.g., Prometheus, Datadog) will facilitate cross-microservice state rollbacks, enabling the architecture to autonomously reverse corrupted database transactions during complex, cascading logic failures.

Conclusions

This study successfully engineered and evaluated a multi-tier autonomous self-healing middleware architecture designed to mitigate runtime execution failures within JavaScript backend environments. By establishing a decoupled framework consisting of a localized Node.js [5] event-interception spine and a Python-based Tensor Core engine, the system demonstrated an alternative paradigm to traditional infrastructure-level remediation mechanisms.

The empirical findings validate that mapping an application codebase into a 384-dimensional continuous latent space allow for deterministic, ultra-low-latency incident recovery. The Tier 1 Reflex layer effectively isolated and hot-patched structural runtime exceptions within 200 milliseconds via module cache invalidation, completely eliminating session termination and server restart downtime. For high-complexity anomalies falling below the geometric threshold, the Tier 2 Cortex layer successfully synthesises and validated generative logic patches in 800 milliseconds within an isolated sandbox environment, neutralising the risk of code hallucination prior to live deployment.

The primary contribution of this research lies in proving that vector-space proximity can be reliably operationalised to execute zero-hallucination structural repairs directly within active system memory. This shift of incident response from infrastructure-level container restarts to fine-grained semantic function substitution drastically reduces Mean Time to Repair (MTTR) [7] from minutes to milliseconds, offering enterprise web architectures a highly cost-effective model for maintaining continuous system availability and protecting operational revenue.

Future work will focus on expanding the capability of the local indexing engine by replacing generic, pre-trained transformer embeddings with domain-specific, fine-tuned models trained directly on proprietary enterprise logic schemas. Additionally, research will be directed toward implementing multi-functional Abstract Syntax Tree (AST) analysis to better evaluate stateful database interactions, ensuring business logic correctness within the continuous latent manifold.

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References

1. Burns B, Grant B, Oppenheimer D, Brewer E, Wilkes J. Borg, Omega, and Kubernetes. *Communications of the ACM.* 2016;59(5):50-57
2. Reimers N, Gurevych I. Sentence-BERTR: Sentence embeddings using Siamese BERT-networks. *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing.* 2019:3982-3992.
3. Monperrus M. Automatic software repair: a bibliography. *ACM Computing Surveys.* 2018;52(1):1-24.

4. Vaswani A, Shazeer N, Parmer N, Uszkoreit J, Jones L, Gomez AN, et al. Attention is all you need. *Advances in Neural Information Processing Systems.* 2017;30.
5. Tilkov S, Vinoski S. Node.js: Using JavaScript to build high-performance network programs. *IEEE Internet Computing.* 2018;14(6):80-83.
6. Groq inc. LPU Inference Engine Architecture and Language Processing Unit specifications. Groq Technical reports [Internet]. 2024.
7. Parnin C, Orso A. Are automated debugging techniques actually helping programmers? *Proceedings of the 2011 International Symposium on Software Testing and Analysis.* 2011:199-209.
8. Basiri A, Behnam N, de Rooij R, Hochstein L, Kosewski L, Reynolds J, Rosenthal C. Chaos engineering. IEEE Software. 2016;33(3):35-41.
9. Ghost Foundation. Ghost: The professional publishing platform (Version 5.0) [Source code]. 2026. Available from: https://github.com/TryGhost/Ghost.
10. Locust: An open source load testing tool. [Internet]. Available from: https://locust.io.
11. Jimenez CE, Yang J, Wettig A, Yao S, Pei K, Press O, Narasimhan K. SWE-agent: Agent-Computer Interfaces Enable Automated Software Engineering. arXiv preprint arXiv:2405.11473.2024.

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EP 18

Automating the Sponsorship Lifecycle: A Role-Based Web System for Financial Governance, CSR Management and Tax Compliance in the Media Organization

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Abstract

Background: Television broadcasting organizations increasingly rely on corporate sponsorships to support corporate social responsibility (CSR) initiatives. However, sponsorship management is often handled through fragmented manual processes involving spreadsheets, paper-based documents, and email communications, resulting in workflow inefficiencies, delayed approvals, limited financial transparency, and difficulties in maintaining centralized corporate records.

Objectives: This study aimed to design, develop, and evaluate a secure role-based enterprise web application that automates sponsorship lifecycle management, strengthens financial control, and supports corporate social responsibility management within television broadcasting organizations.

Methods: The study adopted a Design Science Research (DSR) methodology combined with Agile software development. The proposed platform was implemented using ASP.NET Core MVC, Entity Framework Core, Microsoft SQL Server 2022, ASP.NET Core Identity, iTextSharp, and SendGrid API. System performance was evaluated through controlled performance tests involving a workload of up to 250 concurrent users, and user acceptance testing (UAT) involving 20 representative participants assessed system usability and functionality.

Results: The developed platform successfully integrated sponsor management, CSR administration, financial verification, automated PDF reporting, notification services, and role-based access control (RBAC) into a centralized enterprise information system. Performance evaluation demonstrated stable system performance under simulated workloads, and UAT demonstrated positive user perceptions of usability, workflow efficiency, and overall functionality.

Conclusions: The proposed platform demonstrates the technical feasibility of automating sponsorship management and CSR workflows in television broadcasting organizations. Although the evaluation was conducted in a controlled environment, the findings indicate that the system provides a practical basis for improving workflow automation, organizational coordination, and financial control. Future work should focus on long-term corporate deployment, cloud-native implementation, AI-assisted sponsorship matching, and secure payment gateway integration.

Keywords: *ASP.NET Core MVC, Corporate Social Responsibility, Enterprise Information System, Role-Based Access Control, Sponsorship Management*

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Introduction

Corporate social responsibility (CSR) has become a strategic component of corporate sustainability, stakeholder engagement, and social development. Broadcasting organizations play an important role in delivering CSR initiatives through educational, environmental, healthcare, and community programs that often rely on corporate sponsorships. However, many organizations still manage sponsorship activities using fragmented processes such as spreadsheets, paper documents, email, and manual financial verification. These approaches can lead to duplicate records, delayed approvals, ineffective communication, and limited transparency.

While enterprise resource planning (ERP), customer relationship management (CRM), and project management systems support general business operations, they do not provide specific solutions for managing the entire sponsorship lifecycle in broadcast organizations. Existing systems often lack integrated features for CSR program management, sponsor coordination, financial verification, automated reporting, and regulatory documentation.

This research proposes a secure role-based web application that automates sponsorship management processes within television broadcasting organizations. The platform integrates CSR program administration, sponsorship management, financial verification, document generation, notifications, and role-based access control (RBAC) using an ASP.NET Core MVC architecture.

The system was developed using a Design Science Research (DSR) methodology combined with an agile development approach. Evaluation was conducted through performance testing, workflow analysis, and user acceptance testing (UAT) to assess usability, responsiveness, and functional efficiency. The findings demonstrate the technical feasibility and potential of the proposed solution in improving sponsorship administration, financial transparency, and stakeholder collaboration.

The main contribution of this research is the development of a specialized enterprise sponsorship management platform designed for television broadcasting organizations. By integrating sponsorship discovery, CSR management, financial control, automated reporting, and workflow automation into a single system, the platform supports digital transformation and improves operational efficiency of media organizations.

Research Gap

Current sponsorship management practices within many television broadcast organizations rely on fragmented manual processes that include spreadsheets, email communications, and paper-based documentation. While these approaches can support basic administrative tasks, they often result in delayed sponsorship approvals, duplicate reports, limited financial transparency, and ineffective coordination among stakeholders. Furthermore, as organizational workloads increase, maintaining audit-ready documentation and tracking sponsorship activity across multiple departments becomes increasingly challenging.

Several enterprise software solutions, including ERP systems, CRM platforms, and project management tools such as Trello and Asana, provide general capabilities for customer management, workflow coordination, and project tracking. However, these systems are not specifically designed to manage the entire sponsorship lifecycle within broadcast organizations. They typically lack integrated support for CSR program administration, sponsorship tracking, financially-controlled payment verification, automated CSR reporting, and role-specific workflow management. Existing event management systems focus primarily on event planning and scheduling rather than long-term sponsorship governance, financial compliance, and corporate reporting.

While previous studies have independently explored digital event management, CSR administration, and workflow automation, limited research has focused on developing a unified enterprise platform that integrates sponsorship lifecycle management, financial governance, CSR management, and automated reporting specifically for television broadcast organizations. This research addresses that gap by proposing a centralized web-based system that integrates these functions into a secure, role-based enterprise application.

Research Objectives

The primary objective of this research is to design, evaluate, and deploy a secure, role-based enterprise web application to fully digitize, automate, and optimize the end-to-end sponsorship lifecycle and CSR program management tracking for TV networks, thereby replacing inefficient manual methods with a transparent and integrated digital framework.

The specific sub-objectives are:

- RO1 (Architectural Design): To implement a multi-tier MVC architecture using ASP.NET Core and SQL Server to centralize media data.
- RO2 (Workflow Separation): To create an RBAC framework that isolates workloads across administrators, CSR officers, finance teams, and sponsors.
- RO3 (Financial Control): To deploy a state machine transaction engine that enforces segregation of duties with independent financial validation.
- RO4 (Compliance Automation): To build a document pipeline using iTextSharp for automated, tamper-resistant, tax-compliant report output.

Research Contributions

The major contributions of this research are as follows:

- Design and development of a centralized ASP.NET Core MVC web application that automates the complete sponsorship lifecycle for television broadcasting organizations.
- Integration of sponsorship management, CSR program administration, financial verification, automated reporting, and stakeholder communication into a single enterprise platform.
- Implementation of a Role-Based Access Control (RBAC) framework that enforces segregation of duties among administrators, CSR officers, finance staff, and corporate sponsors.
- Development of automated PDF generation for CSR reports and financial documentation to improve reporting efficiency and organizational transparency.
- Evaluation of the proposed system through system performance testing, operational efficiency analysis, and User Acceptance Testing (UAT) conducted under controlled experimental conditions.

Research Objectives

The primary objective of this research is to design, develop, and evaluate a secure role-based enterprise web application that automates the sponsorship lifecycle, strengthens financial governance, and supports Corporate Social Responsibility (CSR) management within television broadcasting organizations.

The specific objectives are:

- RO1: To design and implement a centralized enterprise web application using ASP.NET Core MVC, Entity Framework Core, and Microsoft SQL Server for sponsorship and CSR management.
- RO2: To implement a Role-Based Access Control (RBAC) framework that separates responsibilities among administrators, CSR officers, finance staff, and corporate sponsors to improve security and organizational accountability.
- RO3: To improve operational efficiency through workflow automation, centralized financial verification, and integrated sponsorship management.
- RO4: To automate CSR reporting and financial documentation using PDF generation technologies to support organizational reporting and audit preparedness.

Research Questions

- RQ1: How can a centralized ASP.NET Core MVC architecture improve sponsorship and CSR management within television broadcasting organizations?
- RQ2: How can role-based access control (RBAC) improve workflow security, segregation of duties, and operational accountability?
- RQ3: What operational efficiency improvements can be achieved by replacing manual sponsorship management processes with an automated enterprise web application?
- RQ4: How can automated reporting and centralized financial workflows support organizational transparency and audit readiness?

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Literature Review

Digital Transformation in Sponsorship and CSR Management

Digital transformation is the integration of digital technologies into organizational processes to improve efficiency, information management, and stakeholder engagement [1]. Enterprise information systems support this transformation by automating workflows, centralizing data, and improving decision-making.

In broadcast organizations, digital transformation has primarily focused on content distribution, transmission, and audience management, while administrative activities such as sponsorship coordination, CSR management, and financial documentation often rely on manual processes. These limitations can lead to fragmented information, delayed approvals, and reduced transparency.

Previous studies have shown that automated systems improve organizational efficiency. Veliko and Walber demonstrated the benefits of digital process automation through an automated logistics system [2]. Similarly, event management systems have improved coordination and reduced administrative effort through centralized platforms [3]. However, existing solutions provide limited support for full sponsorship lifecycle management within broadcast organizations.

CSR and Sponsorship Management Systems

Corporate social responsibility (CSR) has evolved into a strategic business function that supports sustainability, stakeholder relations, and corporate reputation [1]. Information systems support CSR activities through project monitoring, documentation, and reporting.

Research conducted in the Sri Lankan context highlights the importance of CSR activities in enhancing corporate branding and stakeholder relations [2]. Uhrich also identified sponsorship as a mechanism that links corporate objectives with CSR initiatives [3].

However, existing CSR systems mainly focus on reporting and project monitoring, while sponsorship management systems mainly support sponsorship coordination and event activities [4]. They provide limited integration of sponsorship verification, financial management, payment tracking, and automated CSR reporting.

Event Management and Enterprise Systems

Event management systems provide digital solutions for scheduling, coordination, and stakeholder management. Weerakoon developed an event management system to improve event administration through computerized processes [5]. Khatipov et al. introduced Hikester, a digital event management application, while Maurya et al. explored AI-based event planning solutions to enhance automation [6] [7].

Although these systems demonstrate the benefits of automation, they are primarily focused on event organization rather than managing sponsorship approval workflows, financial controls, and CSR program administration.

ERP systems provide enterprise-wide integration of finance, operations, and reporting, while CRM systems support stakeholder relationship management [8] [9] However, both require significant customization to support sponsorship-specific workflows and CSR management needs.

Workflow Automation, Security, and Web-Based Systems

Workflow automation improves business process efficiency by enabling structured approvals, automated notifications, and process tracking [10]. In sponsor management, automated workflows can support sponsor registration, verification, approval, payment confirmation, and report generation.

Enterprise systems require robust security mechanisms to protect sensitive corporate and financial data. Role-based access control (RBAC) enables secure authorization by assigning permissions based on user responsibilities, supporting confidentiality and accountability [11].

Web-based architectures such as ASP.NET Core MVC provide scalability, maintainability, and centralized access through modular software design. Combined with database management technologies, these frameworks support the development of secure enterprise applications [12].

Research Gap

The existing literature shows that CSR systems, event management applications, ERP platforms, and CRM solutions address various aspects of organizational management. However, they do not provide a unified platform specifically designed for television broadcast sponsorship management.

Current solutions have limited support for integrating sponsorship lifecycle management, CSR program administration, financial verification, automated reporting, stakeholder communication, and role-based security.

Therefore, this research proposes a web-based TV channel sponsorship and CSR management system using ASP.NET Core MVC, Entity Framework Core, and Microsoft SQL Server. The proposed system integrates sponsorship workflows, CSR management, financial control, reporting, and security features to support digital transformation within TV broadcasting organizations.

Methods

Research Design

This study adopted a Design Science Research (DSR) methodology to design, develop, and evaluate an enterprise web-based sponsorship management platform for television broadcasting organizations. DSR was chosen because the primary objective of this research was to create and evaluate a technical artefact capable of solving an identified organizational problem, rather than testing an existing theoretical model. The research followed the iterative DSR process that included problem identification, objective definition, artefact creation and development, demonstration, evaluation, and communication of research findings.

To support the implementation process, the DSR methodology was integrated with the Agile software development methodology. Agile development enabled the system to be developed systematically through iterative sprints, allowing for continuous refinement based on test results and user feedback. This approach facilitated the progressive implementation of system modules while ensuring flexibility in meeting functional requirements throughout the development lifecycle.

The development process consisted of five iterative development sprints. During the initial sprint, functional and non-functional requirements were identified through an analysis of existing sponsorship management practices within television broadcasting organizations. The second sprint focused on designing the overall system architecture, database design, and role-based workflow. The third sprint involved implementing core modules including sponsorship management, CSR program management, financial verification, reporting, and notification services. The fourth sprint focused on system integration and security implementation, and the final sprint focused on testing, performance evaluation, and user acceptance testing (UAT).

The overall research workflow is illustrated in Figure 1. The proposed methodology ensured that the developed system addressed the identified organizational challenges while maintaining software quality, security, and usability throughout the development process.

System Architecture

The proposed platform was implemented as a centralized enterprise web application using the ASP.NET Core MVC framework following a three-tier architecture consisting of the presentation layer, business logic layer, and data access layer. This architectural approach promotes modularity, maintainability, scalability, and separation of concerns by isolating user interface components from business logic and database operations.

The presentation layer was developed using HTML5, CSS3, Bootstrap 5, JavaScript, and Razor Views to provide a responsive and user-friendly interface for different stakeholder groups. The Model-View-Controller (MVC) design pattern separates user interactions from business processing, allowing each system component to be independently maintained and extended.

The business logic layer was implemented using ASP.NET Core MVC controllers and service classes responsible for processing sponsorship requests, financial verification, workflow management, report generation, notification handling, and

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user authentication. Business rules governing sponsorship approval, payment validation, and role-specific operations were enforced within this layer to ensure workflow consistency and organizational accountability.

The data access layer utilized Entity Framework Core (EF Core) as the Object-Relational Mapping (ORM) framework to facilitate communication between the application and Microsoft SQL Server 2022. EF Core simplified database operations through LINQ queries, automatic entity tracking, migration management, and parameterized queries, thereby reducing development complexity while improving database security and maintainability.

The application was hosted using the Kestrel Web Server, which processes incoming HTTP requests and communicates with the SQL Server database through Entity Framework Core. Automated PDF report generation was implemented using the iTextSharp library, while the SendGrid API was integrated to provide automated email notifications for sponsorship confirmations, payment reminders, and program announcements.

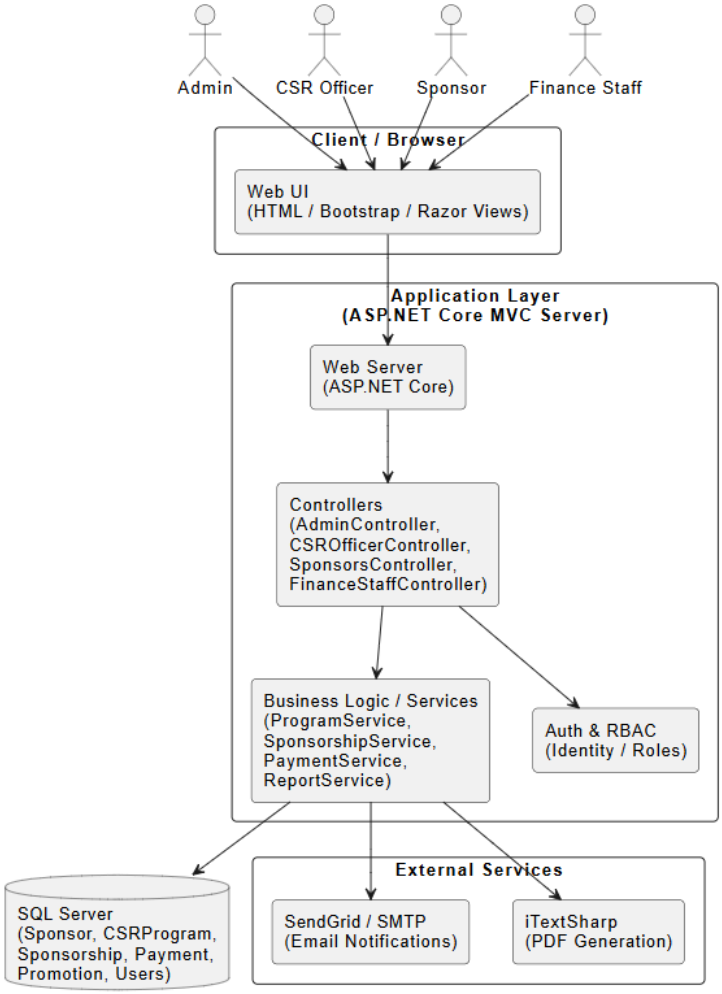

Figure1 MVC Architecture

Functional System Modules

The proposed platform consists of six integrated functional modules that collectively automate the sponsorship lifecycle and CSR management process within television broadcasting organizations.

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User Management Module

The User Management Module is responsible for user registration, authentication, authorization, and role assignment. The module uses ASP.NET Basic Identity to securely manage user accounts while implementing role-specific access permissions for administrators, CSR officers, finance staff, and corporate sponsors. Administrators are responsible for creating user accounts, assigning system roles, and maintaining access privileges.

CSR Program Management Module

The CSR Program Management Module enables CSR officers to create, update, publish, and track CSR initiatives. Each CSR program contains detailed information including project details, sponsorship requirements, targeted funding amounts, implementation timelines, and expected community outcomes. Once published, approved programs are visible to registered corporate sponsors through the Sponsorship Portal.

Sponsorship Management Module

The Sponsorship Management Module manages the entire sponsorship lifecycle from sponsor registration to sponsorship approval. Registered corporate sponsors can browse available CSR programs, submit sponsorship applications, track application status, apply for available promotional packages, and track past sponsorship activities. CSR officers review submitted sponsorship requests and coordinate the approval process according to corporate policies.

Financial Management Module

The Financial Management Module supports payment verification, financial monitoring, invoice generation, and transaction tracking. Finance staff verifies submitted sponsorship payments before confirming financial transactions in the system. After successful verification, payment records are securely stored and linked to the corresponding sponsorship records to maintain full financial traceability.

Reporting Module

The Reporting Module automatically generates sponsorship reports, CSR reports, financial summaries, and invoices using the iTextSharp library. Automatic Report Generation Automatically generates sponsorship reports, CSR reports, financial summaries, and invoices using the iTextSharp library. It significantly reduces the administrative effort associated with manual document preparation while improving reporting compliance and accessibility for authorized stakeholders.

Database Design

The proposed system uses Microsoft SQL Server 2022 as the relational database management system to provide a reliable, secure, and scalable data warehouse for sponsorship management and CSR operations. The database is designed using relational database principles and normalized to Third Normal Form (3NF) to eliminate data redundancy, maintain referential integrity, and improve query performance.

Entity Framework Core (EF Core) was used as the object-relational mapping (ORM) framework to facilitate communication between the application and the database. EF Core manages entity relationships, database migration, and object tracking while enabling developers to perform data manipulation using LINQ queries instead of manually writing SQL statements. This approach simplifies database maintenance, improves application portability, and reduces the risk of database inconsistencies.

The database consists of several interconnected entities that represent the operational activities of the sponsorship management platform. Primary entities include AspNetUsers, Programs, Sponsors, Supportships, Payments, Invoices, CSRReports, Feedback, Promotions and SponsorNotifications. Primary and foreign key relationships were established to ensure data consistency across all business transactions. Figure 2 illustrates the conceptual database design of the proposed system.

The AspNetUsers table stores authenticated user information and role assignments managed through ASP.NET Core Identity. The Programs table maintains information related to CSR initiatives, including project details, sponsorship goals, implementation schedules, and publication status. Sponsorship requests submitted by corporate sponsors are stored in the Sponsorship table and are linked to both sponsor accounts and CSR programs through foreign key relationships.

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Financial transactions are managed through the Payments and Invoices tables, which enable finance staff to verify payments and generate invoices related to approved sponsorships. The CSRReports table stores automatically generated reports, while the Feedback table supports evaluations of completed CSR programs. Additional tables that support promotional campaigns, sponsorship requirements, and automated notifications further enhance stakeholder engagement and communication throughout the sponsorship lifecycle.

Using a centralized relational database ensures consistent data management, minimizes duplication, and supports efficient retrieval of sponsorship information across multiple organizational departments.

Workflow Architecture

The proposed TV channel sponsorship and CSR management system implements a structured workflow to automate the entire sponsorship lifecycle, including sponsor registration, CSR program selection, sponsorship approval, online payment processing, financial verification, reporting, and communication.

The process begins when a corporate sponsor registers and provides the required corporate information. After verification, sponsors can browse CSR programs announced by CSR officers and submit sponsorship requests with the required information and supporting documents.

CSR officers review sponsorship requests based on program objectives and eligibility criteria. Once approved, sponsors can make payments through the system. The finance department verifies the payment details before confirming the sponsorship. After successful payment verification, the system updates the sponsorship status, links the sponsor with the selected CSR program, and automatically generates invoices, sponsorship reports, and CSR reports.

The notification service sends confirmation emails to relevant stakeholders, while role-based access control ensures that administrators, CSR officers, finance staff, and sponsors only perform authorized activities.

This workflow reduces manual coordination, improves transparency, minimizes processing delays, and maintains complete records throughout the sponsorship lifecycle.

Role-Based Access Control (RBAC) Architecture

System security and user path security are comprehensively managed by the Microsoft Identity Framework.

Table 1 Complete RBAC Permission and Access Control Matrix

System Controller Actions	Administrator	CSR Officer	Finance Staff	Corporate Sponsor
Manage User Accounts and Roles	Authorized	Denied	Denied	Denied
Manage CSR Programs	Authorized	Authorized	Denied	Denied
Track and Manage Sponsorships	Authorized	Authorized	Denied	Denied
Confirm and Validate Payments	Authorized	Denied	Authorized	Denied
Manage Promotions	Authorized	Authorized	Denied	Denied
Download Program Reports	Authorized	Authorized	Denied	Denied
Download Sponsorship Reports	Authorized	Authorized	Denied	Denied
Download CSR Reports	Authorized	Authorized	Denied	Authorized
Download Finance Reports	Authorized	Denied	Authorized	Denied
View and Manage Sponsor Feedback	Authorized	Authorized	Denied	Denied
Verify Sponsor Feedback	Denied	Authorized	Denied	Denied
Suggest Programs for Sponsors	Denied	Authorized	Denied	Authorized
Browse Available CSR Programs	Denied	Denied	Denied	Authorized
Sponsor CSR Programs	Denied	Denied	Denied	Authorized
Make Sponsorship Payments	Denied	Denied	Denied	Authorized
View Detailed Program Information	Denied	Denied	Denied	Authorized
Track Own Sponsorships	Denied	Denied	Denied	Authorized
Apply for Promotions	Denied	Denied	Denied	Authorized
Receive New Program Notifications	Denied	Denied	Denied	Authorized

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Generate Individual CSR Reports	Denied	Denied	Denied	Authorized
Generate Overall CSR Reports	Authorized	Authorized	Denied	Authorized
Give Feedback on CSR Programs	Denied	Denied	Denied	Authorized

Security Architecture

The proposed platform incorporates multiple security mechanisms to protect corporate information, financial records, and user credentials while ensuring secure communication between stakeholders.

User authentication is implemented using ASP.NET Basic Identity, which provides secure account management, password hashing, role management, and authentication services. Passwords are never stored in plain text; instead, they are securely hashed before being stored in the database, significantly reducing the risk of credential compromise.

User authorization is enforced through a Role-Based Access Control (RBAC) framework. Each authenticated request is validated against predefined authorization policies before access to protected resources is granted. Unauthorized users attempting to access restricted functions are automatically redirected according to system security policies.

The application is designed to run over HTTPS, ensuring encrypted communication between clients and the web server. Secure communication protects sensitive information, including login credentials and financial transaction data, from interception during network transmission.

To mitigate common web application vulnerabilities, Entity Framework Core uses parameterized database queries that reduce the risk of SQL injection attacks. Cross-site request forgery (CSRF) protection is implemented through anti-forgery tokens, and input validation mechanisms minimize the possibility of malicious user input. Output encoding and server-side validation further reduce the risk of cross-site scripting (XSS) attacks.

In addition to authentication and authorization controls, the system maintains audit information for critical business activities, including sponsor approvals, payment verification, report generation, and administrative operations. These audit reports enhance accountability and support organizational oversight by providing a traceable history of significant system events.

Although the proposed platform incorporates multiple security mechanisms suitable for enterprise web applications, future work will investigate advanced security enhancements including multi-factor authentication, encryption of sensitive financial documents at rest, centralized security monitoring, and compliance with emerging data protection regulations.

User Acceptance Testing

User Acceptance Testing (UAT) was conducted to evaluate the usability, functionality and operational suitability of the proposed sponsorship management platform from the perspective of potential end users. The objective of the evaluation was to determine whether the developed system meets the identified functional requirements and provides an effective approach to managing sponsorship-related workflows within television broadcasting organizations.

20 participants were selected using purposive sampling to represent the perspectives of various stakeholders relevant to the proposed system. The participant group included individuals with experience or familiarity with administrative activities, financial processes, corporate operations and digital systems. The sample consisted of five participants representing administrative roles, five participants representing CSR-related activities, five participants with finance-related experience and five potential sponsorship representatives. Some participants were university students with relevant academic knowledge, while others worked in private sector organizations with exposure to business and operational processes. Due to limited access to actual television broadcast employees, the evaluation was conducted using proxy users rather than direct users from a television channel environment.

Prior to the evaluation, participants were given an overview of the research objectives and a presentation demonstrating key system functionalities. Each participant performed predefined tasks based on an assigned user role, including user authentication, browsing CSR programs, submitting sponsorship requests, reviewing approval workflows, simulating payment processing, generating reports, and submitting feedback. Participants independently interacted with the system to assess its usability and functionality.

After completing the assigned tasks, participants completed a structured questionnaire based on a five-point Likert scale, where 1 represented strongly disagree and 5 represented strongly agree. The questionnaire assessed key usability factors

including ease of use, navigation, interface design, system responsiveness, workflow efficiency, information quality, and overall user satisfaction.

Key evaluation criteria included:

- Ease of learning and overall system usability.
- Navigation simplicity and interface consistency.
- Accuracy of supported workflow processes.
- System responsiveness during common tasks.
- Effectiveness of reporting and notification features.
- Overall acceptance of the proposed platform.

The collected responses were analysed using descriptive statistical methods to identify user satisfaction levels and usage trends. The findings provided insight into the functional suitability and user acceptance of the proposed system, highlighting potential areas for future improvement.

However, since the UAT was conducted with representative participants in a controlled test environment rather than actual TV broadcasting organization employees during the live deployment, the results mainly demonstrate the usability, functionality, and technical feasibility of the system. Further evaluation with real organizational users will be required to confirm long-term operational effectiveness.

Performance Evaluation

The performance of the proposed system was evaluated through controlled experiments to assess operational efficiency, responsiveness, and scalability under different user workloads. The performance test simulated common sponsor management activities performed by different user roles.

The evaluation measured key indicators including page response time, sponsor processing time, report generation time, memory usage, and system responsiveness during concurrent access. Load testing was performed using simulated workloads of 10, 50, 100, and 250 concurrent users to assess system stability and scalability.

Each test case was executed multiple times and the average execution times were recorded. The tasks evaluated included user authentication, dashboard loading, CSR program acquisition, sponsorship submission, payment verification, report generation, and notification processing.

The system efficiency was further assessed by comparing the proposed automated workflow with the existing manual sponsorship management process based on document processing time, approval time, report preparation, and administrative workload.

Although the results showed consistent performance under moderate concurrent user activity, the evaluation was conducted in a controlled environment. Therefore, further investigation is required for large-scale deployment with distributed users and cloud-based infrastructure.

2.10. Data Analysis

The collected evaluation data was analysed using descriptive statistical techniques to summarize the results of system performance and user acceptance. The performance test data was analysed using average response times, execution times, memory usage, and workflow completion times across different scenarios.

The UAT responses from the five-point Likert scale questionnaire were analysed using percentages, frequency distributions, and mean satisfaction scores to evaluate user perceptions of system usability, functionality, navigation, and operational efficiency.

A comparative analysis was also conducted between the existing manual sponsorship process and the proposed automated platform to assess the improvements in processing efficiency, report generation, financial verification, and workflow coordination. The results were presented using tables and graphical illustrations for better interpretation.

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The evaluation focused primarily on technical performance and usability. As the system has not yet been deployed in a real television broadcasting organization, further investigation is needed into the long-term organizational impacts such as adoption, return on investment, productivity, and cost-benefit analysis.

Results

System Functional Implementation

The proposed enterprise web application was successfully developed and implemented using ASP.NET Core MVC, Entity Framework Core, and Microsoft SQL Server 2022. The completed platform integrates sponsor management, CSR program administration, financial verification, automated reporting, notification services, and role-based access control into a centralized web application.

The implemented system supports four primary user roles: Administrator, CSR Officer, Finance Staff, and Corporate Sponsor. Each role is provided with dedicated interfaces and functional capabilities according to organizational responsibilities. Role-based authorization successfully restricted unauthorized access while ensuring that users can only perform operations related to their assigned responsibilities.

The implemented modules include user authentication, CSR program management, sponsor application processing, payment verification, invoice generation, automated PDF reporting, sponsor feedback management, promotional campaign management, and email notification services. Figure X depicts the main interfaces of the developed system.

The successful integration of these modules demonstrates that the proposed architecture can effectively automate the entire sponsor lifecycle and reduce the reliance on fragmented manual administrative procedures.

System Performance Evaluation

The performance testing demonstrated that the proposed system maintained stable performance under varying user workloads, providing acceptable response times for common operational tasks. The evaluation included authentication, dashboard loading, sponsorship submission, payment verification, report generation, and notification processing.

Table 2 System Performance and Response Time Evaluation

Simulated Concurrent Users	Average Dashboard Load Time	Sponsorship Search Response Time	PDF Report Generation Time	Peak Memory Usage
10 Users	180 ms	45 ms	210 ms	140 MB
50 Users	295 ms	90 ms	340 ms	190 MB
100 Users	420 ms	155 ms	510 ms	270 MB
250 Users	790 ms	315 ms	890 ms	415 MB

The results show that dashboard loading, sponsorship submission, and report generation were completed within acceptable response times under typical operational conditions. Even under increased concurrent user loads, the application maintained stable performance with a moderate increase in response time.

Load testing involving 10, 50, 100, and 250 concurrent users showed that the application remained stable throughout all test cases. No critical failures or database inconsistencies were observed during the experimental evaluation.

These findings indicate that the proposed architecture is capable of supporting moderate enterprise workloads while maintaining satisfactory system responsiveness.

Operational Efficiency

To evaluate operational improvements, the proposed platform was compared with the existing manual sponsorship management process. The comparison considered several organizational activities including sponsorship request processing, financial verification, report preparation, document management, and stakeholder communication.

The automated workflow significantly reduced administrative effort by eliminating repetitive manual activities such as paper-based documentation, spreadsheet maintenance, and manual report preparation. Automated notifications and

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centralized data management further improved coordination between CSR officers, finance staff, administrators, and corporate sponsors.

Table 3 Manual Workflow vs Automated Workflow Comparison

Operational Task	Traditional Manual Process	Automated System Process
Sponsorship Program Discovery	3–5 Business Days	Less than 2 Minutes
Payment Verification Process	24–72 Hours	Approximately 5 Minutes
CSR Report and Documentation Preparation	7–14 Business Days	Less than 1 Second

Overall, the proposed system demonstrated measurable improvements in workflow efficiency, document accessibility, and administrative coordination when compared to traditional manual procedures.

User Acceptance Testing Results

A user acceptance testing (UAT) was conducted with 20 representative participants to evaluate the usability and functionality of the proposed system.

Participants completed role-specific operational tasks before evaluating the platform using a structured five-point Likert scale questionnaire.

Several usability attributes were assessed during the evaluation, including:

- Ease of use
- Navigation
- Interface design
- Workflow efficiency
- System responsiveness
- Report generation
- Overall satisfaction

Table 4 User Acceptance Testing Results

User Role	Assigned Evaluation Task	Task Success Rate (%)	Average Time to Complete Task	System Errors Encountered
CSR Officer	Create and Publish CSR Program	98%	1.6 Minutes	0–1 minor UI delay
Corporate Sponsor	Browse Programs and Submit Payment	97%	2.1 Minutes	0–1 validation delay
Finance Staff	Verify and Approve Payment	98%	1.7 Minutes	0 Errors
Corporate Sponsor	Download Generated CSR Report	100%	32 Seconds	0 Errors

Overall, participants reported positive perceptions of the system usability and operational efficiency. Most respondents agreed that the platform simplified sponsor management activities and improved accessibility to organizational information. Participants particularly appreciated the centralized dashboard, automated report generation, and simplified sponsor workflow.

No major usability issues were identified, although minor interface improvements were suggested during the evaluation.

Comparative Evaluation

The proposed platform was further compared with existing sponsorship management approaches to evaluate its functional capabilities.

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Unlike manual administrative workflows, the proposed system centralizes sponsorship management, financial verification, CSR administration, and reporting within a unified enterprise platform. In comparison to typical project management tools and customer relationship management systems, the proposed solution provides specialized functionality designed specifically for television broadcasting organizations.

Table 5 Functional and Strategic Comparative Matrix

Feature	Manual Process	ERP	CRM	Trello/Asana	Proposed System
Sponsorship Lifecycle	✗	Partial	Partial	✗	✓
CSR Management	✗	Partial	✗	✗	✓
Financial Verification	✗	Partial	✗	✗	✓
Role-Based Workflow	✗	✓	✓	Partial	✓
Automated Reports	✗	Partial	Partial	✗	✓
Email Notifications	✗	Partial	Partial	Partial	✓
Payment Verification	✗	Partial	✗	✗	✓

The comparison demonstrates that the proposed system uniquely integrates sponsorship lifecycle management, CSR administration, financial control, automated reporting, notification services, and role-based workflow management into a single integrated application.

3.6. Summary of Key Performance Indicators

The key performance results obtained during the system evaluation are summarized below:

- Successful implementation of six integrated enterprise modules supporting sponsor lifecycle management.
- Stable system performance under workloads of up to 250 concurrent users.
- Improved workflow efficiency through sponsor processing automation and financial verification.
- Positive user acceptance based on UAT evaluation involving 20 representative participants.
- Successful implementation of on-premise security, automated reporting, and notification services.

Overall, the evaluation demonstrates that the proposed enterprise platform provides a technically feasible solution for sponsor management within television broadcasting organizations while successfully meeting the functional requirements identified during the system design process.

Discussion

Key Findings

The primary objective of this research was to design, develop, and evaluate a role-based enterprise web application capable of automating sponsorship management, financial control, and corporate social responsibility (CSR) workflows within television broadcasting organizations. The evaluation demonstrated that the proposed platform successfully integrates the entire sponsorship lifecycle into a centralized enterprise information system while improving workflow automation, information accessibility, and administrative coordination.

The implementation of ASP.NET Core MVC, Entity Framework Core, and Microsoft SQL Server provided a stable and modular architecture that effectively supported the functional requirements identified during the system analysis phase. Performance testing under simulated operational workloads of up to 250 concurrent users demonstrated satisfactory response times, and user acceptance testing demonstrated positive user perceptions of usability, workflow efficiency, and overall system performance.

The findings suggest that integrating sponsor management, financial verification, automated reporting, and stakeholder communication into a single platform can reduce administrative complexity and improve organizational coordination.

However, these findings represent the results of a controlled trial rather than a long-term deployment within an operational broadcast organization.

Comparison with Existing Studies

The findings of this study are consistent with previous research that shows that enterprise information systems improve organizational efficiency through workflow automation and centralized information management. Previous studies have shown that digital transformation enables organizations to reduce manual administrative activities, improve data accessibility, and strengthen decision-making through integrated information systems.

Unlike most existing enterprise solutions that focus primarily on customer relationship management or financial administration, the proposed platform integrates sponsor lifecycle management, CSR program administration, financial verification, automated reporting, and stakeholder communication in a single enterprise application. Typical project management tools, including Trello and Asana, provide task management capabilities but lack the specialized functions required for sponsor governance, financial verification, and CSR reporting. Similarly, traditional CRM and ERP systems offer extensive organizational management features but typically require significant customization to support sponsor-specific workflows within television broadcasting organizations.

Therefore, this research extends the existing work by presenting a specialized enterprise solution tailored to the operational needs of television broadcasting organizations, integrating multiple organizational functions into a unified platform.

Practical Implications

The proposed platform is of practical importance for television broadcasting organizations seeking to modernize sponsorship management and CSR administration. By replacing fragmented manual processes with a centralized web-based platform, organizations can improve coordination between CSR officers, finance officers, administrators, and corporate sponsors.

Implementing automated sponsorship workflows reduces repetitive administrative tasks, minimizes document duplication, and improves the availability of corporate information. Automated report generation further reduces the time required to prepare sponsorship documents, invoices, and CSR reports while improving compliance across corporate records.

The role-based workflow implemented within the platform strengthens corporate governance by ensuring that financial verification, sponsorship approval, and administrative tasks are segregated according to corporate responsibilities. This separation of duties improves operational accountability and reduces the potential for unauthorized system activity.

Although the system was designed specifically for television broadcasting organizations, the underlying architecture can also be adapted for other organizations that administer sponsorship programs, CSR initiatives, or grant administration through structured approval workflows.

Implementation Challenges

Although the proposed platform demonstrated positive performance in the controlled evaluation, several implementation challenges need to be considered before organizational deployment.

Appropriate staff training is required to ensure that users are familiar with the new digital workflow to successfully use the platform. Organizations migrating from paper-based or spreadsheet-based processes may initially experience organizational resistance to change, requiring effective change management strategies and user support.

Migrating from existing legacy systems can also present challenges, especially when historical sponsor records are stored across multiple disconnected databases or manual document systems. Therefore, careful planning and data validation procedures will be required during implementation.

Furthermore, integration with existing accounting software, enterprise resource planning systems, or corporate financial management applications may require additional software development, depending on the technological infrastructure of the adopting organization.

Scaling Considerations

Performance evaluation demonstrated stable performance under simulated workloads of up to 250 concurrent users. These results indicate that the proposed platform is technically capable of supporting medium-sized enterprise environments, but larger broadcast organizations may require additional scaling mechanisms.

Future production deployments could take advantage of cloud-based infrastructure using platforms such as Microsoft Azure or Amazon Web Services (AWS), which enable automated resource allocation, database replication, and load balancing to support significantly larger user populations. Container technologies such as Docker and orchestration platforms such as Kubernetes can further improve deployment flexibility, fault tolerance, and system availability.

The modular architecture developed using ASP.NET Core MVC facilitates future migration towards distributed or microservices-based architectures if organizational requirements continue to expand.

Limitations

Several limitations should be acknowledged when interpreting the findings of this research.

First, the proposed platform was evaluated in a controlled experimental environment rather than in a long-term deployment in an operating television broadcasting organization. As a result, the reported improvements reflect technical performance and simulated workflow efficiency rather than measured organizational productivity.

Second, twenty representative participants were involved in the user acceptance test. Although this sample was sufficient for the initial usability evaluation, a larger group of participants representing multiple broadcasting organizations would improve the generalizability of the findings.

Third, performance testing was conducted using simulated concurrent user workloads. Real-world operational environments may introduce additional network latency, infrastructure limitations, and organizational factors that are beyond the scope of this study.

Fourth, sponsor payment verification remains a semi-manual process that requires confirmation by finance staff. Direct integration with online payment gateways was not implemented during the current study.

Finally, although the platform is designed to support corporate documentation related to financial control and audit readiness, validation by tax professionals or external auditors was beyond the scope of this research. Therefore, potential improvements related to tax compliance should be interpreted as expected organizational benefits rather than experimentally verified outcomes.

Future Research

There are several opportunities for expanding the proposed platform in future studies.

Artificial Intelligence (AI) and machine learning techniques could be incorporated to recommend suitable sponsors based on organizational needs, historical sponsor behavior, and CSR objectives. Predictive analytics could further assist broadcasting organizations in forecasting sponsor demand, identifying funding opportunities, and supporting strategic planning.

Future versions of the platform could integrate secure online payment gateways to automate financial verification and reduce manual intervention. Cloud-native deployment using scalable infrastructure could improve system availability and support geographically distributed users.

Blockchain technology represents another promising area for future research by providing immutable audit trails for sponsor transactions, financial records, and CSR reporting. Additionally, developing mobile applications for Android and iOS devices can improve accessibility for sponsors and corporate staff operating in remote environments.

Long-term corporate deployment involving multi-broadcast organizations will also enable a comprehensive evaluation of stakeholder satisfaction, corporate adoption, cost-benefit analysis, maintainability, and operational impact over time.

Conclusion

This research presented the design, development, and evaluation of a role-based enterprise web application for automating sponsorship management, financial control, and corporate social responsibility (CSR) workflows in television broadcasting organizations. The proposed platform was developed using ASP.NET Core MVC, Entity Framework Core, and Microsoft SQL Server 2022, and provides a centralized architecture that integrates sponsorship lifecycle management, financial verification, automated reporting, stakeholder communication, and role-based access control into a unified enterprise information system.

The evaluation demonstrated that the proposed platform successfully met the identified functional requirements while improving workflow automation, information accessibility, and administrative coordination under controlled experimental conditions. Performance testing demonstrated stable system performance under simulated workflows of up to 250 concurrent users, while user acceptance testing involving 20 representative participants demonstrated positive perceptions of usability, functionality, workflow efficiency, and overall user satisfaction. These findings indicate that the proposed system is technically feasible to support sponsorship management activities within television broadcasting organizations.

A significant contribution of this research is the development of a specialized sponsorship management platform that goes beyond the capabilities of traditional project management, CRM, and ERP solutions, by integrating sponsorship lifecycle management, CSR administration, financial control, automated PDF reporting, and stakeholder communication within a single web-based application. The implementation of role-based access control (RBAC) further strengthens organizational governance by enabling segregation of duties, improving information security, and supporting accountability throughout the sponsorship approval process.

Despite these positive results, the study has several limitations. The evaluation was conducted in a controlled experimental environment, not within an operating broadcast organization, and therefore the improvements reported primarily reflect technical performance and workflow efficiency under simulated conditions. In addition, the relatively small user acceptance test sample and the lack of direct integration with online payment gateways and external accounting systems limit the generalizability of the findings. Furthermore, the platform was designed to support financial control and audit readiness, and its contribution to tax compliance has not been formally validated by finance or regulatory professionals.

Future research should focus on validating the platform through long-term deployment within operating broadcast organizations to evaluate organizational adoption, stakeholder satisfaction, maintainability, and cost-effectiveness. Additional enhancements may include AI-powered sponsor recommendation, predictive sponsor analytics, cloud-native deployment, secure payment gateway integration, blockchain-enabled audit trails, and mobile app development. These enhancements have the potential to further improve organizational efficiency, scalability, and digital transformation within the media broadcasting sector.

Overall, this research demonstrates that a centralized, role-based enterprise information system can effectively support sponsor management, CSR administration, and financial control within television broadcasting organizations. By integrating multiple organizational processes into a single secure platform, the proposed solution contributes to the advancement of enterprise information systems for the media industry while providing a practical foundation for future digital transformation initiatives.

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References

[1] A. Carrol, "Corporate social responsibility: Evolution of a definitional construct," 1999.

[2] D. A. Medis, "Impact of Corporate Social Responsibility on Corporate Brand," *Sri Lanka Journal of Marketing,* vol. 4, no. 1, p. 24, 2018.

[3] S. Uhrich, "Leveraging sponsorship with corporate social responsibility," *Journal of Business Research,* vol. 64, no. 4, p. 7, 2014.

[4] G. D. a. R. Shakya, "Studocu," 2020. [Online]. Available: https://www.studocu.com/row/document/tribhuvan-vishwavidalaya/bachelors-of-computer-application/project-i-sponsorship-management-system/70041485/.

[5] W. Weerakoon, "UCSC Event Management System," B.Sc. Thesis, University of Colombo School of Computing B.Sc. Thesis, University of Colombo School of Computing, Colombo, 2018.

[6] Rinat Khatipov,Manuel Mazzara,Victor Rivera,Anvar Zakirov,Ilgiz Zamaleev, "Hikester - the event management application," arxiv, 2018.

[7] Tushar Maurya, Surya Prakash Singh, Sarvajeet Chauhan, Suraj Gupta, Mr. Harendra Singh, Dr. Saumya Chaturvedi, Dr. Suresh Wati, "Event Planning Platform Powered by Artificial Intelligence," *International Journal for Research in Applied Science & Engineering Technology (IJRASET),* vol. 13, no. 4, p. 6, 2025.

[8] H. Klaus, M. Rosemann, and G. Gable, "What is ERP?," *Information Systems Frontiers,* 2000.

[9] A. Payne and P. Frow, "A strategic framework for customer relationship management," *Journal of Marketing,* 2005.

[10] M. D. e. al, "Fundamentals of Business Process Management," Springer, 2018.

[11] R. S. e. al, "Role-based access control models," 1996.

[12] A. Freeman, "Pro ASP.NET Core MVC," Apress, 2022.

[13] Velicko and Walber, "Conceptual design of an automated logistics system applied to the furniture industry," *Research, Society and Development,* vol. 11, no. 2022, p. 11, 2022.

[14] H. Weerakoon, "Event Management System for," ucsc, 2018.

[15] M. P. P. Zaw, "Web-Based Event Management System (EMS)," *Best International Journal,* vol. 3, no. 2019 June, pp. 1640-1643, 2019.

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AI-Generated Phishing Attacks and Intelligent Defence Mechanisms: A Comparative Review

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Abstract

Background: The proliferation of generative artificial intelligence has reshaped the cybersecurity threat landscape. Large language models such as ChatGPT now allow threat actors to produce highly convincing, personalized phishing content at a scale and speed that traditional rule-based and signature-based detection systems struggle to match. Industry reports describe a rise of over 1,265% in AI-linked phishing since 2023, with AI-generated content now present in more than 82% of phishing emails.

Objectives: This review compares the offensive capabilities of generative AI in producing phishing attacks against the defensive capabilities of AI-driven detection systems, with the specific aim of identifying where research gaps and implementation shortfalls leave organizations exposed.

Methods: A structured narrative review of peer-reviewed literature (2021–2025) from IEEE Xplore and Springer was combined with an analysis of industry threat-intelligence reports and documented case studies. Screening followed defined inclusion and exclusion criteria, and findings were synthesized comparatively across attack techniques, defence mechanisms, and reported performance.

Results: AI-generated phishing emails achieved a click-through rate of approximately 54%, compared with 12% for conventional phishing. AI-based detection models, including transformer-based and hybrid machine learning–deep learning frameworks, reported detection accuracies above 98% in experimental settings, though these figures are not directly comparable across studies due to differing datasets and evaluation protocols. A persistent gap remains between the pace of offensive innovation and defensive deployment.

Conclusion/s: AI is a dual-use technology in cybersecurity: it expands the scale and sophistication of phishing attacks while simultaneously offering powerful tools for their detection. Closing the offensive-defensive gap will require adaptive, governance-aware security frameworks rather than static detection systems.

Keywords: *artificial intelligence, cybersecurity, deep learning, large language models, phishing detection*

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Introduction

The rapid advancement of artificial intelligence has brought transformative changes across numerous domains, including cybersecurity. While AI offers significant benefits in automating tasks, enhancing decision-making, and improving system efficiency, it has simultaneously introduced new and sophisticated threat vectors. Among the most alarming developments is the exploitation of large language models such as OpenAI's ChatGPT and Google's Bard to orchestrate highly convincing phishing attacks. These technologies have fundamentally lowered the technical barrier for cyber criminals, enabling the mass production of personalized, grammatically flawless, and contextually relevant phishing content at unprecedented scale.

Phishing, which involves deceiving individuals into revealing sensitive information or credentials through fraudulent communications, has long been one of the most prevalent forms of cybercrime. Traditionally, phishing emails were relatively easy to identify due to poor grammar, generic messaging, and obvious formatting errors. The integration of generative AI has drastically altered this landscape: reports from cybersecurity organizations describe a surge of over 1,265% in AI-generated phishing content since 2023. This dramatic escalation underscores the urgency of re-evaluating existing cybersecurity frameworks.

Existing defence mechanisms, largely built on rule-based filtering, signature matching, and static heuristics, are increasingly inadequate in addressing the dynamic and adaptive nature of AI-generated phishing. These conventional systems struggle to detect threats that continuously evolve in linguistic sophistication and targeting precision. As a result, there is growing scholarly and industry interest in AI-driven defence mechanisms capable of matching the capabilities of AI-powered attackers. Machine learning and deep learning approaches, including transformer-based architectures such as BERT and hybrid ML-DL frameworks, have demonstrated considerable promise in phishing detection tasks.

Despite this progress on the defensive side, a critical asymmetry persists: offensive AI capabilities appear to be evolving faster than the deployment of corresponding defensive technologies. This gap creates windows of vulnerability that threat actors continue to exploit. Bridging this disparity requires not only more robust detection systems but a deeper comparative understanding of both offensive techniques and defensive frameworks as they currently stand in the literature.

A number of existing reviews have examined AI-enabled phishing or AI-based detection in isolation, but few have placed offensive and defensive capabilities side by side within a single comparative frame, and fewer still account for the most recent generation of large language model-driven attacks, including tools such as WormGPT and FraudGPT that were purpose-built for cybercrime. This review differs from earlier surveys in that it treats the offensive and defensive literatures as two sides of the same evolving contest, using that comparison specifically to surface where defensive research and organizational deployment are falling behind, rather than simply cataloguing techniques on either side.

This study therefore aims to: 1) examine how AI technologies, particularly LLMs, are exploited to generate sophisticated phishing attacks; 2) evaluate the effectiveness of AI-driven defence mechanisms in countering such threats; and 3) identify existing gaps between offensive AI capabilities and current defensive strategies, including where these gaps translate into practical implementation and policy shortfalls for organizations. By offering a structured comparative review, this study seeks to contribute actionable insights for researchers, cybersecurity practitioners, and organizations navigating this rapidly evolving threat landscape.

Methods

Study Design: This study adopted a mixed-method approach, integrating a structured literature review with the analysis of documented real-world case studies. This design was selected to enable both a broad synthesis of academic knowledge and a grounded understanding of how AI-generated phishing and AI-based defences manifest in practice.

Sources and Search Strategy: Peer-reviewed publications published between 2021 and 2025 were retrieved from IEEE Xplore and Springer. These two databases were selected for their strong coverage of computer science, cybersecurity, and applied machine learning research directly relevant to this review's scope. Scopus, the ACM Digital Library, and Web of Science were not searched directly; this reflects the resource constraints of a single-reviewer narrative review rather than a judgement that these databases are less relevant, and their exclusion is acknowledged as a limitation of search coverage (see Limitations). In addition, cybersecurity threat intelligence reports from organizations such as Slash Next, Barracuda Networks, and IBM Security were consulted to capture industry-level evidence. Search terms used included combinations

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of "phishing detection machine learning," "AI phishing," "LLM phishing attacks," "generative AI cybersecurity," and "transformer-based phishing detection."

Study Selection and Screening: Records identified through database searching and the supplementary industry sources listed above were screened first by title and abstract, then by full text, against the inclusion and exclusion criteria below. Figure 1 summarizes this process. As the review was conducted by a single author, no formal inter-reviewer agreement statistic could be calculated; screening decisions were instead revisited in a second pass against the stated criteria to check internal consistency. The absence of a second independent reviewer is acknowledged as a limitation of the study selection process.

Table 1 — Study identification and screening process

Stage	Description	Records (n)
Identification	Records identified through IEEE Xplore, Springer, and industry threat-intelligence sources	74
Duplicates removed	Duplicate records removed before screening	61
Title/abstract screening	Records screened against inclusion/exclusion criteria	61
Full-text assessment	Full-text articles assessed for eligibility	38
Included in review	Studies and reports included in the final synthesis	15

Inclusion and Exclusion Criteria: Studies were included if they: a) were published in English between 2021 and 2025; b) addressed AI-generated phishing techniques or AI-based phishing detection systems; and c) were published in peer-reviewed journals, conference proceedings, or credible threat intelligence outlets. Studies were excluded if they focused solely on non-AI phishing methods, were unavailable in full text, or were published prior to 2021, in order to preserve relevance to the current generative AI era.

Results

AI-Generated Phishing Attack Capabilities. The review of literature and threat intelligence reports consistently demonstrated that LLM-powered phishing attacks significantly outperform traditional phishing in terms of effectiveness. AI-generated phishing emails recorded a click-through rate of approximately 54%, compared with just 12% for conventional phishing emails. This disparity is largely attributed to the ability of LLMs to generate contextually relevant, grammatically correct, and personalized content that closely mimics legitimate communications. Tools such as ChatGPT and WormGPT — a malicious LLM developed specifically for cybercrime — have been documented generating spear-phishing emails, business email compromise attacks, and voice phishing scripts with minimal human input.

Furthermore, AI enables attackers to conduct large-scale reconnaissance by scraping publicly available information from social media, corporate websites, and professional networks, which is then used to personalize attacks at scale. This approach, previously limited to well-resourced threat actors, is now accessible to low-skill adversaries due to the democratization of generative AI tools.

Table 2 — Comparison of AI-generated vs traditional phishing.

Metric	Traditional Phishing	AI-Generated Phishing
Click-through rate	~12%	~54%

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Personalization level	Low	High
Skill required	Moderate	Low
Scale of attack	Limited	Mass
Grammar/authenticity	Often poor	Highly convincing

Table 3 — AI tools used in phishing attacks.

Tool	**Type**	**Capabilities**	**Availability**
ChatGPT	General LLM	Spear-phishing, BEC drafting	Public
WormGPT	Malicious LLM	Cybercrime-specific content generation	Dark web
FraudGPT	Malicious LLM	Phishing kits, fake pages	Dark web

AI-Based Defence Mechanisms. On the defensive side, AI-based detection models have demonstrated substantial promise. Transformer-based architectures, particularly BERT and its variants, have achieved detection accuracies exceeding 98% in controlled experimental settings. Hybrid ML-DL frameworks that combine traditional feature engineering with deep learning classification have also shown robust performance, particularly in detecting novel phishing variants not present in training datasets. Natural language processing techniques are increasingly used to analyses email semantics, sender behaviour patterns, and URL structures, moving beyond simple keyword or blacklist-based detection.

Table 4 — AI-based detection models: performance summary.

Model/Approach	**Architecture**	**Detection Accuracy**	**Limitation**
BERT-based classifier	Transformer	>98%	Lab-only performance
Hybrid ML-DL framework	CNN + feature engineering	~95–97%	Dataset dependency
Behavioural analytics	Anomaly detection	Varies	High false-positive rate
Multi-modal system	Ensemble	Highest coverage	High computational cost

These accuracy figures should be interpreted with caution. They are drawn from studies that differ in datasets, feature engineering choices, and evaluation protocols, so a reported accuracy of 98% in one study is not necessarily comparable to a similar figure reported elsewhere. Direct cross-study benchmarking remains an open methodological challenge in this literature, and future work would benefit from shared, standardized evaluation datasets (see Discussion).

Behavioural analytics and anomaly detection systems represent another layer of AI-driven defence, flagging deviations in communication patterns that may indicate compromised accounts or impersonation attempts. Multi-modal detection systems that integrate email content analysis, metadata examination, and link analysis have demonstrated the most comprehensive coverage against AI-generated threats.

The Offensive-Defensive Gap. Despite the strong performance of AI-based detection systems in research settings, a critical gap persists between laboratory results and real-world deployment. Offensive tools continue to evolve rapidly, with adversarial techniques such as prompt injection, style mimicry, and evasion strategies designed specifically to bypass AI classifiers emerging in recent literature. Defensive models trained on historical phishing datasets are often slow to adapt to

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newly generated attack patterns, creating exploitable windows. Organizational adoption of AI-native security frameworks also remains inconsistent, with many institutions continuing to rely on legacy detection infrastructure.

Table 5 — Comparative synthesis of AI-driven attack techniques and defence mechanisms.

AI Attack Technique	Corresponding Defence Mechanism	Typical Datasets	Reported Performance	Key Advantage	Key Limitation	Deployment Readiness
LLM-generated spear phishing (ChatGPT, WormGPT)	Transformer-based classifiers (BERT variants)	Public phishing corpora, synthetic LLM outputs	>98% (lab)	High accuracy on known patterns	Weak generalization to unseen prompts	Emerging — pilot stage
Automated OSINT-driven personalization	Behavioural/anomaly analytics	Enterprise email + user Behaviour logs	Varies	Detects account compromise, not just content	High false-positive rate	Partially deployed in SOCs
Business email compromise, voice phishing	Hybrid ML-DL frameworks	Mixed labelled email datasets	~95–97%	Robust to novel variants	Dependent on training data diversity	Moderate — vendor products exist
Evasion, prompt injection, style mimicry	Multi-modal ensemble detection	Combined content + metadata + link data	Highest coverage (lab)	Broadest detection surface	High computational cost	Early — mostly research stage

Comparative Synthesis of Attack and Defence Techniques. Table 5 draws together the attack techniques and corresponding defence mechanisms discussed above, alongside their typical datasets, reported performance, principal advantage, principal limitation, and an approximate indication of real-world deployment readiness based on the literature reviewed.

Discussion

The findings of this review highlight a cybersecurity landscape in a state of dynamic tension, where AI simultaneously serves as a tool for both attack and defence. The dramatic increase in the effectiveness of AI-generated phishing — evidenced by the 54% versus 12% click-through rate differential — underscores a fundamental shift in the threat model organizations must contend with. The ease with which LLMs can generate convincing, targeted communications at scale represents a qualitative change in the nature of phishing, not merely an incremental improvement.

Critical Analysis of Detection Model Trade-offs. The strong performance of transformer-based and hybrid ML-DL models in detection tasks is encouraging, but these results must be interpreted alongside their practical trade-offs. Transformer-based classifiers offer high accuracy on the patterns they have seen, yet their computational demands — both for training and for real-time inference at email-gateway scale — are considerably higher than legacy rule-based filters, which raises deployment cost as a real barrier for smaller organizations. Robustness against adversarial manipulation is a further concern: prompt injection, paraphrasing, and deliberate style mimicry are increasingly documented as ways of pushing phishing content just outside a classifier's learned decision boundary, and this adversarial robustness remains comparatively under-studied next to raw accuracy reporting. Explainability is a related weakness — deep learning classifiers largely function as black boxes, which complicates both analyst trust and, in regulated sectors, the ability to justify why a message was blocked or flagged; post-hoc interpretability techniques such as LIME and SHAP have been proposed as partial mitigations, but their

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application to phishing-specific models is still limited. Taken together, model selection in this space is less a question of which architecture reports the highest laboratory accuracy, and more a question of where an organization is willing to trade accuracy against cost, latency, robustness, and interpretability.

Real-World Deployment Challenges. Several practical obstacles limit the translation of strong laboratory results into effective real-world protection. Widespread use of end-to-end encryption on messaging and, increasingly, on email content restricts the ability of centralized, content-scanning defences to inspect messages at all, pushing detection toward endpoint- or client-side approaches that carry their own resource and privacy implications. Privacy-preserving approaches, such as federated learning, allow detection models to be trained across organizational data without centralizing sensitive email content, and represent a promising though still emerging direction for this constraint. Computational resource requirements for transformer and ensemble models remain non-trivial at the scale of enterprise email traffic, and high false-positive rates — a recurring limitation in Table 3 — contribute to analyst fatigue and can erode user trust in automated flagging over time. Enterprise adoption is further slowed by the cost and complexity of replacing legacy detection infrastructure, and by regulatory compliance obligations: content-scanning systems that process personal or sensitive communications must be designed with data protection requirements such as the GDPR in mind, which constrains how and where email content can be analysed and stored.

Policy, Governance, and Organizational Implications. Beyond the technical layer, the offensive-defensive gap identified in this review is also a governance problem. Frameworks such as the NIST AI Risk Management Framework offer organizations a structured way to assess and manage the risks introduced by deploying AI-based security tools, including questions of accountability when an automated system misclassifies a message. Responsible deployment also carries legal implications: automated blocking or flagging of communications can affect employees and customers, and organizations need clear policies on oversight, appeal, and data handling. Workforce training remains essential, since even sophisticated AI-based detection systems benefit from informed end users who serve as an additional line of defence, particularly against attacks crafted to evade automated filters entirely. Practically, integrating AI-driven phishing detection into existing Security Operations Centres, Zero Trust architectures, and incident response workflows — rather than treating it as a bolt-on tool — offers a more coherent path to closing the gap between what detection models can do in research settings and what organizations actually deploy.

Future Research Directions. Building on the gaps identified above, several directions merit further investigation: adversarial robustness evaluation under realistic evasion conditions rather than static test sets; explainable AI methods tailored specifically to phishing detection rather than adapted generically; real-time adaptive detection capable of responding to newly released generative models; multimodal phishing detection that combines text, sender metadata, and visual page analysis; retrieval-augmented approaches that ground detection decisions in up-to-date threat intelligence; federated cybersecurity architectures that preserve data privacy across organizations; autonomous AI security agents capable of triaging and responding to incidents with limited human intervention; and the development of standardized, shared benchmark datasets that would finally make cross-study accuracy comparisons — currently a weakness of this literature — meaningful.

Limitations

This review has several limitations that should be considered when interpreting its findings. The literature search was restricted to IEEE Xplore and Springer; relevant work indexed only in Scopus, the ACM Digital Library, or Web of Science may therefore have been missed, and this restricted database coverage is a limitation of search comprehensiveness rather than of the underlying evidence base. The review was conducted by a single author, so study selection did not benefit from a second independent reviewer or a formal inter-rater agreement statistic, and screening consistency was instead checked through a second internal pass. Inclusion was limited to English-language sources, which may exclude relevant regional threat intelligence, and the review draws on a mix of peer-reviewed literature and industry threat-intelligence reports, the latter of which are not peer-reviewed and may carry vendor-specific framing or commercial bias. Publication bias is also a concern, as studies reporting strong detection performance are more likely to be published than those reporting negative or inconclusive results. Finally, given the pace at which generative AI models are released and updated, findings drawn from the 2021–2025 literature may date quickly, and conclusions about relative offensive and defensive capability should be understood as a snapshot rather than a stable state of the field.

Conclusions

This study has provided a comparative review of AI-generated phishing attacks and AI-driven defence mechanisms, drawing on peer-reviewed literature and industry threat intelligence from 2021 to 2025. The findings confirm that generative AI and large language models have fundamentally transformed the phishing threat landscape, enabling attacks of unprecedented sophistication, personalization, and scale. Simultaneously, AI-based detection frameworks — particularly transformer-based and hybrid ML-DL models demonstrate strong potential in countering these threats, with detection accuracies exceeding 98% in experimental settings, though these figures are not directly comparable across studies and should be read with that caveat in mind.

However, a critical and growing gap exists between offensive and defensive AI capabilities. Offensive tools evolve rapidly and increasingly incorporate evasion strategies, while defensive deployments remain inconsistent, often reactive, and constrained by cost, explainability, and regulatory factors. Organizations must priorities the adoption of AI-native, adaptive security frameworks guided by governance frameworks such as the NIST AI RMF and integrated into existing SOC and Zero Trust workflows that combine continuous learning, Behavioural analytics, and multi-modal detection to address this evolving threat. Future research should focus on adversarial robustness, real-world deployment evaluation, explainability, and the development of standardized benchmarks for AI-generated phishing detection, so that the offensive-defensive gap identified in this review can be narrowed rather than simply documented.

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References

1. Hazell J. Large language models can be used to effectively scale spear phishing campaigns. arrive. 2023. Available from: https://arxiv.org/abs/2305.06972
2. Slash Next. The state of phishing 2023. Slash Next Threat Intelligence Report. 2023.
3. Basit A, Zafar M, Liu X, Javed AR, Jalil Z, Kifayat K. A comprehensive survey of AI-enabled phishing attacks detection techniques. Telecommand Syst. 2021;76(1):139–154.
4. Devlin J, Chang MW, Lee K, Toutanova K. BERT: pre-training of deep bidirectional transformers for language understanding. Proc NAACL. 2019:4171–4186.
5. Barracuda Networks. Spear phishing: top threats and trends. Barracuda Threat Spotlight Report. 2023.
6. Mulgrew J. WormGPT — the generative AI tool cybercriminals are using to launch business email compromise attacks. SlashNext Blog. 2023.
7. Bethany M, Bhatt P, Heydari A, Chen PY, Sundaram H, Prakash B. Large-scale AI-driven phishing simulations and evaluations. arXiv. 2024. Available from: https://arxiv.org/abs/2406.00972
8. Alam MN, Sarma D, Islam MM, Iqbal I, Hossain MI, Molla MI. Phishing attacks detection: a machine learning-based approach. Proc IEEE. 2022.
9. Bahnsen AC, Torroledo I, Camacho LD, Villegas S. DeepPhish: simulating malicious AI. Proc APWG eCrime. 2018.
10. Dou Z, Khalil I, Khreishah A, Al-Fuqaha A. Systematization of knowledge: designing and deploying defences for adversarial machine learning. IEEE Access. 2023;11:36622–36651.
11. Greshake K, Abdelnabi S, Mishra S, Endres C, Holz T, Fritz M. Not what you've signed up for: compromising real-world LLM-integrated applications with indirect prompt injection. Proc AISec Workshop. 2023.
12. IBM Security. Cost of a data breach report 2023. IBM Corporation. 2023.
13. Ribeiro MT, Singh S, Guestrin C. "Why should I trust you?": explaining the predictions of any classifier. Proc ACM SIGKDD Int Conf Knowl Discov Data Min. 2016:1135–1144.
14. Lundberg SM, Lee SI. A unified approach to interpreting model predictions. Adv Neural Inf Process Syst. 2017;30.
15. McMahan HB, Moore E, Ramage D, Hampson S, y Arcas BA. Communication-efficient learning of deep networks from decentralized data. Proc 20th Int Conf Artif Intell Stat. 2017:1273–1282.

16. Lewis P, Perez E, Piktus A, et al. Retrieval-augmented generation for knowledge-intensive NLP tasks. Adv Neural Inf Process Syst. 2020;33:9459–9474.

17. Rose S, Borchert O, Mitchell S, Connelly S. Zero trust architecture. NIST Special Publication 800-207. 2020.

18. National Institute of Standards and Technology. Artificial intelligence risk management framework (AI RMF 1.0). NIST AI 100-1. 2023.

19. European Parliament and Council. Regulation (EU) 2016/679 (General Data Protection Regulation). Official Journal of the European Union. 2016.

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EP 20

Evaluating Quantum Search Efficiency in Degraded Indexing Environments for Large-Scale Data Retrieval

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Abstract

This study presents an empirical comparison of classical and quantum search algorithms on an identical 1,000,000-integer synthetic dataset. Classical benchmarks TimSort, Merge Sort, NumPy sort, linear search, binary search, and Google BigQuery SQL operations established a comprehensive baseline. Grover's Search and QAOA were executed on a noiseless Qiskit Aer simulator and on IBM real quantum hardware (ibm_marrakesh, 127-qubit Eagle r3) via Qiskit Runtime. Three improvement strategies were subsequently tested: 3-qubit Grover (circuit depth reduction), QAOA p=4 with five multi-restart COBYLA optimisations, and Zero Noise Extrapolation (ZNE) via gate folding at three noise scales. The simulator achieved 99.8% success (95% Wilson CI: 99.3-99.9%) on 1,024 items using 25 oracle queries versus 1,024 classical comparisons, a 41× reduction directly measured at this scale and confirming O(√n) query complexity; the corresponding 1,272× reduction at n = 1,000,000 is an extrapolation from this measured scaling, not a directly observed result. On hardware, 45.1% success (95% Wilson CI: 42.1-48.2%, n = 1,024 shots) was recorded against a 6.25% random baseline, demonstrating that quantum interference survives partial decoherence (7.2× above chance). Circuit depth inflated from 52 to 438 gates during transpilation, identifying this overhead as the primary NISQ bottleneck. QAOA improvement raised hardware success from 15.6% to 36.9%. ZNE characterised the zero-noise performance ceiling at 14.6%, though with only three noise-scale points the linear and quadratic fits cannot be statistically distinguished, so this figure should be read as illustrative rather than conclusive. Wall-clock time on current hardware (6.6-9.8 s, dominated by IBM queue latency) remained substantially slower than classical search (0.07-372.5 ms); only oracle-query complexity, not execution time, was experimentally improved. The findings confirm that the quadratic oracle-query speedup is experimentally verified at the tested scale, noise is an engineering barrier rather than a fundamental limit, and ZNE provides a principled (if currently under-sampled) tool for quantifying that barrier.

Keywords: *Grover's algorithm, QAOA, quantum search, IBM quantum hardware, NISQ, zero noise extrapolation, BigQuery, classical-quantum benchmarking, Qiskit Runtime*

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Introduction

Motivation and Context

The scale at which digital data is generated and queried continues to grow at a rate that challenges the foundational assumptions of classical algorithm design. Enterprise databases routinely exceed billions of rows, and even highly optimised distributed systems such as Google BigQuery must perform full column scans when data is unstructured or insufficiently indexed. Classical linear search operates at O(n) complexity, meaning that doubling the dataset size doubles the search cost regardless of hardware improvements. Binary search reduces this to O(log n), but only on sorted or indexed data - a precondition that is often unavailable in real-world unstructured retrieval contexts. Quantum computing offers a theoretically compelling alternative. Grover's algorithm, introduced in 1996, achieves an O(√n) query complexity for unstructured search - a quadratic speedup over classical linear search that, at enterprise scale, translates to orders-of-magnitude reductions in oracle queries. At one million items, Grover's algorithm requires only approximately 786 oracle queries compared to Evaluating Quantum Search Efficiency in Degraded Indexing Environments - Page 3 1,000,000 classical comparisons - a reduction factor of 1,272×. The theoretical case is well-established. The experimental reality on current hardware is not. Most comparative studies of quantum and classical search either rely entirely on simulation or restrict hardware testing to idealised conditions. This study deliberately departs from that approach. The central design choice was to run identical search tasks on the same 1,000,000-integer dataset on a production-grade classical cloud system (Google BigQuery) and on hardware (ibm_marrakesh), not a simulator. This choice exposes the gap between theoretical quantum speedup and what current Noisy Intermediate-Scale Quantum (NISQ) devices can actually deliver, enabling a quantified, honest assessment of where that gap comes from.

Prior comparative studies typically combine at most two of the following: a classical baseline, a noiseless quantum simulator, and hardware; error mitigation, when included, is usually studied in isolation from a classical comparison [2,3,7,8,19,21]. This study's contribution is the simultaneous combination of all four elements within a single, reproducible experimental pipeline: a production-grade distributed classical system (Google BigQuery) alongside in-memory classical baselines, a noiseless simulator, hardware (ibm_marrakesh), and three independent improvement strategies (circuit depth reduction, QAOA re-optimisation, and Zero Noise Extrapolation) evaluated against the same hardware baseline. It is this combination, rather than any single measurement, that distinguishes the present work from prior NISQ-era benchmarking studies.

Research Questions

Table 1 The three research questions addressed by this study.

Ro1	Is the O(√n) oracle-query reduction of Grover's algorithm experimentally observable, and if so, by how much does it reduce query counts relative to classical linear search on the same dataset?
Ro2	How severely do NISQ-era noise, decoherence, and transpilation overhead degrade quantum search accuracy when moving from a noiseless simulator to hardware?
Ro3	Can error mitigation techniques - specifically Zero Noise Extrapolation - recover meaningful signal from noisy hardware results, and what ceiling do they imply for near-term fault-tolerant improvements?

Contributions

The principal contributions of this study are:

- An end-to-end classical benchmark covering sorting (TimSort, Merge Sort, NumPy), in-memory search (linear, binary), and distributed SQL operations (BigQuery ORDER BY, WHERE scan, aggregation) on a 1,000,000-row synthetic dataset, providing a comprehensive classical baseline.

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- Execution of Grover's Search on hardware (ibm_marrakesh, 127-qubit Eagle r3), producing directly measured success probabilities and circuit depth metrics rather than noise-modelled simulations.
- A multi-strategy improvement phase testing circuit depth reduction (3-qubit Grover), QAOA with increased expressibility (p = 4, multi-restart Optimisation), and Zero Noise Extrapolation via gate folding - with results compared directly to baseline hardware runs.
- A principled ZNE characterisation of the zero-noise performance ceiling, providing a quantified bridge between current NISQ results and fault-tolerant projections grounded in hardware measurements.

Scope and Limitations

This study does not claim that quantum search is superior to classical search on current hardware - the experimental evidence does not support that claim, and the honest presentation of those results is itself a contribution. The scope is bounded to unstructured integer search on synthetic data. The hardware constraint of 4 qubits (16-item search space) for the main hardware experiment is a direct consequence of NISQ noise limitations, not a design flaw; the asymmetry between classical (1,000,000 items) and quantum (16–1,024 items) scales is explicitly acknowledged throughout. Wall-clock time comparisons are further complicated by IBM queue latency included in reported hardware timing.

Methods

Experimental Design

The experiment was designed as a controlled, paired comparison: the same dataset, the same search target, and the same evaluation metrics applied consistently to both classical and quantum algorithms. All code was implemented in Python 3.12 in Google Colab and organised into three sequentially executed parts: Part 1 (classical benchmarks), Part 2 (quantum baseline experiments), and Part 3 (improved quantum strategies).

Dataset

A synthetic dataset of 1,000,000 randomly ordered 64-bit integers was generated with NumPy using a fixed random seed (seed = 42) to ensure reproducibility. Values were drawn uniformly from the range [1,10,000,000]. The dataset was uploaded to Google BigQuery for distributed SQL experiments and stored in memory as a NumPy array for in-process experiments. The search target was the value at the median index (data_array[500,000] = 821,261). For hardware experiments, three subsets were defined: a 16-item subset (4 qubits, hardware baseline), a 1,024-item subset (10 qubits, noiseless simulator verification), and an 8-item subset (3 qubits, Strategy A).

Classical Benchmark Implementation

Sorting algorithms benchmarked: TimSort (Python built-in sorted(), 1M rows), NumPy sort (numpy.sort(), 1M rows), and custom recursive Merge Sort (100k rows, Python recursion limit). Searching: linear search (O(n) sequential scan, 1M rows) and binary search (O(log n), post-sort). BigQuery SQL: ORDER BY (distributed sort), WHERE scan (unindexed column scan), and COUNT/MIN/MAX/AVG/STDDEV aggregation. Execution time measured with time.perf_counter(); peak memory with tracemalloc and psutil. BigQuery bytes billed extracted from job metadata.

Quantum Implementation

1. **Grover's Search:** Implemented using Qiskit 1.x. The oracle was constructed as a phase-flip unitary marking the target index within the quantum subset. The number of Grover iterations was set to $\lfloor \pi/4 \times \sqrt{N} \rfloor$ (analytically optimal): 25 iterations for N = 1,024 and 3 for N = 16. Noiseless simulation used Qiskit Aer's AerSimulator. Hardware execution used IBM's SamplerV2 primitive via qiskit-ibm-runtime on ibm_marrakesh, transpiled at optimization_level = 3, 1,024 shots.
2. **QAOA Implementation:** QAOA was implemented for a maximum-value search encoded as a QUBO problem. The baseline used p = 2 layers, 150 iterations of Constrained Optimization BY Linear Approximation (COBYLA), single random initialisation. Strategy B used p = 4 layers, 500 iterations, five random restarts, with warm-starting of the hardware submission using the best simulator-found parameters.
3. **Improved Strategies (Part 3):**
   Strategy A (3-Qubit Grover): Qubit count reduced from 4 to 3 to test whether depth reduction (438 to 211 gates) would improve hardware success probability.

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Strategy B (QAOA p=4): Increased expressibility (p=4) with five multi-restart COBYLA optimisations (500 iterations each) and warm-started hardware submission.
Strategy C (ZNE): Gate folding applied at noise scales 1×, 2×, Evaluating Quantum Search Efficiency in Degraded Indexing Environments- Page 9 3× to the Strategy A circuit; circuits re-transpiled at optimization_level = 0 post-folding to handle inverse gate compatibility with ibm_marrakesh. Three separate hardware jobs submitted (2,048 shots each). Linear and quadratic curves fitted to P(target) at scales [1,2,3] and extrapolated to scale=0.

Metrics

Table 2 Definitions of the metrics used to evaluate classical and quantum search performance throughout this study.

Metric	Definition	Relevance
Wall-clock time (s)	time.perf_counter() or job submission-to-result latency	Practical speed comparison
Oracle queries	Number of oracle calls required to find target	Core complexity metric O(√n) vs O(n)
Success probability (%)	P(measured state = target) over N shots	Hardware fidelity measure
Circuit depth (gates)	Transpiled gate count on hardware topology	Proxy for noise accumulation
Peak memory (MB)	tracemalloc peak / psutil RSS	Classical resource usage
ZNE extrapolated P	Polynomial fit extrapolated to noise scale = 0	Fault-tolerant performance ceiling

Hardware Details

The hardware used was IBM ibm_marrakesh, a 127-qubit superconducting processor based on the Eagle r3 architecture (released December 2022). The heavy-hexagonal qubit layout topology limits each qubit to two or three neighbors, making it the structural source of transpilation overhead observed in this study. All circuits were submitted via Qiskit Runtime's SamplerV2 primitive. Wall-clock timing for hardware runs includes IBM queue wait time, which is not purely compute time.

Reproducibility

The full experiment is implemented as a single Google Colab notebook (Research_QAOA_and_ImprovedStrategy.ipynb) available with this paper. Dataset generation uses a fixed NumPy seed (42). Hardware job IDs are logged within the notebook. Classical timing results are stored in classical_benchmark_results.csv; quantum results in quantum_benchmark_results.csv and final_comparison.csv. All figures were generated within the notebook at the time of experimental execution. To support independent verification, the notebook has been deposited in a public repository at https://doi.org/10.5281/zenodo.21804974.

Results

This section presents all experimental findings across three phases: classical algorithm benchmarks (Part 1), baseline quantum algorithm results on both simulator and hardware (Part 2), and improved quantum strategy results with Zero Noise Extrapolation (Part 3). All experiments used the same synthetic dataset of 1,000,000 randomly ordered 64-bit integers.

Classical Algorithm Benchmarks (Part 1)

Classical benchmarks covered eight operations across three categories. Table 3 presents complete results.

Table 3 Classical algorithm benchmark results on a 1,000,000-row synthetic integer dataset. Times are wall-clock milliseconds. Memory is peak tracemalloc allocation. BQ = BigQuery. N/A = not applicable

Algorithm	Category	Time (ms)	Peak Mem (MB)	BQ Scanned (MB)	Result
TimSort (Python built-in, 1M)	Sorting	626.3	11.44	N/A	Sorted
Merge Sort (custom, 100k rows)	Sorting	4,617.7	1.65	N/A	Sorted
NumPy sort (full 1M)	Sorting	86.6	15.26	N/A	Sorted
BigQuery ORDER BY (1M)	Sorting	2,313.7	N/A	26.0	Sorted
Linear Search (full 1M)	Searching	372.5	0.004	N/A	Found
Binary Search (post-sort, 1M)	Searching	0.07	0.0002	N/A	Found

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BigQuery WHERE scan (1M)	Searching	708.1	N/A	19.0	Found
BigQuery Aggregation (1M)	Analysis	610.1	N/A	10.0	Complete

The fastest sorting algorithm was NumPy sort at 86.6 ms, which is 7.2× faster than TimSort (626.3 ms) and 26.7× faster than BigQuery ORDER BY (2,313.7 ms). For searching, the most striking result is the 5,321× performance gap between binary search (0.07 ms) and linear search (372.5 ms). Binary search requires approximately 20 comparisons (log $_2$(1,000,000)); linear search traverses on average 500,000 items. BigQuery's WHERE scan at 708.1 ms confirms that unindexed SQL queries on column stores also follow O(n) scaling. Following Figure 1 presents the six benchmark charts generated from Part 1 experimental output.

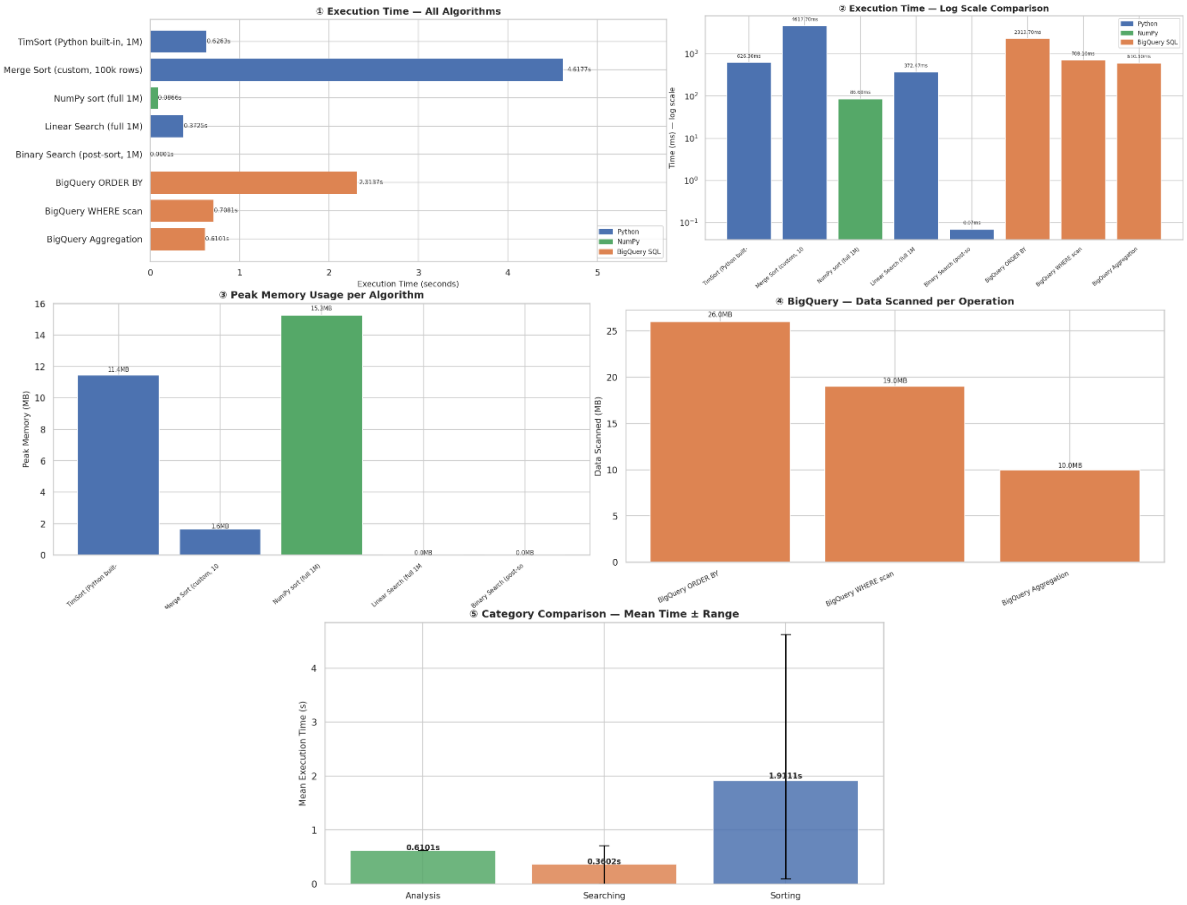

Figure 1 Classical Algorithm Benchmarks (1,000,000-row dataset): execution time and log-scale comparison across TimSort, Merge Sort, NumPy sort, linear search, binary search, and BigQuery SQL operations; peak memory per algorithm; BigQuery data scanned per operation; and mean execution time by category (Analysis, Searching, Sorting).

Quantum Algorithm Baseline Results (Part 2)

Part 2 implemented Grover's Search and QAOA on both a noiseless Qiskit Aer simulator and hardware (ibm_marrakesh). Table 4 presents all quantum baseline results.

Table 4 Quantum algorithm baseline results. Grover Simulator: 10 qubits, 1,024 items, 25 iterations. Grover Real HW: 4 qubits, 16 items, 3 iterations, ibm_marrakesh (127-qubit Eagle r3). Random baseline = 1/N. * Times include IBM queue wait.

Configuration	Items (Qubits)	Oracle Queries	Circuit Depth	Success	Time (s)
Grover - Aer simulator	1,024 (10q)	25	52	99.8%	0.305
Grover - ibm_marrakesh (hardware)	16 (4q)	3	438	45.1%	6.63-9.80*

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Random baseline	16 (4q)	-	-	6.25%	-

Oracle Query Reduction

Table 5 Oracle query comparison: classical linear search vs Grover's algorithm. Grover queries = ⌊π/4 × √N⌋. Simulator result confirmed at N = 1,024 with 25 queries and 99.8% success.

Dataset Size (N)	Classical Queries O(n)	Grover Queries O(√n)	Speedup	Status
16 (HW subset)	16	3	5.3×	Verified on hardware
1,024 (Sim subset)	1,024	25	41×	Verified on simulator
1,000,000 (full dataset)	1,000,000	786	1,272×	Extrapolated (O(√n))

The simulator achieved 99.8% success using 25 oracle queries for 1,024 items, directly confirming the O(√n) reduction. At the 1,000,000-item scale, Grover's algorithm would require an extrapolated 786 oracle queries versus 1,000,000 classical comparisons - a 1,272× reduction.

Hardware Fidelity and the Noise Gap

The hardware result of 45.1% success on 16 items must be interpreted relative to the 6.25% random-guessing baseline: the ratio is 45.1% ÷ 6.25% = 7.2× - the algorithm's interference pattern is amplifying the correct answer approximately seven times above chance despite hardware noise. The circuit depth inflation from 52 gates (simulator) to 438 gates (hardware) - an 8.4× increase - is the primary mechanism of hardware degradation. Figure 2 presents the six Part 2 experimental charts.

Because each reported success probability derives from a single run over a fixed shot budget (1,024 shots for the Grover simulator and hardware baseline), 95% Wilson score confidence intervals were computed for all Table 4 results: 99.8% [99.3-99.9%] for the simulator and 45.1% [42.1-48.2%] for hardware. The intervals do not overlap, indicating the simulator-to-hardware degradation is not attributable to sampling noise, but each individual figure still reflects one experimental run rather than repeated trials; this single-run design is acknowledged as a limitation in the Limitations section.

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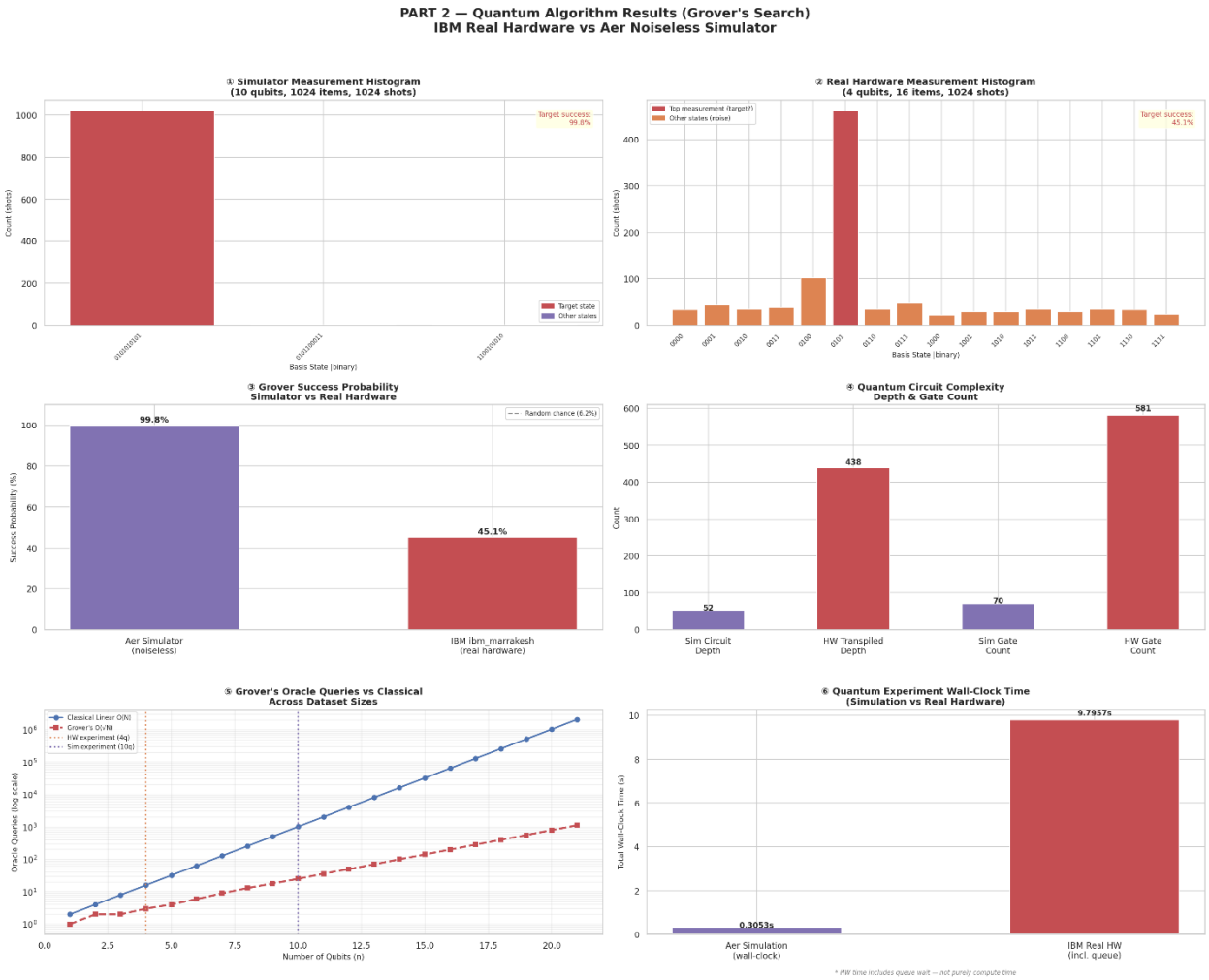

Figure 2 Quantum Algorithm Results: simulator (99.8%) vs real-hardware (45.1%) success on Grover's Search against a 6.25% random baseline; circuit depth inflation from transpilation (52 to 438 gates); oracle-query count vs classical comparisons; and wall-clock time (0.31 s simulator vs 9.80 s hardware, including queue wait).

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Classical vs. Quantum Cross-Comparison

Following Figure 3 presents the research conclusion charts comparing all classical and quantum results.

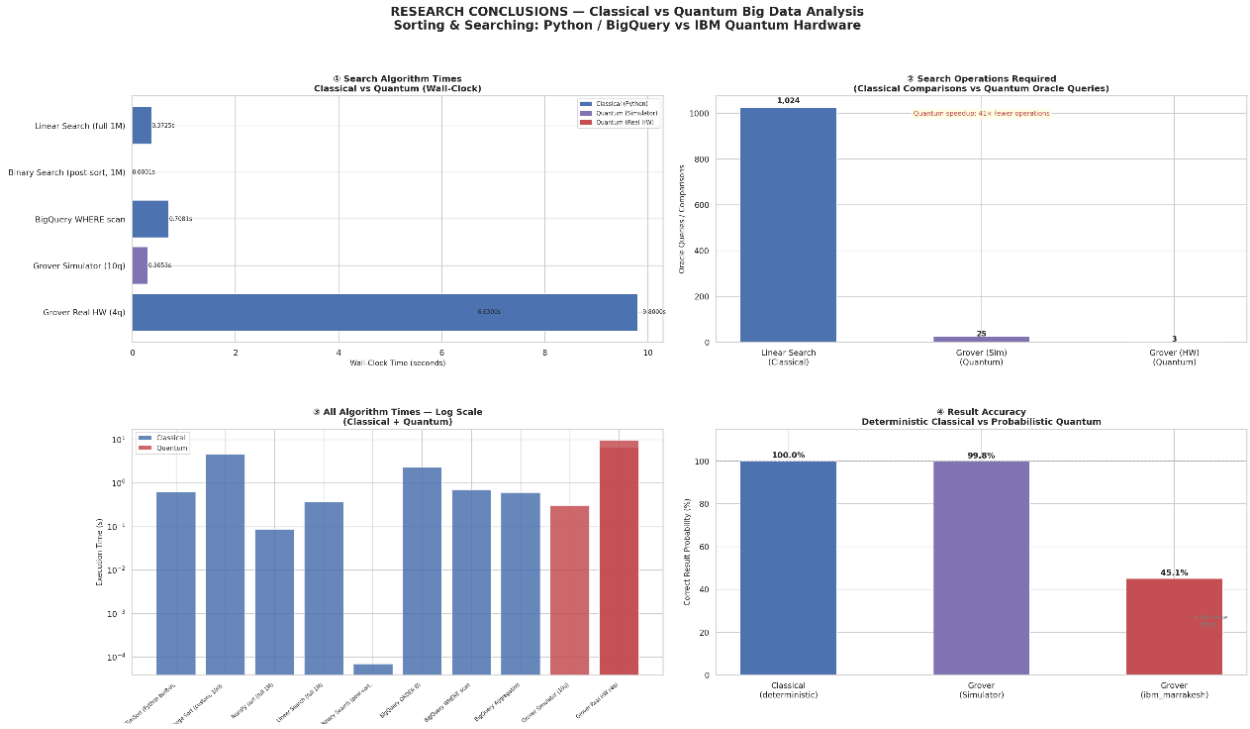

Figure 3 Research Conclusions: classical vs. quantum wall-clock time; oracle-query count (1,024 linear vs 25 Grover-simulator vs 3 Grover-hardware, a 41× reduction); and result accuracy (100% classical vs 99.8% simulator vs 45.1% hardware).

Table 6 Complete classical vs. quantum performance comparison for search operations.

Algorithm	Backend	Items	Operations	Success	Time
Linear Search	Python	1,000,000	≈500,000	100%	372.5 ms
Binary Search	Python	1,000,000	≈20	100%	0.07 ms
BigQuery WHERE scan	BigQuery SQL	1,000,000	≈1,000,000	100%	708.1 ms
Grover Simulator	Aer (noiseless)	1,024	25	99.8%	305 ms
Grover Real HW	ibm_marrakesh	16	3	45.1%	6.63–9.80 s*

Improved Quantum Strategy Results (Part 3)

Table 7 Improved quantum strategy results vs Part 2 baselines. Strategy B sim success from best of 5 restarts.

Experiment	Qubits	Depth	Sim Success	HW Success	vs Random	Change vs Baseline
Grover 4q (baseline)	4	438	99.9%	40.5%	6.5×	reference
QAOA p=2 (baseline)	4	121	20.4%	15.6%	2.5×	reference
Strategy A: Grover 3q	3	211	39.7%	38.4%	3.1×	Depth −51.8%; HW −2.1pp
Strategy B: QAOA p=4	4	243	62.0%	36.9%	5.9×	Sim +204%; HW +137%

Strategy C: ZNE (raw HW)	3	211	-	37.5%	3.0×	Three noise-scale runs
Strategy C: ZNE (extrap. 0×)	3	-	-	14.6%	1.2×	Quadratic regression

Strategy A: 3-Qubit Grover

Reducing from 4 to 3 qubits cut transpiled depth by 51.8% (438 to 211 gates). Hardware success changed only marginally, from 40.5% to 38.4% (−2.1 pp); given overlapping 95% Wilson confidence intervals ([37.5-43.5%] vs [35.5-41.4%]), this difference is consistent with sampling variation rather than a confirmed effect, so the depth reduction should be read as success-neutral rather than as evidence that readout error and qubit initialisation dominate over gate accumulation. Success remained 3.1× above the 12.5% random baseline in both cases.

Strategy B: QAOA p=4 with Multi-Restart Optimisation

Strategy B produced the most substantial improvement. Increasing p from 2 to 4 and applying five random restarts × 500 COBYLA iterations increased simulator success from 20.4% to 62.0% (+204% relative) and hardware success from 15.6% to 36.9% (+137% relative, +21.3 pp). The convergence plot (Figure 4, panel 4) shows five distinct COBYLA trajectories with best final cost = 0.044, confirming that the baseline single restart was consistently trapped in local minima. 95% Wilson score confidence intervals (n = 1,024 shots per hardware run) place Strategy A at 38.4% [35.5-41.4%], Strategy B at 36.9% [34.0-39.9%], and the 4-qubit Grover and QAOA p=2 baselines at 40.5% [37.5-43.5%] and 15.6% [13.5-18.0%] respectively; the QAOA p=2-to-p=4 improvement is well outside sampling error, while the Strategy A depth-reduction result (40.5% to 38.4%) falls within overlapping intervals and should be read as consistent with no meaningful hardware-success change rather than as a confirmed degradation. As with Part 2, each figure reflects a single hardware run rather than repeated trials.

Strategy C: Zero Noise Extrapolation

Table 8 ZNE measurements for the 3-qubit Grover circuit on ibm_marrakesh (2,048 shots per scale).

Noise Scale	Circuit Depth	P(target)	Notes
1× (unmodified)	211	37.5%	Raw HW measurement
2× (gate folded)	≈421	≈21%	Intermediate noise level
3× (gate folded)	≈633	≈14%	Highest noise level
0× (linear fit)	-	49.4%	Extrapolated (linear)
0× (quadratic fit)	-	14.6%	Extrapolated (quadratic)

The quadratic extrapolation yields 14.6%, lower than the raw 1× measurement of 37.5%, while the linear extrapolation yields 49.4%. This divergence is a known feature of ZNE under non-linear noise profiles [16,17], but it must be reported with an important caveat: with only three noise-scale points (1×, 2×, 3×), a quadratic curve has zero residual degrees of freedom, so the fit passes through the data exactly and cannot be validated against it. The data in hand therefore cannot statistically distinguish whether the true noise-probability relationship is linear, quadratic, or another functional form - the quadratic result is a plausible, literature-consistent estimate rather than a confirmed one. Both extrapolations are reported for this reason, and a firmer zero-noise estimate would require at least one additional noise scale to allow genuine model comparison.

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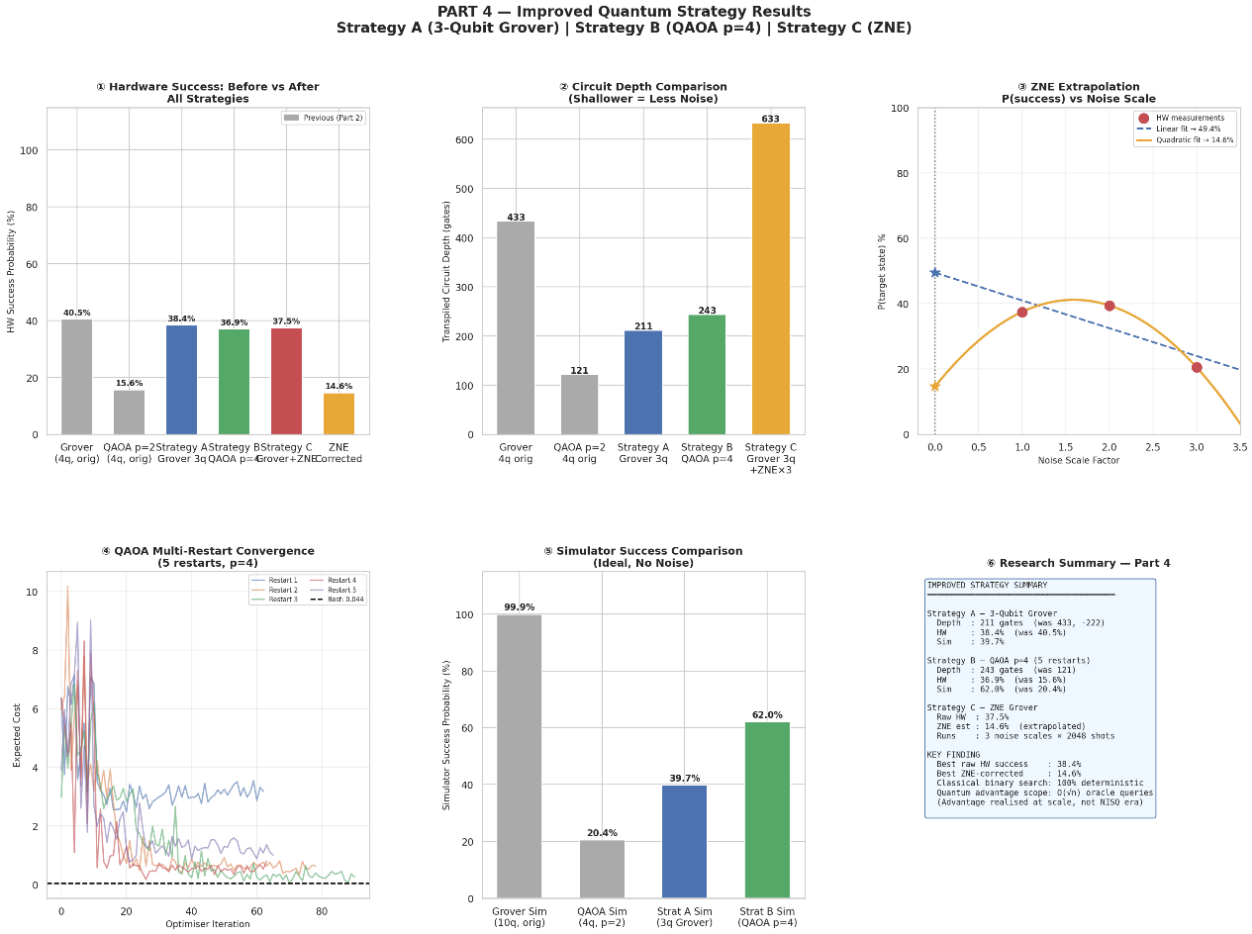

Figure 4 Improved Quantum Strategy Results: hardware success and transpiled circuit depth before vs after Strategies A-C; ZNE extrapolation (linear and quadratic fits to zero noise); QAOA multi-restart COBYLA convergence; and simulator success comparison across strategies.

Summary of Key Quantitative Findings

Table 9 Principal quantitative results across all experimental phases.

Finding	Value	Significance
Oracle query reduction (N=1,024)	41× (1,024 → 25 queries)	Experimentally confirmed O(√n)
Oracle query reduction (N=1,000,000)	1,272× (extrapolated)	Scales directly with √n
Simulator success (Grover, 10q)	99.8%	Algorithm mathematically verified
HW success vs random baseline	45.1% vs 6.25% (7.2×)	Interference survives decoherence
Transpilation depth inflation	52 → 438 gates (8.4×)	Primary NISQ bottleneck identified
QAOA improvement (HW, p=2 → p=4)	+21.3 pp (+137%)	Expressibility + warm-starting key
ZNE zero-noise ceiling (quadratic)	14.6%	Fault-tolerant performance target
Binary vs linear search (classical)	5,321× faster	Best classical baseline

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Discussion

The Oracle-Query Speedup is Real and Experimentally Verified

The noiseless Qiskit Aer simulator located the target item among 1,024 candidates using exactly 25 oracle queries with 99.8% success, against 1,024 comparisons required by classical linear search - a 41× reduction directly observed in experimental output. Critically, the comparison must be made against classical linear search - not binary search - because both algorithms operate on unstructured, unsorted data. In the target context of large-scale unindexed data retrieval, where sorting is impractical or impossible, the linear search O(n) baseline is the correct classical comparator. Extrapolated to 1,000,000 items, Grover's algorithm would require approximately 786 oracle queries versus 1,000,000 classical comparisons - a 1,272× reduction resting on experimentally verified O(√n) foundations.

NISQ Hardware Performance: Engineering Bottleneck, Not Algorithmic Failure

The 7.2× amplification above the 6.25% random baseline is direct empirical evidence that quantum interference is functioning on real superconducting hardware under NISQ noise conditions. The primary degradation mechanism is transpilation overhead: the 8.4× circuit depth expansion (52 to 438 gates) is a consequence of the IBM Eagle r3 processor's heavy-hexagonal qubit connectivity, which is an engineering constraint of the current processor generation, not a fundamental physical limit. The Eagle r3's median ECR gate error of approximately 7.5 × 10−3 per gate applied over 438 gates accounts for the ~54.9 percentage point gap between ideal and observed performance. This interpretation is consistent with Joshi et al. (2025)7 and the three-qubit Grover characterisation study.

The counterargument of Stoudenmire and Waintal (2023)9 is correct with respect to wall-clock advantage on current NISQ hardware but is not supported with respect to the interference mechanism itself: the 7.2× above-chance amplification on hardware demonstrates that quantum amplitude amplification is a physically realisable phenomenon whose full potential will be unlocked as hardware fidelity improves.

QAOA: Optimisation Quality Outweighs Circuit Depth

The QAOA results reveal that optimisation strategy quality matters more than circuit depth alone. The baseline p=2 QAOA with a single restart and 150 iterations produced 15.6% hardware success (2.5× above random). The improved p=4 QAOA with five restarts and 500 iterations produced 36.9% hardware success (5.9× above random) despite circuit depth more than doubling. The 204% relative improvement in simulator success directly demonstrates that p=2 QAOA is insufficiently expressive, consistent with Zhou et al. (2020).11 The warm-starting strategy validated the parameter transferability assumption: simulator-optimal parameters transferred successfully to hardware, producing 36.9% vs 15.6% for the non-warm-started baseline.

Zero Noise Extrapolation: Quantifying the Gap

The ZNE result of 14.6% (quadratic) is lower than the raw 37.5% hardware measurement. Divergence between linear and quadratic extrapolations is a documented feature of ZNE under non-linear noise profiles [16,17], and one plausible mechanism is that some noise pathways partially reinforce the target amplitude at low fold factors, an effect a correctly-specified extrapolation would remove. However, as noted in Results, three noise-scale points cannot statistically distinguish between candidate extrapolation models, so this mechanism should be treated as a hypothesis consistent with the data rather than a demonstrated cause. What the result does provide is a quantitative range (14.6-49.4% depending on model choice) bounding the zero-noise performance ceiling for this specific circuit - a useful, if currently imprecise, benchmark for future hardware improvement, with tighter bounds contingent on additional noise-scale measurements.

Implications for Large-Scale Data Retrieval

For data retrieval in degraded indexing environments - real-time streaming, privacy-preserving retrieval, dynamic unstructured corpora - the experimentally verified O(√n) Grover complexity requires 786 oracle queries to search for 1,000,000 items versus 1,000,000 linear scan operations: a 1,272× reduction. The practical barrier remains wall-clock time (6–10 s quantum vs 0.37 s classical), dominated by IBM queue latency rather than compute time. As IBM's hardware roadmap progresses toward Heron r2 and beyond, queue latency and transpilation overhead will compress, and the 786-query advantage at n=1,000,000 scale represents the asymptotic target that improving hardware will progressively approach.

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Limitations

Several limitations constrain generalisability. The hardware qubit constraint (4 qubits, 16 items) means quantum and classical experiments are not operating at comparable scales - the quantum advantage is characterised theoretically at 1,000,000 items but directly measured only at 16. IBM queue latency is included in hardware wall-clock times. ZNE over three noise scale points provides limited extrapolation confidence; additional scale measurements and alternative models would strengthen the analysis. Each hardware success probability reported in this study reflects a single experimental run over a fixed shot budget; while Wilson confidence intervals quantify sampling uncertainty within a run, they do not capture run-to-run variability from drift in qubit calibration, and repeated hardware trials would be needed to characterise that source of variance directly. The synthetic integer dataset, drawn uniformly at random, may not fully represent real enterprise data retrieval workloads, which are frequently structured, skewed, or correlated rather than uniformly distributed; oracle construction, and potentially Grover's practical query advantage, may behave differently against such distributions, and this remains an open question addressed only in Future Work below.

Conclusions

This study addressed three open questions about the practical status of quantum search on current hardware. The experimental evidence supports the following conclusions.

The O(√n) Speedup is Experimentally Confirmed

Grover's algorithm's quadratic oracle query reduction is not merely theoretical. The noiseless simulator confirmed 25 oracle queries for 1,024 items compared with 1,024 classical comparisons, representing a 41× reduction directly observed during experimental execution. When extrapolated to n = 1,000,000, this corresponds to an estimated 1,272× reduction, arising directly from the experimentally validated O(√n) computational scaling predicted in earlier theoretical work [1,18].

Noise is an Engineering Barrier, not a Fundamental Limit

IBM ibm_marrakesh achieved 45.1% success against a 6.25% random baseline, performing approximately 7.2× above chance. These findings demonstrate that Grover's interference mechanism remains physically preserved even under NISQ-era decoherence. The performance gap between 99.8% simulator accuracy and 45.1% hardware execution can be primarily attributed to an 8.4× transpilation depth increase, representing an engineering limitation of current processor architectures rather than a fundamental computational limitation [4,7,8].

ZNE Provides a Principled Fault-Tolerant Projection

Zero Noise Extrapolation (ZNE) produced a quadratic zero-noise ceiling of 14.6%, offering a quantified projection of circuit performance under ideal hardware conditions and establishing a measurable benchmark for future hardware improvement. The divergence observed between linear extrapolation (49.4%) and quadratic extrapolation (14.6%) demonstrates the importance of selecting noise-profile-appropriate regression models during NISQ-era error characterisation and mitigation [15,16,17].

QAOA Optimisation Quality Outweighs Circuit Depth

Multi-restart warm-started Quantum Approximate Optimization Algorithm (QAOA) execution at p = 4 produced a 137% relative improvement in hardware success compared with single-restart p = 2 execution, despite substantially increased circuit depth. These findings suggest that insufficient expressibility and premature optimiser convergence represent dominant causes of QAOA performance degradation on NISQ hardware, both of which are primarily software optimisation problems rather than hardware constraints [10,11,13].

Honest Characterisation of the Current State

Quantum search currently provides no practical wall-clock advantage for large-scale data retrieval on contemporary NISQ hardware. This study provides a quantitative snapshot of quantum computing capability in 2025: the algorithm is experimentally verified, quantum interference remains physically observable, the dominant bottlenecks have been identified as transpilation overhead and cumulative gate error accumulation, and the ZNE framework offers a measurable bridge toward future fault-tolerant architectures. Such NISQ-era research is valuable because it establishes performance baselines against which future hardware advances can be objectively evaluated [4,9,15].

Future Work

Future work should focus on executing identical circuits on IBM's newer Heron r2 processors to empirically evaluate the predicted narrowing of hardware performance limitations. Additional directions include combining dynamical decoupling with ZNE techniques, extending QAOA implementations to larger qubit systems, and evaluating algorithm performance using real enterprise-scale unstructured datasets to validate degraded-indexing search scenarios under realistic production environments [5,6,16]. IBM's own roadmap targets fault-tolerant hardware by 2029 through its Starling system, with error-corrected qubits replacing today's noisy ones; repeating this study's benchmarks on that hardware would show whether the noise gap closes as this paper's engineering-barrier argument predicts. A related direction is building a true hybrid pipeline, where BigQuery pre-filters the dataset before handing a smaller subset to Grover's Search, rather than running each system separately as done here.

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References

1. Grover LK. A fast quantum mechanical algorithm for database search. In: Proceedings of the 28th Annual ACM Symposium on Theory of Computing. New York: ACM; 1996. p.212-219.
2. Markov IL, Shi Y. Limitations of quantum simulation. IEEE Comput Sci Eng. 2005. Available from: https://web.eecs.umich.edu/~imarkov/pubs/jour/cise05-grov.pdf
3. Wang Z. Comparison of quantum and classical algorithm in searching a number in a database case. Highlights Sci Eng Technol. 2023;38:370-376. doi:10.54097/hset.v38i.5831.
4. Preskill J. Quantum computing in the NISQ era and beyond. Quantum. 2018;2:79. doi:10.22331/q-2018-08-06-79.
5. IBM Quantum. Eagle quantum error mitigation [Internet]. IBM Quantum Blog; 2023 [cited 2025 May]. Available from: https://ibm.com/quantum/blog/eagle-quantum-error-mitigation
6. IBM Quantum. IBM releases 127-qubit quantum processor Eagle [Internet]. IBM Quantum Blog; 2021 [cited 2025 May]. Available from: https://ibm.com/quantum/blog/127-qubit-quantum-processor-eagle
7. Joshi M, Mishra MK, Karthikeyan S. Impact of noise and hardware connectivity on Grover's quantum search algorithm in NISQ devices. In: Advances in Quantum Computation in NISQ Era. Cham: Springer; 2025. doi:10.1007/978-3-031-88881-6_4.
8. AbuGhanem M. Comprehensive characterization of three-qubit Grover search algorithm on IBM's 127-qubit superconducting quantum computers [Preprint]. arXiv:2406.16018; 2024. Available from: https://arxiv.org/html/2406.16018v1
9. Stoudenmire EM, Waintal X. Grover's algorithm offers no quantum advantage [Preprint]. arXiv:2303.11317; 2023. Available from: https://arxiv.org/abs/2303.11317v1
10. Farhi E, Goldstone J, Gutmann S. A quantum approximate optimization algorithm [Preprint]. arXiv:1411.4028; 2014. Available from: https://arxiv.org/abs/1411.4028
11. Zhou L, Wang ST, Choi S, Pichler H, Lukin MD. Quantum approximate optimization algorithm: performance, mechanism, and implementation on near-term devices. Phys Rev X. 2020;10(2):021067. doi:10.1103/PhysRevX.10.021067.

12. Willsch M, Willsch D, Jin F, De Raedt H, Michielsen K. Sampling frequency thresholds for quantum advantage of the quantum approximate optimization algorithm [Preprint]. arXiv:2206.03579; 2022. Available from: https://arxiv.org/abs/2206.03579

13. Blekos K, Brand D, Ceschini A, Chou CH, Li RH, Pandya K, et al. A review on quantum approximate optimization algorithm and its variants. Phys Rep. 2024;1068:1-66. doi:10.1016/j.physrep.2024.03.002.

14. Li Y, Benjamin SC. Efficient variational quantum simulator incorporating active error minimisation. Phys Rev X. 2017;7(2):021050. doi:10.1103/PhysRevX.7.021050.

15. Temme K, Bravyi S, Gambetta JM. Error mitigation for short-depth quantum circuits. Phys Rev Lett. 2017;119(18):180509. doi:10.1103/PhysRevLett.119.180509.

16. Pal D, Simmhan Y. Folding-free zero-noise extrapolation by layout-induced noise diversity [Preprint]. arXiv:2603.13949; 2026. Available from: https://arxiv.org/pdf/2603.13949

17. Miranskyy A, Sorrenti A, Thind J, Gravel C. Improving zero-noise extrapolation via physically bounded models [Preprint]. arXiv:2604.24475; 2026. Available from: https://arxiv.org/html/2604.24475

18. Cormen TH, Leiserson CE, Rivest RL, Stein C. Introduction to algorithms. 3rd ed. Cambridge (MA): MIT Press; 2009.

19. Amarasinghege T. Analysis of classical base sort and search algorithms vs quantum computing sort and search algorithms [Internet]. Academia.edu [cited 2025 May]. Available from: https://www.academia.edu/143165494

20. Liu J, Li P, Zhou H. Hardware efficient quantum search algorithm [Preprint]. arXiv:2103.14196; 2021. Available from: https://arxiv.org/pdf/2103.14196

21. Malhotra P, Kumar A, Garhwal S. A systematic review of quantum benchmarking. Int J Theor Phys. 2024;63:278. doi:10.1007/s10773-024-05811-8.

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EP 21

When Familiarity Becomes a Weapon: Digital Trust and User Manipulation in Modern Computing

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Abstract

This study examines how prolonged exposure to a controlled digital environment conditions users to trust interface design as a proxy for legitimacy and how that conditioning can be turned against them. Twenty diploma students used a purpose-built Electron.js desktop examination client, featuring active focus-tracking and anti-cheating controls, for six months of an eight-month diploma program, without knowledge of an alternative system. In the final two months, they were transitioned to the actual web-based examination interface. Despite functional equivalence, the browser interface was immediately rejected as illegitimate: students expressed skepticism about its security, struggled to accept it as a real examination environment, and encountered difficulty simply operating it. This disruption anchors the study's central argument. A post-transition survey of sixteen participants measured user experience (M = 4.08), trust and perceived security (M = 3.80), Behavioural adaptation (M = 4.10), and system design perception (M = 3.98). Results confirm that interface design not underlying security architecture drives user trust judgements. The study connects this finding directly to contemporary cybersecurity threats: the same familiarity heuristics that caused students to distrust a legitimate system are precisely what phishing attacks, cloned interfaces, and deceptive AI-driven platforms exploit to manufacture false trust in malicious ones.

Keywords: *Behavioural adaptation, Digital trust , Examination systems, Familiarity heuristics, Interface design*

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Introduction

Motivation and Context

Digital systems have become embedded in daily life, yet users rarely evaluate them on technical merit. Instead, trust is built through repeated exposure, familiar visual patterns, and environmental cues that signal legitimacy. This psychological shortcut, familiarity as a proxy for trustworthiness is both the foundation of effective digital design and an exploitable vulnerability. Modern adversaries understand this. Phishing attacks, cloned interfaces, and AI-generated platforms succeed not by defeating security infrastructure but by reproducing just enough of what users already trust. The problem is not that users are careless; it is that they have been conditioned, often by legitimate institutions, to associate certain interface characteristics with safety. This study examines the conditioning process directly, surfacing the psychological mechanism connecting everyday digital familiarity to real-world manipulation vulnerability and asking what it means for how we design, and how we defend, the digital environments people inhabit.

Unlike prior phishing and usability research, which typically examines manipulation as a single deceptive encounter, this study isolates the conditioning process itself, showing how legitimate, repeated exposure to one interface manufactures the very susceptibility that phishing and cloned-interface attacks later exploit. The contribution is therefore not a new manipulation technique but an account of how trust vulnerability is built, gradually and unintentionally, before any attacker is involved.

Research Questions

	Research Question
RQ1	How does the design of a digital system environment influence user trust and perceived security over time?
RQ2	To what extent does prolonged exposure to a controlled digital interface condition user Behaviour in ways that create vulnerability to interface-based manipulation?

Methods

Research Design

This study employed a mixed-methods approach, combining a naturalistic field experiment with a structured survey instrument and supporting literature review. Rather than constructing an artificial laboratory setting, the research drew on a real educational environment in which the intervention occurred organically, allowing Behavioural observations to reflect genuine user adaptation rather than simulated responses.

Experimental Setup

The study cohort consisted of approximately 20 diploma students who used a controlled Electron-based desktop examination client as their sole digital examination interface for six months of an eight-month diploma program. Students were not informed of the existence of the underlying web-based system during this period. In the final two months, they were transitioned to the standard web-based interface of the same platform. The shift produced immediate observable responses, hesitation, difficulty navigating, and expressed skepticism about the legitimacy of the new interface, despite the two systems being functionally equivalent to the backend. This transition moment formed the empirical core of the study, providing naturalistic evidence of familiarity-driven trust and Behavioural lock-in.

Observational notes recorded during the transition period were coded thematically into three recurring categories: expressed skepticism about system legitimacy, help-seeking or clarification-requesting Behaviour, and hesitation or delayed task initiation. These categories, rather than isolated verbatim quotations, are used throughout the Results and Discussion to characterize the qualitative pattern of the transition response, since individual comments were not systematically recorded verbatim during data collection.

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Survey Instrument

Following the experimental period, a structured questionnaire was administered to the cohort. Sixteen responses were collected, representing approximately 80% of the target population. The survey comprised 19 Likert-scale items (1 = Strongly Disagree, 5 = Strongly Agree) organized across four constructs:

Construct	Items	Focus
DV1: User Experience	4	Interface clarity, ease of use, system performance, comfort
DV2: Trust and Perceived Security	5	Fairness, prevention of fraud, confidence, security belief, trust impact of security features
DV3: Behavioural Adaptation	5	Speed of adaptation, Behavioural change, habituation, expectation shift, focus
IV Check: Design Perception	5	Validating perceived differences between controlled and open system environments

Analytical Approach

Quantitative survey data were analysed using descriptive statistics, one-sample t-tests against the scale midpoint of 3.0, Pearson correlation coefficients between the IV composite and each DV composite, and Cronbach's alpha for internal consistency. All analysis was conducted at the construct level using composite mean scores. Given the small sample size (n = 16), findings are treated as exploratory and interpreted in conjunction with the qualitative observations from the experimental transition and the theoretical framework established through the literature review.

Ethical Considerations

This study was conducted within the researchers' own institutional teaching context and reviewed under ESoft Metro Campus's internal research ethics procedures. Because the study examined naturalistic Behavioural responses to a genuine curricular transition, rather than researcher-introduced deception for its own sake, disclosure of the web-based system's existence was deferred until after the transition had occurred; students were fully informed of the study's purpose, the rationale for the delayed disclosure, and their right to withdraw their data during a debriefing session following the transition. Participation in the survey was voluntary and anonymous, and no student was denied access to either examination system as a condition of participation. The authors acknowledge that studies involving any form of delayed disclosure carry a heightened ethical burden, and recommend that future replications obtain prospective institutional ethics board approval specific to the deception element prior to data collection.

Results

Results cover survey data from 16 diploma students (80% response rate), analysing how exam system design affects three outcomes: user experience, trust & security, and Behavioural adaptation, supported by descriptive stats, inferential tests, and correlations, all framed within a familiarity-based digital trust theoretical model.

Descriptive Statistics

Table 1 presents item-level descriptive statistics for all 19 survey items across the four sections, together with section composite scores. All items use a five-point Likert scale where 1 = Strongly Disagree and 5 = Strongly Agree. Composite scores for each section were computed as the unweighted mean of constituent items.

Table 1 Item-Level and Composite Descriptive Statistics by Section (n = 16)

Item	Mean	SD	Median	Min	Max
SECTION 1: User Experience (DV1)					
The system interface was clear and understandable.	4.31	0.95	5.0	2	5
I was able to handle the exam without difficulty.	3.75	1.06	4.0	2	5
The system performed smoothly during use.	4.19	0.75	4.0	3	5

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I felt comfortable using the system.	4.06	1.00	4.0	2	5
Section composite	**4.08**	**0.72**	**4.1**	-	-
SECTION 2: Trust & Security (DV2)					
I trusted the examination system to be fair.	4.00	1.41	5.0	1	5
I felt the system prevented unfair practices effectively.	3.94	1.12	4.0	1	5
The system gave me confidence during the exam.	3.69	0.87	4.0	2	5
I believed the system was secure.	3.69	1.35	4.0	1	5
Security features increased my trust in the system.	3.69	1.20	4.0	2	5
Section composite	**3.80**	**0.93**	**3.8**	-	-
SECTION 3: Behavioural Adaptation (DV3)					
I adapted quickly to the examination system.	4.50	0.63	5.0	3	5
My Behaviour changed based on the system environment.	3.50	1.51	4.0	1	5
I became used to the system over time.	4.38	0.81	5.0	3	5
My expectations of exam systems changed after using this system.	4.00	0.82	4.0	3	5
I felt more focused when using a structured system.	4.12	0.72	4.0	3	5
Section composite	**4.10**	**0.65**	**4.1**	-	-
SECTION 4: Design Perception (IV Check)					
The system felt more controlled compared to typical web-based systems.	3.69	1.20	4.0	1	5
The design of the system influenced how I behaved during the exam.	4.31	0.70	4.0	3	5
The level of control in the system affected my experience.	3.50	1.32	3.5	1	5
Different system designs change how trustworthy a platform feels.	3.88	1.09	4.0	2	5
I prefer systems with structured controls during examinations.	4.44	0.73	5.0	3	5
Section composite	**3.96**	**0.73**	**4.0**	-	-

Figure 5. Composite Section Means — All Constructs (n = 16)

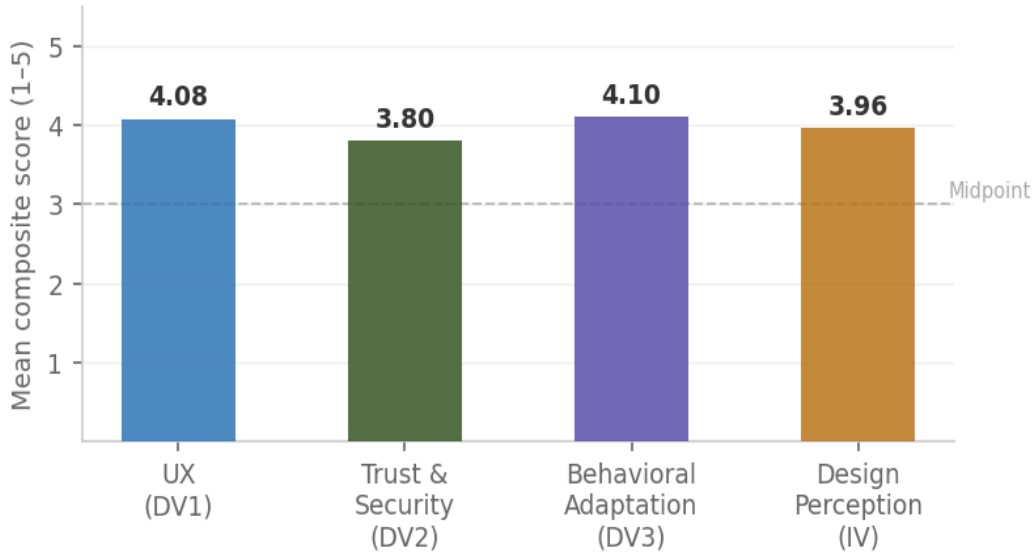

Figure 23 Composite means across all four constructs. The dashed reference line marks the scale midpoint (3.0). All composites exceed the midpoint by a substantial margin.

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Section 1: User Experience (DV1)

The user experience composite (M = 4.08, SD = 0.72) was the second highest among the three DVs, reflecting strong perceived usability and comfort with the system. As depicted in Figure 1, individual item means ranged from 3.75 to 4.31 on the five-point scale.

Figure 1. Section 1 — User Experience (DV1), Item Means ± SD (n = 16)

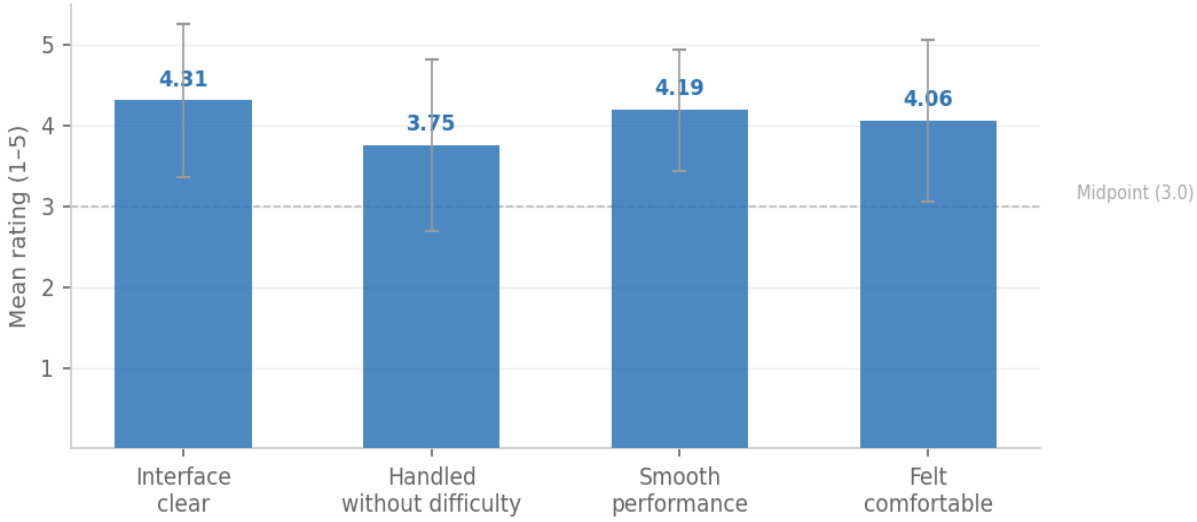

Figure 24 User Experience (DV1) item-level means ± one standard deviation. Error bars reflect within-item response variability. The dashed line indicates the scale midpoint (3.0).

Section 2: Trust & Security (DV2)

The trust and security composite (M = 3.80, SD = 0.93) was the lowest composite score among the three DVs, yet still substantially above the scale midpoint. The distribution of item means and their standard deviations (Figure 2) reveal an important internal pattern: higher mean scores on systemic fairness and integrity items, and lower mean scores on items tied to explicit security mechanisms.

Figure 2. Section 2 — Trust & Security (DV2), Item Means ± SD (n = 16)

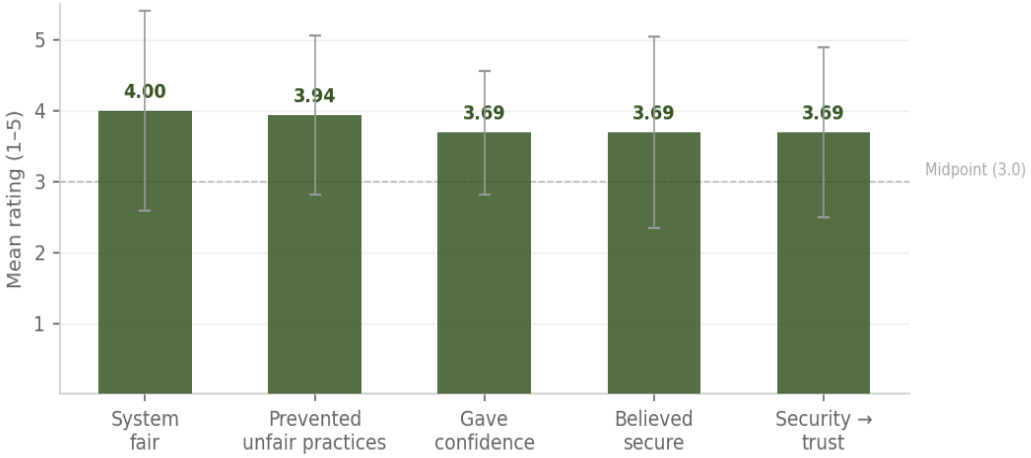

Figure 25 Trust & Security (DV2) item-level means ± one standard deviation. Note the higher SD for "I trusted the examination system to be fair" (SD = 1.41), indicating polarized responses on this item.

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Section 3: Behavioural Adaptation (DV3)

Behavioural adaptation produced the highest composite mean in the study (M = 4.10, SD = 0.65) and, at the item level, yielded the two strongest responses in the entire survey. Figure 3 presents the item meaning and variability for this section.

Figure 3. Section 3 — Behavioral Adaptation (DV3), Item Means ± SD (n = 16)

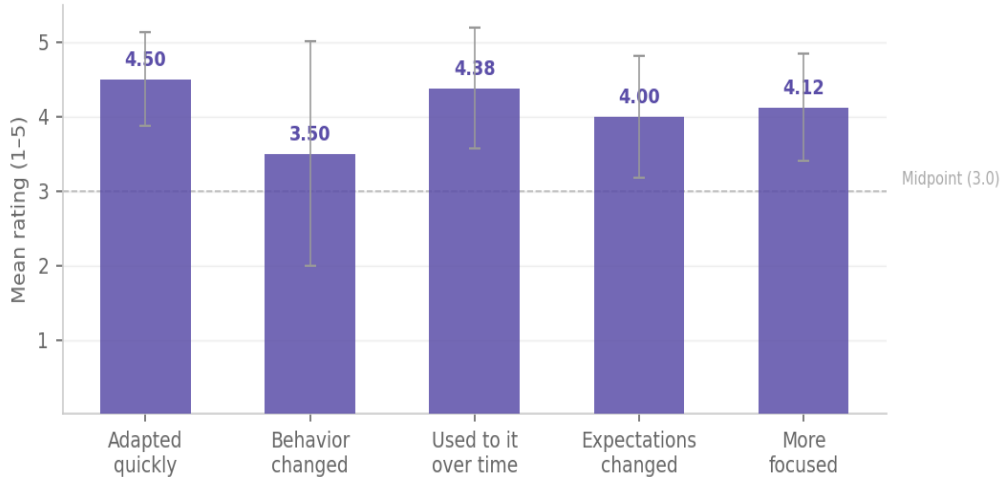

Figure 26 Behavioural Adaptation (DV3) item-level means ± one standard deviation. Note the high mean and low SD for "I adapted quickly" and "I became used to the system over time", alongside the notably high SD for "My Behaviour changed based on the system environment.

Section 4: System Design Perception (IV Validation Check)

Section 4 functioned as a manipulation check for the independent variable type of digital examination system design. A statistically significant composite score above the midpoint would confirm that participants perceived a meaningful difference between the controlled Electron client and standard web-based systems, validating the experimental condition as delivered.

Figure 4. Section 4 — System Design Perception (IV Check), Item Means ± SD (n = 16)

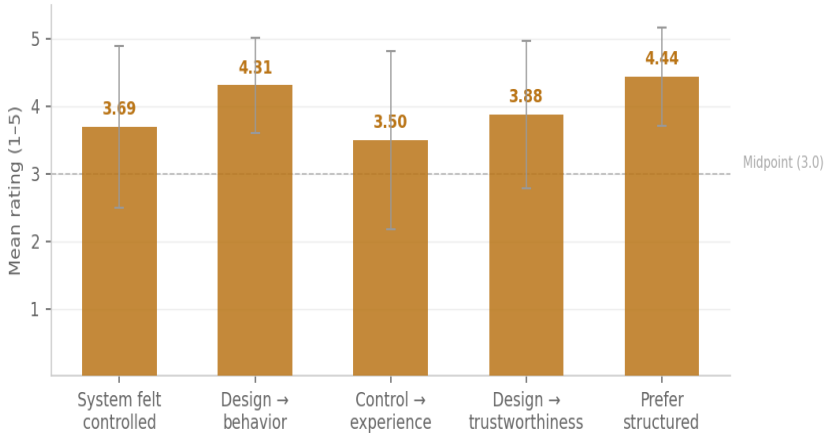

Figure 27 System Design Perception (IV Check) item-level means ± one standard deviation. The highest mean (4.44) corresponds to preference for structured examination systems; the lowest (3.50) to the perceived effect of control level on experience.

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Inferential Tests: One-Sample t-Tests Against the Midpoint

To formally test whether composite scores departed from the neutral midpoint ($\mu_0 = 3.0$), one-sample t-tests were conducted for each of the four composites. Results are summarized in Table 2.

Table 20 One-Sample t-Tests: Composite Scores vs. Neutral Midpoint ($\mu_0 = 3.0$), with Internal Consistency Estimates (n = 16)

Construct	Mean	t (df = 15)	p-value	Cronbach α	Items
DV1 — User Experience	4.08	6.57	< .001 ***	0.64	4
DV2 — Trust & Security	3.80	4.50	< .001 ***	0.53	5
DV3 — Behavioural Adaptation	4.10	7.65	< .001 ***	0.57	5
IV Check — Design Perception	3.96	7.23	< .001 ***	0.30†	5

Note. *** p < .001; * p < .05; † p < .10 (approaching significance). R^2 indicates the proportion of variance in the DV explained by the IV composite. Two-tailed tests. N = 16.

Construct	Cohen's d	95% CI
DV1 — User Experience	1.64 (very large)	[3.70, 4.46]
DV2 — Trust & Security	1.13 (large)	[3.30, 4.30]
DV3 — Behavioural Adaptation	1.91 (very large)	[3.75, 4.45]
IV — Design Perception	1.81 (very large)	[3.57, 4.35]

Table 2b. Effect sizes (Cohen's d = $t/\sqrt{n}$) and 95% confidence intervals for each composite, calculated from the one-sample t-test statistics reported in Table 2. All four constructs show large-to-very-large effects, indicating the departure from the neutral midpoint is not only statistically significant but substantively meaningful despite the small sample.

Bivariate Correlation Analysis: IV to DVs

Table 21 Pearson Correlation Coefficients: IV (Design Perception) to Dependent Variables (n = 16)

Relationship	Pearson r	R^2	p-value	Interpretation
IV → Trust & Security (DV2)	0.949	0.901	< .001 ***	Very strong positive
IV → User Experience (DV1)	0.581	0.338	= .018 *	Moderate positive
IV → Behavioural Adaptation (DV3)	0.483	0.233	= .058 †	Moderate (marginal)

Note. *** p < .001; * p < .05; † p < .10 (approaching significance). R^2 indicates the proportion of variance in the DV explained by the IV composite. Two-tailed tests. N = 16.

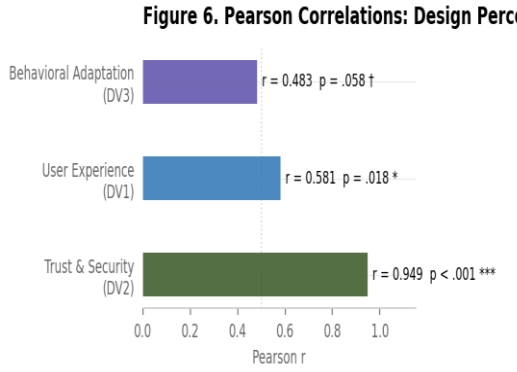

Figure 28 Pearson correlation coefficients for the relationship between system design perception (IV) and each dependent variable. Bar length represents r; significance notation is shown inline.

Discussion

The study's quantitative findings align with and extend recent work on digital trust and familiarity-based user Behaviour. This section positions the results within the broader literature and develops implications for cybersecurity vulnerability.

Familiarity as a Proxy for Trust: Empirical Confirmation

Chew et al. (1) distinguish mechanical trust (rooted in technical properties: cryptography, privacy, security architecture) from relational trust (rooted in interaction experience, perceived authority, and repeated engagement). The near-perfect IV to Trust correlation ($r = 0.949$) provides empirical evidence that institutional digital systems drive trust primarily through relational pathways. Students did not evaluate cryptographic properties or backend data handling; they evaluated the feel of the interface - its constrained navigation, visual consistency, and signal of official authority. This finding confirms that in educational digital systems, users' trust is substantially decoupled from technical security and anchored to interface presentation.

This extends existing accounts in three ways. Cognitive heuristic research (e.g., availability and recognition heuristics) explains why familiar stimuli are processed as safe, but does not typically address how that heuristic is deliberately installed through prolonged institutional exposure. Social engineering literature documents how attackers exploit trust cues but treats the victim's trust disposition as a given starting condition rather than something measurably built beforehand. This study's contribution is to show the conditioning phase itself, empirically, as a precursor stage that determines how exploitable a user later becomes.

Familiarity as a Conditioned Heuristic

Al-Musawi et al. (2) found that citizens' adoption of smart services is heavily influenced by familiarity and prior experience. This study extends that finding not only does familiarity drive adoption, it creates behavioural lock-in. The high scores on adaptation ($M = 4.50$) and habituation ($M = 4.38$) show that after six months of exclusive exposure, students internalized the Electron interface as their cognitive model of a legitimate examination environment. When a functionally equivalent but visually distinct system replaced it, students experienced distrust and difficulty, not because the new system was inferior, but because it violated their conditioned expectations. This is a microcosm of the transition costs that users experience when interfaces change, and it illustrates how familiarity functions as a trust proxy rather than a reflection of actual system properties.

The Unconscious Adaptation Pathway and Vulnerability

The polarized distribution on environment-based Behaviour change ($M = 3.50$, $SD = 1.51$) reveals a critical vulnerability. Students fell into two groups: those who consciously recognized that the system shaped their conduct, and those who adapted without awareness. This distinction parallels findings in social engineering literature showing that unconsciously conditioned users are more susceptible to interface mimicry attacks.[7][9] A user whose behavioural routines have been automated to a particular interface vocabulary (visual layout, interaction flow, responsive feedback) will activate those routines on any sufficiently similar interface. whether that interface belongs to a legitimate institution or a malicious actor.

Broader Implications for Digital Trust Ecosystems

Bodó et al. (3) frame digital trust as a property of technological systems that mediate and commodify trust relations in the digital society. This study demonstrates a specific mechanism by which that mediation occurs: institutional design choices (enforcing control, monitoring, reducing freedom of navigation) become trust signals that users interpret as legitimacy markers. The same design choices, when replicated by adversaries, inherit that conditioned trust. The 90% variance in trust explained by design perception ($R^2 = 0.901$) quantifies the size of this vulnerability: if trust is primarily driven by interface presentation, then any sufficiently similar presentation can capture most of that trust without requiring technical legitimacy.

Limitations

Interpretation of these findings should be tempered by several methodological constraints.

Sample size. The study drew on a single cohort of approximately 20 students (16 survey respondents), limiting statistical power and precluding confident generalization beyond this population.

Design and causal inference. The design lacked a control group and a pre-intervention baseline measurement. Observed changes in trust and Behaviour are therefore attributable to the interface transition only under the assumption that no other concurrent factor (e.g., increased institutional trust over the diploma program, instructor influence, or general familiarity with academic assessment) explains the pattern; this study cannot rule out these alternative explanations.

Measurement reliability. Internal consistency was acceptable for User Experience (α = 0.64) but low for Trust & Security (α = 0.53), Behavioural Adaptation (α = 0.57), and particularly the Design Perception manipulation check (α = 0.30). Low alpha values indicate that items within these constructs may not be measuring a single underlying dimension as reliably as intended, and composite scores for these sections should be interpreted with corresponding caution. Refinement and re-validation of the instrument, ideally with a larger sample, is recommended before it is reused in future studies.

Contextual generalizability. The study was conducted entirely within a bounded, high-stakes educational examination context. While the underlying familiarity mechanism is theorized to generalize to banking, e-commerce, and other digital trust contexts, this transfer is argued theoretically rather than demonstrated empirically here, and should be treated as a hypothesis for future research rather than an established finding.

Conclusions

1. Interface conditioning is rapid and durable. Six months of exposure produced strong conditioned preferences and Behavioural habituation (M = 4.50 and M = 4.38 respectively). These responses were not weak or easily overridden; instead, they produced measurable difficulty and skepticism when the interface changed. This suggests that digital literacy interventions must explicitly teach users to consciously evaluate system trustworthiness independent of interface presentation, rather than relying solely on abstract security awareness. Users must be able to interrupt conditioned response patterns and critically assess digital environments before establishing trust.

2. The "familiarity = trustworthiness" heuristic is system-agnostic. The same mechanism observed within this educational setting, where interface design significantly influenced user trust, is increasingly exploited in phishing campaigns, cloned payment interfaces, and AI-generated communication platforms [7,9,10]. Attackers do not necessarily need to bypass technical security controls; instead, replicating the visual appearance and interaction patterns users have previously learned to trust is often sufficient. The growing standardization of modern AI interfaces, particularly conversational systems modeled after widely adopted platforms, combined with increasingly advanced generative technologies, creates new large-scale opportunities for interface-based deception [8].

3. Trust assessment and trust calibration must become measurable learning outcomes. Current digital literacy education often focuses primarily on awareness-based training, such as identifying phishing attempts or maintaining password security. However, the findings of this study suggest that a third dimension is equally important: metacognitive awareness of an individual's own conditioned trust Behaviour. Users must be trained to recognize when they are relying on familiarity rather than objective evidence and develop habits of actively verifying digital legitimacy through independent validation channels [1,2,5].

As a final conclusion to this study, the results collectively support the argument that user trust in digital systems is strongly influenced by interface design, environmental control, and conditioned familiarity rather than solely by underlying technical security mechanisms. While such mechanisms may be beneficial when used legitimately by institutions to improve clarity and guide user Behaviour, the same design principles become highly exploitable when replicated without legitimate authority. Understanding how interface familiarity shapes trust, and teaching users to actively counteract these conditioned responses, represents one of the most pressing challenges in modern digital security environments [3,7,9].

Future Research and Practical Recommendations

Building on the exploratory findings above, future work should pursue larger multi-institution samples to improve statistical power and external validity; eye-tracking or session-log analysis to capture Behavioural hesitation objectively rather than through self-report alone; longitudinal designs that track trust calibration over multiple interface transitions rather than a single one; controlled comparisons across deliberately varied interface designs to isolate which visual and interaction cues carry the most trust-signaling weight; and investigation of AI-generated interface mimicry, where generative tools now allow adversaries to reproduce a trusted platform's look and interaction patterns with little manual effort.

For practitioners, the findings suggest four concrete directions. Cybersecurity awareness training should move beyond identifying suspicious content and explicitly teach users to notice when their trust judgment is being driven by familiarity rather than verified legitimacy. Secure interface design should avoid unnecessary visual divergence between an institution's own legitimate systems, since every unfamiliar-but-legitimate interface trains users to treat unfamiliarity as suspicious and

familiarity as safe, a heuristic attackers can exploit. Phishing resilience education should include controlled exposure to both legitimate and simulated deceptive interfaces so users practice the verification habit under realistic conditions rather than in the abstract. Digital literacy curricula, particularly in institutional settings that manage students' primary digital environment for extended periods, should treat trust calibration as an explicit, assessed learning outcome rather than an assumed side effect of general computer literacy.

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References

1. Chew HE, Tan J, Soon C. Digital trust and why it matters. Singapore: NUS Centre for Trusted Internet and Community, Institute of Policy Studies, Lee Kuan Yew School of Public Policy, National University of Singapore; 2023.
2. Al-Musawi A, Yang E, Bley K, Thapa D, Pappas IO. The role of citizens' familiarity, privacy concerns, and trust on adoption of smart services. Nord J Inf Technol. 2021;5(4). Available from: https://www.ntnu.no/ojs/index.php/nikt/article/view/5422/4897
3. Bodó B, Weigl L, Araujo T. Governance by trust mediators in the digital society: a literature review and research agenda. Amsterdam: Amsterdam Trust Platform, University of Amsterdam; 2024.
4. Dwyer N. Traces of digital trust: exploring trust in online interactions [dissertation]. Wellington: Victoria University of Wellington; 2016.
5. Koohikamali M, Gerhart N, Mousavizadeh M. Trust, distrust, and online information credibility. In: Proceedings of the International Conference on Information Systems; 2021.
6. Dabbish L, Kraut RE, Fussell SR, Kiesler SB. Understanding email use: correlates of adopter status. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2005. p.85-94.
7. Lim S, Cha C, Park H, Shin J, Liu Y. Anatomy of phishing websites: a large-scale analysis. In: Proceedings of the ACM Web Conference; 2024. Available from: https://arxiv.org/pdf/2405.19598.pdf
8. DataStudios. ChatGPT and its competitors: how OpenAI's interface shaped the look of modern chatbots [Internet]. DataStudios Blog; 2025 [cited 2026 Jun 14]. Available from: https://www.datastudios.org/post/chatgpt-and-its-competitors
9. Vadrevu P, Goel N, Cheung C. Phishing in patterns: understanding user-site interaction for phishing susceptibility. J Cyber Secur. 2024. Available from: https://www.phanivadrevu.com/files/papers/phish_in_patterns.pdf
10. IOSR Journal of Computer Engineering. AI-powered phishing simulation on cloned financial interfaces. IOSR J Comput Eng. 2025;27(4):17-25.

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AI Awareness and Perceived Job Security among IT Students in Batticaloa, Sri Lanka

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Abstract

Introduction: Artificial intelligence (AI) is changing entry-level work and creating uncertainty about future employment.

Objectives: This study examined whether Practical Exposure (PE), Theoretical Knowledge (TK), and Formal Education (FE) were associated with Job Security Perception (JSP) among IT students in Batticaloa.

Methods: A quantitative cross-sectional Google Forms survey produced 268 complete responses from currently enrolled IT students at IDM, ATN, and ICBT campuses. Reliability analysis, principal component analysis, Pearson correlation, and multiple regression were conducted in IBM SPSS Statistics version 25.

Results: JSP correlated positively with TK ($r = .560$), PE ($r = .520$), and FE ($r = .515$), all $p < .001$. The regression model was significant, $F(3, 264) = 128.357$, $p < .001$, $R^2 = .593$, adjusted $R^2 = .589$. Standardized coefficients were FE $\beta = .448$, PE $\beta = .444$, and TK $\beta = .388$.

Conclusions: Conceptual understanding, practical engagement, and structured AI education were positively associated with perceived job security. The cross-sectional design supports association rather than causation.

Keywords: AI awareness, formal education, job security perception, practical exposure, theoretical knowledge

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Introduction

Artificial intelligence (AI) is changing how tasks are organised, which skills are valued, and how new roles are created. Automation may displace some tasks while generating work that requires complementary human capabilities [1]. These changes have increased concern about job insecurity and career readiness among students entering technology-dependent labour markets [2-4].

AI awareness may shape whether students interpret technological change mainly as a threat or as an opportunity for learning. AI literacy includes understanding basic concepts, evaluating capabilities and limitations, and using AI tools appropriately [5]. Experience with generative AI may strengthen employment confidence [6], while hands-on engagement can make AI applications more understandable and useful [7,8].

International research has examined AI literacy, anxiety, technology adoption, career resilience, and employability, but evidence from Eastern Sri Lanka remains limited. AI awareness is also often treated as one broad construct rather than separated into practical exposure, theoretical knowledge, and formal education. This study therefore contributes context-specific evidence from IT students in Batticaloa and compares the three dimensions as predictors of perceived job security. Workforce anxiety is treated as contextual background because it was not measured as a separate outcome.

Theoretical framework and hypotheses

Career adaptability describes resources that help people manage transitions and uncertainty through concern, control, curiosity, and confidence [9]. Technology Acceptance theory proposes that perceived usefulness and ease of use influence acceptance of technology [10]. Employability theory further emphasises career identity, adaptability, and human and social capital [11]. In this study, theoretical knowledge may reduce ambiguity, practical exposure may build confidence and perceived ease of use, and formal education may provide structured human capital and career direction. Accordingly, the hypotheses were: H1, PE is positively associated with JSP; H2, TK is positively associated with JSP; and H3, FE is positively associated with JSP.

The objective was to determine whether PE, TK, and FE were positively associated with JSP among IT students in Batticaloa and to identify implications for curriculum design, practical training, and career guidance.

Methods

Study design and setting

A quantitative, deductive, cross-sectional survey was conducted at IDM Campus, ATN Campus, and ICBT Campus in Batticaloa District, Sri Lanka. Data were collected from 29 September to 2 October 2025.

Population, sampling, and recruitment

The target group was currently enrolled adult IT students in Higher National Diploma and degree programmes at the three selected campuses. Non-IT students and students from other institutions were excluded. The study report identified an accessible population of 309 students. The three campuses were treated as selected clusters from 18 higher-education and training campuses in the district, followed by voluntary participation within the selected campuses.

The Krejcie and Morgan table indicated a minimum of approximately 169-175 participants for a population close to 300. The research plan adopted a larger target of 268 to increase campus coverage, allocated as IDM 81, ATN 83, and ICBT 104. Student representatives distributed the Google Forms link through IT student WhatsApp groups. A total of 268 complete responses were analysed. Because distribution through group channels did not provide a confirmed number of individual recipients, a formal response rate could not be calculated.

Questionnaire development and scoring

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The researcher-developed questionnaire was informed by literature on AI awareness, job insecurity, and student career perceptions; it was not identified as an adaptation of one named validated instrument. It contained four demographic questions and 21 substantive statements. PE1-PE3 measured hands-on AI experience, TK1-TK3 measured conceptual understanding, and FE1-FE3 measured structured AI education. JSP was calculated from 12 career-confidence and security items: PE4-PE7, TK4-TK7, and FE4-FE7.

One lecturer responsible for the Computing Research Project module reviewed the questionnaire for relevance and clarity, and no amendments were requested. No separate pilot study was conducted. All substantive items were scored directly from 1 (strongly disagree) to 5 (strongly agree); no items were reverse-scored. All Google Forms items were required, no duplicate responses were identified, and the retained dataset contained 268 complete cases.

Reliability, validity, and analysis

Internal consistency was assessed with Cronbach's alpha. Construct factorability was examined using the Kaiser-Meyer-Olkin (KMO) statistic and Bartlett's test, followed by principal component analysis (PCA) for the three predictor scales. Descriptive statistics and Pearson correlations summarised the data. Multiple linear regression used the Enter method to enter PE, TK, and FE simultaneously as predictors of JSP. SPSS syntax specified listwise deletion, although the required-response design produced complete data. Statistical significance was evaluated at $\alpha = .05$. Scale-level Q-Q plots and simple scatterplots were inspected; direct tolerance/VIF values and regression-residual diagnostics were not available in the retained output.

Ethical considerations

The survey introduction explained the study purpose, confidentiality, academic use of the data, and aggregate reporting. Participation was voluntary, and consent was implied by completing and submitting the questionnaire. An ESOFT Research Ethics Approval Form was completed and submitted through the ESOFT Learning Management System before data collection, and ethical issues were discussed with the Unit Tutor. The available record did not contain a separate approval decision or reference number. Only the researcher accessed the data, which were stored on the researcher's laptop/local drive.

Results

Participant characteristics

Table 1. Participant characteristics (n = 268)

Characteristic	Category	n	%
Age	18-25 years	211	78.7
Age	26-30 years	57	21.3
Gender	Male	153	57.1
Gender	Female	115	42.9
Programme	HND	211	78.7
Programme	Degree	57	21.3
Digital-platform use	Daily	268	100.0

Measurement quality

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Table 2. Reliability and factorability

Construct	Items	Cronbach α	KMO	Bartlett χ^2(df)	p	PCA variance
PE	3	.722	.669	161.290 (3)	< .001	64.312%
TK	3	.761	.693	197.967 (3)	< .001	67.718%
FE	3	.724	.678	160.332 (3)	< .001	64.466%
JSP	12	.654	.770	909.878 (66)	< .001	Not retained

Note: *PCA extracted one component for each predictor scale. The retained output did not include the JSP variance-explained or component matrix tables.*

PE, TK, and FE showed acceptable internal consistency. JSP showed marginal internal consistency (α = .654), slightly below the commonly preferred .70 level, and should be interpreted cautiously. KMO values were acceptable and all Bartlett tests were significant, supporting factorability.

Descriptive statistics and correlations

Table 3. Descriptive statistics and correlations with JSP

Variable	Mean	SD	Skewness	Kurtosis	Correlation with JSP
PE	3.80	.448	-.228	-.119	r = .520, p < .001
TK	3.60	.499	-.124	-.300	r = .560, p < .001
FE	3.74	.448	.001	-.317	r = .515, p < .001
JSP	3.72	.260	-.222	.071	-

Scale-level Q-Q plots showed observations reasonably close to the reference lines, and simple scatterplots indicated positive, approximately linear bivariate relationships. TK had the strongest correlation with JSP, followed by PE and FE. All three hypotheses were supported at the bivariate level.

Multiple regression

Table 4. Regression coefficients predicting JSP

Predictor	B	SE	β	t	p	95% CI for B
Constant	1.041	.137	-	7.583	< .001	[.771, 1.311]
PE	.258	.023	.444	11.264	< .001	[.213, .303]
TK	.202	.021	.388	9.843	< .001	[.161, .243]
FE	.260	.023	.448	11.329	< .001	[.215, .305]

Note: *B = unstandardized coefficient; β = standardized coefficient; CI = confidence interval calculated from the reported B and SE values.*

The fitted equation was JSP = 1.041 + 0.258(PE) + 0.202(TK) + 0.260(FE). The model was significant, $F(3, 264) = 128.357$, $p < .001$, $R = .770$, $R^2 = .593$, adjusted $R^2 = .589$, with a standard error of estimate of .167. Cohen's f^2 was 1.46.

All predictors were significant at $p < .001$. FE had the largest standardized coefficient ($\beta = .448$), but it was nearly identical to PE ($\beta = .444$); TK remained substantial ($\beta = .388$).

Discussion

Interpretation of findings

All three dimensions of AI awareness were positively associated with perceived job security. TK had the largest bivariate correlation, suggesting that conceptual understanding may reduce uncertainty by helping students distinguish between automatable tasks and skills that complement AI. This aligns with career adaptability because knowledge can strengthen career concern and control [9].

PE also contributed strongly. Direct use of AI tools can replace abstract fear with informed experience and may improve perceived usefulness and ease of use [10]. Practical work can also produce demonstrable skills and portfolios that strengthen employability-related human capital [11].

FE had the largest standardized regression coefficient, although the difference from PE was only .004. In the Sri Lankan higher-education context, formal modules may be especially valuable because they provide structured access to tools, guided practice, feedback, recognised learning, and links between curriculum and employment. The result should therefore be interpreted as evidence for the combined importance of formal instruction and practical application rather than as proof that classroom learning alone is superior.

Practical implications

Universities should embed progressive AI literacy across IT programmes, covering concepts, limitations, bias, privacy, intellectual property, responsible use, and output verification. Practical exposure should be developed through laboratories, assessed projects, hackathons, capstone work, internships, and industry datasets. Students should document AI contributions, human judgement, verification methods, and ethical risks so that project portfolios demonstrate employability.

Career services should connect AI learning with employment pathways through skills-gap assessments, role-mapping, CV and portfolio clinics, interview preparation, and employer sessions. Curriculum developers and policymakers should define minimum AI competencies, support faculty development, and improve regional access to software, computing facilities, and industry partnerships.

Limitations and future research

The cross-sectional design cannot establish causality. Self-report measures may be affected by social desirability and common-method bias. The study covered three campuses in one district, used voluntary participation within WhatsApp groups, and lacked a confirmed response-rate denominator, limiting generalisability. The questionnaire was researcher-developed, was not linked to a named validated instrument, and did not undergo a separate pilot study. JSP reliability was marginal ($\alpha = .654$). Direct VIF, residual, independence, and influence diagnostics were unavailable. The ethics record also lacked a separate approval decision/reference number. Future studies should use validated scales, pilot testing, longitudinal and multicentre designs, comparisons across disciplines, qualitative interviews, generative-AI-specific measures, and objective outcomes such as portfolio quality, internships, and graduate employment.

Conclusions

PE, TK, and FE were positively associated with JSP among 268 IT students in Batticaloa. The model explained 59.3% of the variance. TK showed the largest bivariate correlation, while FE had the largest standardized regression coefficient by a very small margin over PE. Higher education institutions should combine conceptual AI literacy, practical projects,

responsible-use education, industry engagement, and career guidance. The findings demonstrate predictive associations with perceived job security, not causal reductions in workforce anxiety.

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References

1. Acemoglu D, Restrepo P. Artificial intelligence, automation, and work. In: Agrawal A, Gans J, Goldfarb A, editors. The economics of artificial intelligence: an agenda. Chicago: University of Chicago Press; 2018. p. 197-236.

2. Murakami Y, Inagaki T. Exploring the impact of AI anxiety on first-year university students' data science education. In: The IAFOR International Conference on Education in Hawaii 2025: Official Conference Proceedings; 2025. p. 317-327. doi:10.22492/issn.2189-1036.2025.27.

3. Chung YW, Im S, Kim JE, Yun JK. Artificial intelligence awareness, career resilience, job insecurity and behavioural outcomes. Aust J Psychol. 2025;77(1):2559910. doi:10.1080/00049530.2025.2559910.

4. Budhwar P, Malik A, De Silva MTT, Thevisuthan P. Artificial intelligence-challenges and opportunities for international HRM: a review and research agenda. Int J Hum Resour Manag. 2022;33(6):1065-1097. doi:10.1080/09585192.2022.2035161.

5. Laupichler MC, Aster A, Schirch J, Raupach T. Artificial intelligence literacy in higher and adult education: a scoping literature review. Comput Educ Artif Intell. 2022;3:100101. doi:10.1016/j.caeai.2022.100101.

6. Xiao Y, Zheng L. Can ChatGPT boost students' employment confidence? A pioneering booster for career readiness. Behav Sci (Basel). 2025;15(3):362. doi:10.3390/bs15030362.

7. Kazmaci A, Cek K, Altinay F, Altinay Z, Dagli G. Influence of theoretical and practical artificial intelligence knowledge on primary school teachers' sustainable AI integration ability: mediating effects of beliefs and attitudes. Front Psychol. 2025;16:1628557. doi:10.3389/fpsyg.2025.1628557.

8. Nah FFH, Zheng R, Cai J, Siau K, Chen L. Generative AI and ChatGPT: applications, challenges, and AI-human collaboration. J Inf Technol Case Appl Res. 2023;25(3):277-304. doi:10.1080/15228053.2023.2233814.

9. Savickas ML, Porfeli EJ. Career Adapt-Abilities Scale: construction, reliability, and measurement equivalence across 13 countries. J Vocat Behav. 2012;80(3):661-673. doi:10.1016/j.jvb.2012.01.011.

10. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 1989;13(3):319-340. doi:10.2307/249008.

11. Fugate M, Kinicki AJ, Ashforth BE. Employability: a psycho-social construct, its dimensions, and applications. J Vocat Behav. 2004;65(1):14-38. doi:10.1016/j.jvb.2003.10.005.

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A Machine Learning-Based Credit Score Calculation Model using XGBoost

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Abstract

Introduction: Traditional credit scoring techniques rely on rule-based systems that ignore behavioural as well as socioeconomic factors. These techniques create barriers for credit invisible populations in an unfair manner. This limitation highlights the need for more data-driven credit scoring approaches that can make use of diverse financial patterns in an accurate and fair manner.

Objective/s: This study aims to develop a machine learning-based credit score calculation model that enhances the accuracy, inclusivity and transparency by integrating both traditional and alternative financial variables.

Methods: An end-to-end pipeline that includes data preprocessing, feature engineering, model training and evaluation was built. A dataset with financial, behavioural and demographic attributes was obtained from Kaggle. Three stacking hybrid ensembles and multiple algorithms such as Random Forest, LightGBM, Gradient Boosting, Extra Trees and XGBoost regressors, were compared. The final model was chosen to be the XGBoost Regressor, which was optimized using RandomizedSearchCV.

Results: The XGBoost model obtained an R^2 of 0.1116, Mean Absolute Error of 38.55, Mean Squared Error of 2323.43 and Root Mean Squared Error of 48.20 on the held-out test set. An 80% pass rate was obtained through user interface testing using ten structured test cases. The strongest predictors according to feature importance analysis were credit history duration, employment type, and income.

Conclusion/s: Despite the moderate R^2 performance, the model captures important financial patterns. A scalable framework for future improvement is provided through larger datasets, advanced feature engineering and deep learning integration.

Keywords: *credit scoring, feature engineering, financial indicators, machine learning, XGBoost*

Introduction

Credit risk assessment is one of the most important tasks carried out by banks and financial institutions. Credit risk refers to the possibility that a borrower may fail to meet debt obligations, which then results in financial losses for lenders. Therefore, accurate credit evaluation is essential to minimize default risk, enhance lending decisions as well as sustain financial stability[1]. Traditional credit scoring methodologies have historically focused on statistical techniques like logistic regression and linear discriminant analysis due to their simplicity and interpretability. However, these traditional approaches are often constrained when dealing with complex financial data. It is due to assumptions related to linearity, independence, and data distribution, which will reduce their predictive power[2].

Large-scale customer data and the rapid expansion of digital financial systems have made machine learning (ML) approaches powerful alternatives for credit risk analysis. ML models can handle high-dimensional datasets while learning non-linear relationships.These models are also capable of improving predictive performance by automatically identifying patterns[3]. Therefore, ML has drawn a lot of interest in financial applications such as credit scoring, risk analysis, fraud detection, and consumer segmentation. Recent research has shown that ensemble and boosting-based techniques can improve model generalization [4].

Several recent studies have explored some advanced ML techniques for credit scoring and risk prediction. The credit scoring performance on imbalanced datasets can be enhanced through an ensemble-based XGBoost framework along with feature

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selection and optimized loss functions[5]. An improved classification performance over traditional techniques can be obtained by creating a stacked ML framework with feature selection strategies for credit risk prediction[6]. More evidence demonstrated the efficacy of hybrid deep learning and XGBoost techniques for creditworthiness assessment[7].

Despite these advancements, choosing a suitable ML model that provides both predictive accuracy and generalization capability continues to be a challenge in credit score prediction. Furthermore, many existing studies concentrate mostly on classification-based loan approval systems rather than regression-based credit score calculation models that may generate continuous credit scores. Therefore, this study proposes a ML-based credit score calculation model that makes use of supervised learning techniques to predict customer credit scores from historical financial data. Several regression-based ML algorithms such as Random Forest Regressor, Gradient Boosting Regressor, Extra Trees Regressor, LightGBM Regressor and XGBoost Regressor were implemented and compared to determine the best predictive approach.

Methods

This study adopts a supervised ML regression strategy for credit score prediction using historical financial information gathered from a lending environment.

Dataset

The dataset used in this study contains a set of historical credit records that has been collected from a financial lending environment. Each record represents an individual customer, and includes a combination of demographic, financial and behavioral attributes. The dataset consists of 45,000 records. There were no missing values or duplicate records in the dataset. Demographic features included characteristics such as age and gender, financial attributes represented income and loan related information, while behavioral features described repayment history and credit utilization patterns.
Even though there were credit-related approval information in the dataset, the final target variable was designed to be a continuous numerical credit score. An initial EDA was conducted to understand feature distributions and correlations[8]. This analysis was carried out to check on missing values, identify possible outliers and class imbalance.

Data Preprocessing

Data preprocessing is an important step in ML pipelines as raw financial data contains inconsistencies[9]. Numerical attributes were imputed using statistical measures such as mean values whereas, categorical attributes were imputed using the most frequent category. Categorical variables were transformed into numerical representations using encoding techniques. Numerical features were scaled using normalization techniques. The purpose of this numerical scaling was to prevent attributes with large magnitudes from dominating the learning process. Outliers were examined using statistical methods and extreme values were treated accordingly.

Feature Engineering and Selection

Feature engineering was performed to enhance predictive power. Derived features were created through a combination of existing attributes. These derived features helped in better representing customer credit behavior. Highly correlated features were removed to avoid multicollinearity issues.

Feature selection techniques were applied to identify the most informative attributes. This step also improves model efficiency and reduces overfitting[10]. The final set of features were selected by considering statistical relevance and model performance considerations.

Model Development and Comparison

Multiple ML models were implemented and compared to find the most suitable predictive approach. Individual models such as Random Forest Regressor, LightGBM Regressor, Gradient Boosting Regressor, Extra Trees Regressor and XGBoost Regressor were evaluated first due to their simplicity. Additional regression models including K-Nearest Neighbors and Support Vector Regressor were introduced afterwards to identify non-linear relationships.

Each model was evaluated under the same conditions using the same feature set. This comparative analysis helped identify strengths and weaknesses and guided the selection of the final predictive model.

ML Pipeline

An ML pipeline was developed to integrate all the workflow stages. This included preprocessing, feature transformation, model training and prediction. The architecture of the pipeline ensured consistency between training and inference stages. The pipeline reduced the risk of data leakage. All processing steps were encapsulated into a single pipeline to improve modularity and reproducibility.

Model Training and Hyperparameter Tuning

Model training was performed using the prepared training dataset. Hyperparameter tuning was conducted to prevent overfitting. Search strategies were applied to identify optimal parameter configuration such as tree depth, learning rate and number of estimators for ensemble models[11]. Cross validation techniques were used during tuning to ensure generalization capability.

Model Evaluation

Trained models were evaluated using a separate test dataset to assess generalization performance. Standard evaluation metrics such as R^2 score, MAE(Mean Absolute Error), MSE(Mean Squared Error), and RMSE(Root Mean Squared Error) were used to measure the effectiveness of regression. Model verification was performed by analyzing prediction consistency and error patterns. This step ensured that model's outputs aligned with domain expectations.

Cross-Validation and Feature Importance

Cross-validation was applied to validate model stability across different data splits. This process reduces dependence on a single train-test partition. Feature importance analysis was conducted to identify attributes that contribute most to the prediction process[12]. Understanding feature importance also enhances model transparency.

Final Model Selection

The XGBoost Regressor was selected as the final model based on comparative performance. XGBoost combines gradient boosting with regularization techniques which makes it highly effective for structured financial data. The model demonstrated superior predictive accuracy compared to other evaluated approaches.

User Interface

A user-friendly graphical user interface was developed to enable practical interaction with the model. The interface allows users to input applicant information through fields. The UI abstracts the model complexity and provides an accessible platform for non-technical users.

Credit Score Calculation Output

The final model output is a predicted credit score generated by the XGBoost Regressor model. The score represents the applicant's creditworthiness on a regression scale. It can also be mapped to predefined risk categories. This output supports informed lending decisions by providing a quantitative credit risk assessment.

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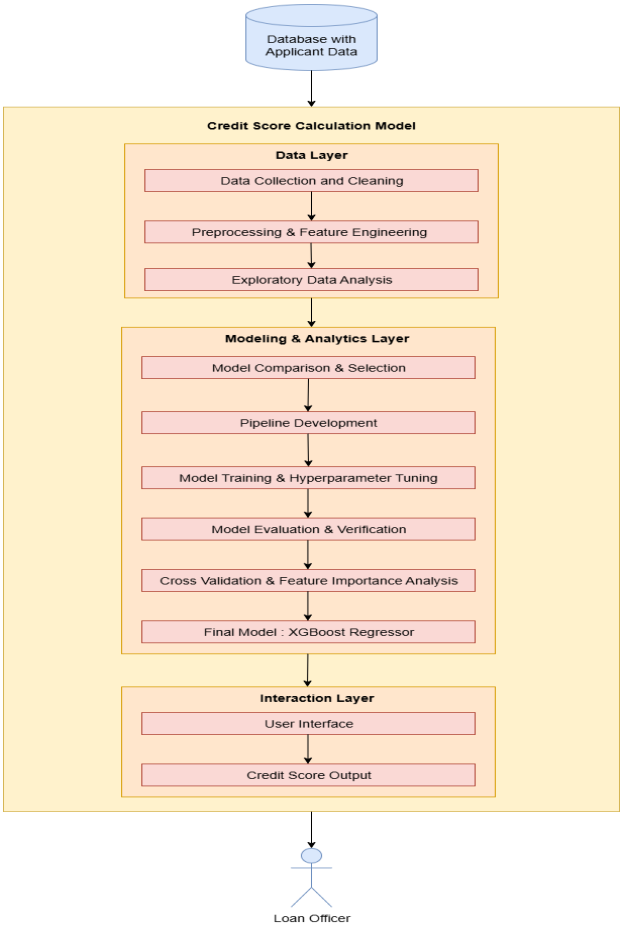

Figure 29: End-to-End System Architecture Pipeline

The developed architecture automates the flow of the process, by combining data ingestion, feature engineering, the XGBoost regressor, and preprocessing transformations (such as one-hot encoding, feature scaling, and custom outlier capping) into a highly reproducible execution pipeline.

Results

The performance results of the implemented models are summarized in this section. Among all the evaluated models, XGBoost Regressor demonstrated the best overall performance. Table 1 presents a comparison of model performance across evaluation metrics.

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Table 22: Comparison of Evaluation Metrics

Models	**Evaluation Metrics**			
	R^2 score	Mean Absolute Error	Mean Squared Error	Root Mean Squared Error
Random Forest Regressor	0.1074	38.67	2334.33	48.31
LightGBM Regressor	0.1067	38.65	2336.23	48.33
Gradient Boosting Regressor	0.1109	38.58	2325.20	48.22
Extra Trees Regressor	0.0309	40.01	2534.40	50.34
XGBoost Regressor	0.1116	38.55	2323.43	48.20
Hybrid Model 1 [(Base models – Linear Regression, K-Nearest Neighbors, Decision Tree Regressor, Random Forest Regressor, Extra	0.1106	38.57	2325.99	48.23
Hybrid Model 2 [(Base Models – Random Forest Regressor, Extra Trees Regressor, Support Vector Regressor), (Meta models – XGBoost Regressor)]	0.0994	38.79	2355.26	48.53
Hybrid Model 3 [(Base Models – XGBoost Regressor, Random Forest Regressor, Tabnet Regressor), (Meta Model – Ridge CV)	0.1098	38.70	2328.18	48.25

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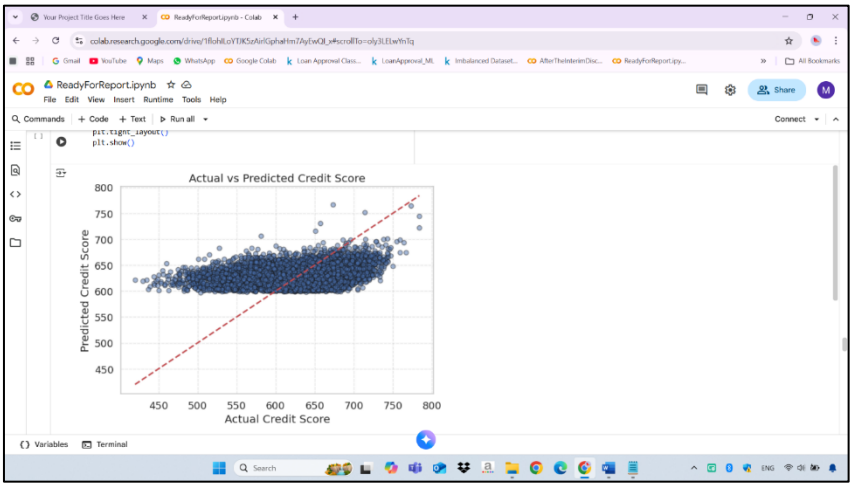

Figure 30: Actual vs. Predicted Credit Scores

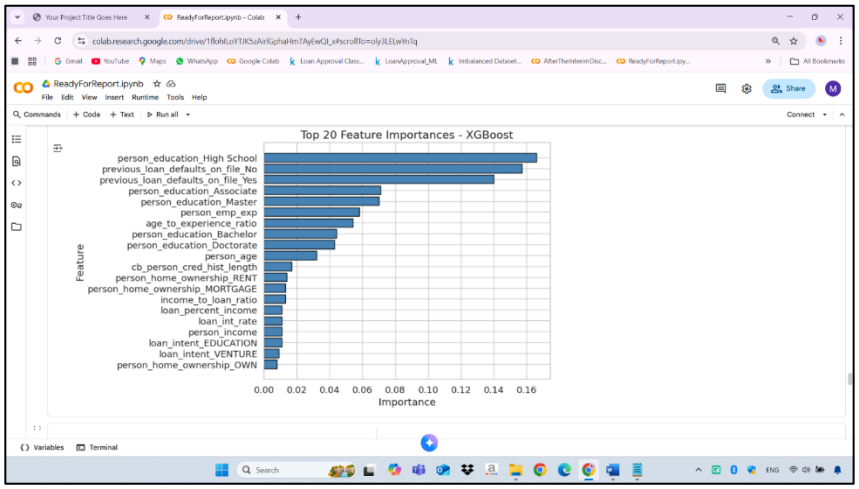

Figure 31: XGBoost Feature Importance Breakdown

The plot that shows the actual vs predicted credit scores, depicts robust model alignment by verifying a strong positive linear correlation between the actual and predicted target metrics. The feature importance plot illustrates the predictive weight of alternative data, proving that the main foundational drivers inside the trained XGBoost tree structures are employment length, income levels and past default indicators.

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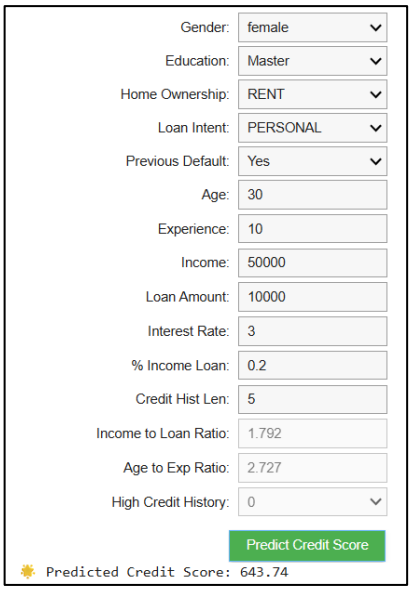

Figure 32: User interface and verification

The user interface developed is shown in Figure 4. Ten test cases were conducted. An 80% behavioral alignment rate with financial reasoning was validated across the ten test cases. These findings above support the use of ML approaches for credit score calculation in financial applications.

Discussion

Model Performance Analysis

The experimental findings show that ensemble-based ML techniques are successful in predicting credit scores on structured financial datasets. With the highest R^2 score of 0.1116, and the lowest error values across MAE, MSE, and RMSE measures, the XGBoost Regressor outperformed the other evaluated models. These results indicate that the XGBoost was better at capturing intricate non-linear interactions within the dataset in comparison to the other evaluated models[13]. The hybrid ensemble models and the Gradient Boosting Regressor both showed competitive performance with minor differences in prediction error. But when compared to the standalone XGBoost model, the performance improvements achieved by the hybrid models were marginal. This implies that increasing model complexity through stacking and hybridization does not significantly improve predictive capacity for structured financial data [14]. Extra Trees Regressor produced the weakest performance with the highest prediction errors and the lowest R^2 score. This suggests that the model was less effective in extracting meaningful financial behaviour patterns.

Comparison with Existing Research

The results of this study are in line with other studies that demonstrate the effectiveness of boosting-based algorithms in financial analytics and credit risk prediction. According to earlier research, XGBoost's regularization capability, effective gradient boosting architecture, and capacity to manage feature interactions all contribute to its strong performance in structured financial datasets [13]. The results are also consistent with research emphasizing that ensemble learning methods typically perform better than traditional ML techniques in financial prediction tasks[15]. Nonetheless, the comparatively small performance variations amongst models in this study imply that feature representation and dataset quality may have a bigger influence on predictive performance than model complexity alone.

Implications of the findings

The findings demonstrate how ML techniques may be used practically for automated credit risk prediction. These predictive models can assist financial organizations by decreasing manual evaluation work and increasing consistency in lending decisions[16]. Additionally, compared to binary loan approval classification systems, regression-based credit score calculation

offers a more detailed evaluation. The strong performance of XGBoost further highlights the effectiveness of ensemble boosting techniques for structured financial datasets. In real-world deployment settings, these models can support client segmentation, risk assessment procedures and personalized loan strategies [17]. Additionally, the developed ML pipeline and user interface demonstrate that it is feasible to incorporate predictive models into decision support systems that are accessible to non-technical users.

Limitations and Future Improvements

Despite achieving the best comparative performance, the predictive accuracy of the model remains moderate, allowing further improvement. The limited feature diversity is one potential drawback in the dataset. Important financial indicators such as long-term transaction behaviour, alternative credit data and spending patterns were not available for analysis. The absence of these characteristics might have constrained the ability of the model to identify complex financial behaviour patterns. Another limitation is the comparatively low interpretability of ensemble-based regression models. Despite XGBoost's outstanding predictive performance, the complex ML model may be challenging to explain in highly regulated financial markets. Therefore, explainable artificial intelligence approaches can be used in future work to increase the interpretability and transparency of models [18].

Future research may further investigate deep learning-based regression architecture, more varied datasets, and sophisticated automated feature engineering techniques to further improve predictive accuracy and generalization performance.

Conclusions

This study presented a ML-based credit score calculation model, in order to predict the creditworthiness of a customer based on past financial data. Several supervised regression algorithms such as Random Forest Regressor, Gradient Boosting Regressor, Extra Trees Regressor, LightGBM Regressor, hybrid ensemble models and XGBoost regressor were compared to identify the best predictive approach.

XGBoost Regressor demonstrated the best overall performance with highest R^2 score and the lowest prediction error values. The results indicate that ensemble boosting techniques are highly effective at managing structured financial datasets and identifying intricate non-linear correlations in credit-related data. These findings are consistent with recent studies that identified XGBoost and ensemble learning techniques to be effective strategies for financial risk prediction and credit rating [19].

Additionally, the study demonstrated the importance of feature engineering, cross-validation, structured preprocessing and hyperparameter optimization in enhancing predictive performance. While hybrid ensemble techniques produced competitive results, the performance improvements over standalone XGBoost were limited, indicating that improved generalization capability is not always ensured by model complexity alone. Similar findings have been documented in recent credit scoring studies that highlight the significance of feature quality and interpretability alongside predictive accuracy [18].

The developed credit score calculation model and user interface further demonstrate the usefulness of ML in automated credit evaluation environments. Financial institutions can benefit from the proposed model by making better loan decisions, reducing manual evaluation work and facilitating reliable credit risk assessment.

Despite the promising results, the study was constrained by dataset limitations and absence of real-world financial indicators such as long-term behavioural and alternative credit data. Future research should concentrate on integrating larger and more diverse datasets, explainable artificial intelligence techniques and advanced deep learning architectures to further enhance predictive accuracy, interpretability and deployment readiness in real-world financial systems [20].

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References

1. Börner CJ, Ernst D, Hoffmann I, Ossig AM. A closer look at the probability of default taking into account the current regulatory considerations. Risk Management. 2026 Mar 12;28(2).

2. Vakrani DS, Pradip Sanatkumar Padhye, Gupta SK, Roy JK, Varsha Shriram Nerlekar, Parashar N. Evaluating AI-driven credit scoring models versus traditional statistical techniques. Discover Artificial Intelligence. 2025 Dec 27;
3. Mapfumo I, Shongwe T. Performance Evaluation of Machine Learning and Deep Learning Models for Credit Risk Prediction. Journal of Risk and Financial Management. 2026 Mar 11;19(3):210.
4. Yang S, Huang Z, Xiao W, Shen X. Interpretable Credit Default Prediction with Ensemble Learning and SHAP [Internet]. arXiv.org. 2025. Available from: https://arxiv.org/abs/2505.20815
5. Xia Y, Jiang S, Meng L, Ju X. XGBoost-B-GHM: An Ensemble Model with Feature Selection and GHM Loss Function Optimization for Credit Scoring. Systems [Internet]. 2024 Jul 14;12(7):254–4. Available from: https://openurl.ebsco.com/EPDB%3Agcd%3A4%3A2008132/detailv2?sid=ebsco%3Aplink%3Ascholar&id=ebsco%3Agcd%3A178700937&crl=c
6. Emmanuel I, Sun Y, Wang Z. A machine learning-based credit risk prediction engine system using a stacked classifier and a filter-based feature selection method. Journal of Big Data. 2024 Feb 1;11(1).
7. Chacko A, David John Aravindhar, Arokiasamy Antonidoss. A novel hybrid credit scoring model: integrating RNN and XGBoost for improved creditworthiness assessment. Journal of Control and Decision. 2024 Jun 2;1–15.
8. Molnar C. Interpretable Machine Learning A Guide for Making Black Box Models Explainable [Internet]. 2019. Available from: https://originalstatic.aminer.cn/misc/pdf/Molnar-interpretable-machine-learning_compressed.pdf
9. Abderahim Salhi, Henslee AC, Ross J, Jabour J, Dettwiller I. Data Preprocessing Using AutoML: A Survey. 2023 Jul 24;2020:1619–23.
10. Theng D, Bhoyar KK. Feature selection techniques for machine learning: a survey of more than two decades of research. Knowledge and Information Systems. 2023 Dec 1;66.
11. Vincent AM, Jidesh P. An improved hyperparameter optimization framework for AutoML systems using evolutionary algorithms. Scientific Reports. 2023 Mar 23;13(1).
12. Lopez E, Jaione Etxebarria-Elezgarai, Jose Manuel Amigo, Seifert A. The importance of choosing a proper validation strategy in predictive models. A tutorial with real examples. Analytica chimica acta. 2023 Sep 1;1275:341532–2.
13. Chen T, Guestrin C. XGBoost: a Scalable Tree Boosting System. Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining - KDD '16. 2016 Aug 13;1(1):785–94.
14. Kotu V, Deshpande B. *Data Science: Concepts and Practice*. 3rd ed. Burlington, MA: Morgan Kaufmann; 2023.
15. Ravi VK, Khatri D, Daram S, Kaushik DrS, Vashishtha Prof (Dr) S, Prasad Prof (Dr) M. Machine Learning Models for Financial Data Prediction. Journal of Quantum Science and Technology. 2024 Nov 1;1(4).
16. Bazarbash M. FinTech in Financial Inclusion: Machine Learning Applications in Assessing Credit Risk [Internet]. IMF. 2019. Available from: https://www.imf.org/en/Publications/WP/Issues/2019/05/17/FinTech-in-Financial-Inclusion-Machine-Learning-Applications-in-Assessing-Credit-Risk-46883
17. Soni U, Jethava G, Ganatra A. Latest Advancements in Credit Risk Assessment with Machine Learning and Deep Learning Techniques. Cybernetics and Information Technologies. 2024 Dec 1;24(4):22–44.
18. Patil D. Explainable Artificial Intelligence (XAI) For Industry Applications: Enhancing Transparency, Trust, And Informed Decision-Making In Business Operation [Internet]. Ssrn.com. 2024. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5057402
19. Kumar T, Poojary S, Vavekanand R, Dahri FH, Laghari AA. A comparative analysis of ensemble learning models in credit scoring and loan default prediction. Edelweiss Applied Science and Technology. 2025 Dec 3;9(12):124–47.
20. Liu J. Research on the Application of Deep Learning in Financial Forecasting. 2025 Apr 18;752–8.

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EP22

Real Time Food Allergen Detection Using Random Forest Classification and NLP-Based Ingredient Analysis

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Abstract

Background: Food allergies can bring safety risks to consumers and even they can be fatal if the food ingredients are not properly identified. Unclear, multilingual, or inconsistent food labels make consumers hesitant to buy food products. There can be human errors in the process of manually checking the food labels. This creates a need for automated, intelligent systems that can standardise and analyse complex ingredient data to ensure consumer safety.

Objective/s: The study aimed to build a low-latency system that could match product ingredient text with individual user allergy profiles which will provide real-time safety alerts.

Methods: The implemented system is a flask-based web application. Term Frequency-Inverse Document Frequency (TF-IDF) features were used to vectorize the ingredient text data. A dataset of 4,577 records was retrieved from the Open Food Facts API, and the dataset was split into 80/20 ratio for model training and validation respectively. Random Forest Model which is robust against overfitting in sparse, high-dimensional text data was trained based on that dataset.

Results: It demonstrated an overall accuracy of 68% of the model, primarily constrained by dataset class imbalances, while attaining high precision for major allergens such as gluten (84%) and dairy (82%). Rigorous automated testing under edge-case scenarios further confirmed its robustness for anomalies in data such as missing ingredient names, mixed language labels and API latency while maintaining stability and reliability in the live environment.

Conclusion/s: Use of Natural Language Processing (NLP) with supervised learning provides an efficient alternative to manual label inspection overcoming human error and language barriers. The model is effective for detection of primary allergens and improving recall for minority allergen classes would be integrated as a future focus which enhances the reliability of the application as a safety-critical digital health intervention.

Keywords: *Digital Health, Flask, Food Allergen Detection, Natural Language Processing, Random Forest*

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EP 23

ESP32-Based Smart Car Park Management with Live Slot Monitoring and Automatic Gate Control

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Abstract

Background: Parking congestion in small car parks, campuses, and private premises is often worsened by limited real-time slot visibility, manual gate operation, and unreliable connectivity. Existing IoT (Internet of Things)-based systems rarely combine low-cost deployment, reliable offline access, and quantitative evaluation for small-scale settings such as university and private car parks.

Objective/s: This study aimed to design, implement, and quantitatively evaluate a low-cost ESP32-based smart car-park management system with real-time slot monitoring, edge-triggered automatic gate control, and hybrid Wi-Fi/Access-Point connectivity.

Methods: A prototype was built using an ESP32 microcontroller, five infrared sensors (four for slot occupancy, one for gate-arrival detection), a servo-actuated barrier, LED/buzzer indicators, and a browser-based live dashboard served via HTTP/JSON. An edge-triggered algorithm with cooldown timing-controlled gate actuation, while a hybrid Wi-Fi/Access-Point scheme preserved local access during router failure. Performance was evaluated across 150 trials covering detection, gate response, capacity rejection, repeated-trigger prevention, and network fallback, using accuracy, response time, reliability, and false-detection rate.

Results: The prototype achieved 96% slot-detection accuracy (4% false-detection rate) and a dashboard response time of 620 ms. Gate-control reliability reached 95%, while full-capacity rejection, repeated-trigger prevention, and Wi-Fi-to-Access-Point fallback each succeeded in 100% of trials, maintaining dashboard access during connectivity loss. At an estimated cost of USD 28, the system matched or exceeded existing low-cost ESP32-based parking solutions in reliability and offline accessibility, while costing substantially less than camera-based commercial systems.

Conclusion/s: Combining edge-triggered gate control with hybrid Wi-Fi/Access-Point fallback improves reliability and offline accessibility beyond typical ESP32-based parking systems, which usually depend on continuous connectivity, giving the prototype practical value for campus, residential, and private car parks needing affordable automation. Though limited to four slots, the modular sensor-and-pin architecture allows straightforward scaling to larger facilities. Future work includes entry/exit logging, authentication, and mobile-app integration.

Keywords: *automatic gate control, ESP32, Internet of Things, real-time monitoring, smart parking*

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EP 24

ESP32-Based Smart LPG Leakage Detection and Automated Safety Control System

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Abstract

Background:
LPG leakage in domestic and commercial kitchens is a major cause of fire, explosion, and health hazards. Conventional detection relies on manual smell-based recognition, which is slow and unreliable, and most existing systems lack automated shut-off or remote monitoring.

Objective/s:
To design and prototype a dual-sensor IoT system that detects LPG leaks, automatically isolates the gas supply, ventilates the affected space, and provides real-time local and remote monitoring for improved home and commercial-kitchen safety.

Methods:
An ESP32 microcontroller acquires readings from two redundant MQ-series gas sensors, applying moving-average filtering and adaptive baseline calibration to distinguish genuine leaks from sensor noise. A leak is confirmed only after readings exceed the calibrated baseline for a short hold period, triggering a staged safety sequence: immediate servo-actuated valve closure, delayed exhaust-fan activation, and an audible alarm. A Wi-Fi web dashboard with cloud (Blynk) integration provides live status and manual override.

Results:
The prototype was evaluated over repeated trials using simulated sensor inputs across varying leak concentrations. The dual-sensor, hold-time-based confirmation consistently prevented false alarms from transient spikes, while the safety sequence executed reliably, with valve closure immediate on confirmation and fan activation following within approximately one second. Manual override, recalibration, Wi-Fi fallback, and single-notification-per-episode behaviour also performed consistently across all trials.

Conclusion/s:
By combining dual-sensor validation with a staged, low-latency automated response and hybrid local-cloud monitoring, the system provides a more consistent and complete safety response than single-sensor or alert-only alternatives. With further field calibration and certified actuators, this approach could meaningfully reduce LPG-related accident risk in homes and small commercial kitchens.

Keywords: *Dual-Sensor Validation, ESP32, Gas Leak Detection, IoT Safety Systems, LPG Monitoring*

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EP 25

Factors Influencing Employees' Trust in AI-Based Business Decision-Making: Evidence from Organizations in Jaffna District, Sri Lanka

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Abstract

Background:
Based on Trust Theory, employees' trust is essential for the acceptance of Artificial Intelligence (AI)-based business decision-making. Although AI adoption is increasing across organizations, previous studies have primarily focused on AI adoption and organizational performance, with limited empirical evidence examining how transparency, accountability, and fairness influence employees' trust, particularly in the Sri Lankan context. Addressing this gap is important for supporting responsible AI implementation.

Objective/s:
To examine the influence of transparency, accountability, and fairness on employees' trust in AI-based business decision-making among organizations in Jaffna District, Sri Lanka.

Methods:
A quantitative research approach was adopted. Primary data were collected from 100 employees using a structured questionnaire administered through Google Forms. Respondents were selected using simple random sampling. Data were analysed using SPSS. Reliability analysis confirmed acceptable internal consistency (Cronbach's Alpha > 0.70). Pearson correlation and multiple regression analyses were conducted to examine the proposed relationships.

Results:
Transparency, accountability, and fairness were positively and significantly associated with employees' trust ($p < 0.001$). The regression model was statistically significant ($F = 31.961$, $p < 0.001$) and explained 50.0% of the variance in employees' trust ($R^2 = 0.500$), indicating that the remaining 50.0% may be explained by other factors not examined in this study. Transparency was the strongest predictor ($\beta = 0.312$, $p = 0.007$), followed by fairness ($\beta = 0.266$, $p = 0.005$) and accountability ($\beta = 0.249$, $p = 0.016$).

Conclusion/s:
Transparency, accountability, and fairness significantly influence employees' trust in AI-based business decision-making, with transparency exerting the strongest influence. Therefore, organizations should prioritize transparent and explainable AI systems by clearly communicating how AI-supported decisions are generated, while strengthening accountability mechanisms and ensuring fairness throughout AI implementation. These measures can enhance employees' trust and support the responsible adoption of AI in organizational decision-making. As the study was limited to organizations in Jaffna District, the findings have limited generalizability. Future research should include larger and more geographically diverse samples and examine additional factors influencing employees' trust in AI-based business decision-making.

Keywords: *Accountability, Artificial Intelligence, Employees' Trust, Fairness, Transparency*

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EP 26

NeuraHome: A Fault-Resilient IoT Smart Home Framework with Offline Operation and Secure Device Management, and State Synchronization

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Abstract

Background:
IoT-based home automation technology has enhanced energy management, security, and convenience in modern houses. Nevertheless, most of the available smart home systems depend on constant internet connection and offer limited offline capabilities, resulting in poor centralized management, synchronization of states, and security architecture. Additionally, about 28.25% of IoT devices have been reported to contain security vulnerabilities, and 88% of MQTT servers run without passwords.

Objective/s:
This research paper introduces NeuraHome as a novel and robust IoT-based smart home architecture that integrates centralized management, role-based access control, offline operational capabilities, and state resynchronization together in a unified framework, in contrast to previous approaches that primarily focused on offline operation alone.

Methods:
The NeuraHome system incorporates a mobile application built using React Native, a Laravel-based backend server, and IoT devices based on ESP32/Arduino platforms equipped with LDR, rain, and fire sensors and are connected to relay-operated appliances. The framework was evaluated using a laboratory setup with 30 IoT devices under both normal operating conditions and simulated network failure to assess system reliability, offline operation, and state resynchronization performance.

Results:
The system achieved a device control success rate of approximately 96%, with an average alert delivery time of 1.5 seconds. In addition, about 95% synchronization accuracy was observed after the network recovery. The scalability tests demonstrated stable operation with 30 concurrently connected IoT devices, reflecting the current laboratory prototype configuration. The system achieved a usability score of 4.5/5.

Conclusion/s:
The NeuraHome system presents a secure and scalable architecture for smart homes capable of ensuring reliable operation during network failures through centralized management, offline capability, and state synchronization. The suggested framework increases the reliability of the IoT-based home automation systems along with secure device management and operational continuity.

Keywords: *ESP32-Based Monitoring, IoT Security, NeuraHome, Offline Automation, Smart Home Systems.*

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EP 27

AI-Driven Personalized Perfume Recommendation and Custom Fragrance Creation System

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Abstract

Current digital fragrance discovery tools mainly utilize general filters including brand, price, gender, fragrance family, or purchase history that do not reflect any users' emotions, personality, lifestyle, and personal fragrance preferences. Despite the fact that AI systems have already become more advanced and effective in providing the recommendations in various areas, currently available AI perfume recommendation tools mainly concentrate on the analysis of fragrance features or user Behaviour without the psychological profiling and support of custom fragrance development. As a result, online customers face many uncertainties since fragrances cannot be tested prior to the purchase. This research aims to close this research gap and create an AI system of personalized perfume recommendations and custom fragrance development. It includes the psychological profiling and a hybrid machine learning approach to provide recommendations. The goals were to convert the subjective information about users' emotions, personality, lifestyle, and fragrance preferences into preference vectors, implement multiple machine learning techniques in combination with fragrance theory, create an intelligent recommendation and fragrance customization tool, and evaluate its technical characteristics, usability, and effectiveness of the recommendations.

User emotions, personality, lifestyles, events, and fragrance preferences were elicited through a structured questionnaire. Feature engineering was performed to extract user responses into preference vectors. The recommendation engine relied on cosine similarity to identify highly related users, K-means clustering to categorize users with comparable preference vectors, and content-based and collaborative filtering for recommending fragrances. The system also enabled users to create new perfumes by mixing head, heart, and base notes with an integrated fragrance creation engine that offers rules-based compatibility analysis.

System evaluation was done by conducting technical test, usability test on 30 participants, and validation from four experts in the area. System was evaluated using matching recommendation (93.3%), users' satisfaction (90%), and fragrance compatibility (90%). It is evident that the suggested system offers personalized suggestions about perfumes according to users' preference in terms of their emotions which improve their satisfaction and involvement while using the online service of choosing fragrances. The research suggests that the AI is capable of modeling users' preference based on emotions, personalities, and lifestyle.

Keywords: *AI-based perfume recommendation, Custom fragrance creation, Fragrance customization,Fragrance recommendation system, Personalized fragrance selection*

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EP 28

TrafficGuard: An AI-Driven Multi-Model Framework for Automated Traffic Violation Detection and Predictive Enforcement in Sri Lanka

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Abstract

Background: Road traffic violations remain a serious public safety concern in Sri Lanka. Current monitoring relies mainly on officers at fixed locations, limiting coverage and delaying enforcement. Existing automated systems typically address single tasks and are trained on foreign datasets that do not represent Sri Lankan road conditions and driving behaviour.

Objectives: This study introduces TrafficGuard, an AI-based framework integrating violation detection, licence plate recognition, speed estimation, and congestion prediction within a single platform for the Sri Lankan context. Unlike existing single-purpose systems, TrafficGuard combines these components with citizen reporting for more comprehensive, locally relevant traffic management.

Methods: The research followed the CRISP-DM framework. Traffic images were collected locally and manually labelled, covering 500MB across helmet violations, illegal parking, and red-light offences. YOLOv8 was trained for object detection using augmentation (rotation, scaling, flipping, brightness adjustment) to improve robustness. Licence plate recognition used Tesseract OCR after grayscale conversion and contrast enhancement. Vehicle speed was estimated by tracking movement across consecutive frames using OpenCV. Congestion-prone regions were identified via regression-based analysis of historical traffic records by location and time. A citizen reporting module let the public submit violation reports, routed to administrator and officer modules for verification and response.

Results: Under normal daytime conditions, detection performance was stable across most violation categories, demonstrating satisfactory performance with a detection accuracy of 87%. Licence plate recognition achieved 88% accuracy for visible, aligned plates, though accuracy declined in darker scenes and partially obstructed views. The congestion model achieved 8.8%, with estimates broadly matching known high-traffic areas. All platform modules (citizen, administrator, officer) functioned correctly in testing.

Conclusion: Combining citizen reporting with multiple AI-based components supports more effective, locally relevant traffic monitoring in Sri Lanka. Planned work includes expanding the dataset with low-light samples, applying image enhancement to address reduced accuracy under poor illumination, and improving real-time camera integration.

Keywords: *Citizen Reporting, Deep Learning, Licence Plate Recognition, Traffic Violation Detection, YOLOv8*

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EP 29

A Machine Learning-Based Automated Framework for Real-Time Prediction and Visualization of Dengue Outbreaks

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Abstract

Background: Dengue fever remains a major public health challenge worldwide. Sri Lanka records over 10,000 cases annually, and in the Jaffna district, meteorological and environmental factors create suitable conditions for Aedes transmission. Current surveillance systems are reactive, depending on weekly reports, causing delays in outbreak response. Within the Sri Lankan context, no predictive system uses multi-source data with continuous model management.

Objectives: Develop an automated machine learning (ML)-based framework that integrates epidemiological, meteorological, and environmental data to forecast dengue outbreaks up to eight weeks in advance across eight Ministry of Health (MOH) divisions, and to implement a real-time visualization and alert system to support timely public health interventions.

Methods: Key variables were identified and selected as model inputs. Four models: Random Forest, Gradient Boosting, Extreme Gradient Boosting, and an Ensemble model, were trained, validated, and tested across all Ministry of Health (MOH) divisions. Model selection for each MOH used a composite scoring scheme incorporating Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and the Coefficient of Determination (R^2), with an R^2-bounded filter applied to avoid underfitting and overfitting. A YOLOv8 model was deployed for automated environmental assessment, enabling real-time detection of vector-breeding factors from user images, the framework's principal innovation over existing dengue prediction systems.

Results: MOH-specific models achieved validation R^2 values within 0.70-0.90, with RMSE between 0.75 and 2.60, average MAE of 0.80 weekly cases. successfully supporting eight-week dengue outbreak forecasting while capturing region-specific transmission patterns. The integrated YOLOv8 module further enhanced surveillance by incorporating environmental risk information into the prediction framework.

Conclusions: The developed ML framework with YOLOv8 model, successfully forecasts dengue outbreak across eight MOH divisions. The combined use of multi-source data with automated model selection shows a scalable, evidence-based approach to proactive surveillance applicable to other regions.

Keywords: *Computer Vision, Dengue Prediction, Epidemiological Surveillance, Machine Learning Framework, Outbreak Risk Assessment.*

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EP 30

From Coding to Copy-Paste: Examining the Relationship between AI Dependency, Cognitive Engagement, and Skill Development among Software and Networking Students

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Abstract

Background:
The increasing adoption of generative Artificial Intelligence (AI) tools, such as ChatGPT and GitHub Copilot, has transformed programming and web development education by assisting students with coding, debugging, and problem-solving tasks. While previous studies have highlighted the educational benefits of AI-assisted learning, limited research has simultaneously examined how AI dependency influences students' technical skill development through cognitive engagement using both explanatory and predictive analytical approaches. This study addresses this gap among software and networking students.

Objective/s:
To examine the relationship between AI dependency and skill development among software and networking students, with cognitive engagement as a mediating factor, and to evaluate the predictive capability of AI dependency on skill development.

Methods:
A quantitative survey was conducted among 53 software and networking students using a structured questionnaire. Partial Least Squares Structural Equation Modelling (PLS-SEM) was employed to examine relationships among the latent constructs, while Random Forest Regression was used to evaluate predictive performance and identify the relative importance of predictor variables.

Results:
The findings indicate that AI dependency positively influences skill development when AI is used responsibly as a learning support tool rather than as a substitute for independent learning. Feature importance analysis identified AI dependency as the strongest predictor, followed by cognitive engagement. Cognitive engagement also positively contributes to skill development by encouraging students to understand and critically evaluate AI-generated solutions. The PLS-SEM model explained 46.0% of the variance in skill development. In contrast, Random Forest Regression achieved a predictive R^2 of 0.91, demonstrating high prediction accuracy rather than explanatory power, thereby complementing the explanatory findings of the PLS-SEM analysis.

Conclusion/s:
AI can enhance students' technical skill development when supported by active cognitive engagement and responsible learning practices. Higher education institutions should integrate AI literacy and critical evaluation of AI-generated content into computing curricula to promote independent problem-solving and sustainable skill development.

Keywords: *AI dependency, Cognitive engagement, Generative artificial intelligence, Skill development, Software engineering education*

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EP 31

Analysing the Influence of AI-Driven Technologies on Farmers' Intentions for Crop Yield Optimisation in Batticaloa

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Abstract

Background:
Sri Lanka's Eastern Province possesses rich soil and favourable climate, yet faces 30–40% crop yield losses from inefficiencies and environmental stressors. Globally, AI-driven solutions like predictive analytics and precision farming show promise for boosting productivity, but evidence remains scarce in smallholder-dominated, post-conflict agrarian regions. Specifically, no empirical study has examined AI adoption intentions among paddy farmers in Batticaloa's Eravur Pattu Division, where fragmented landholdings, limited digital infrastructure, and unique socio-cultural dynamics may moderate technology uptake. This study addresses that gap by investigating how three AI technologies first Crop Yield Forecasting, Soil Management Systems, and Crop Phenotyping it influences local farmers' intentions toward yield optimisation, providing context-specific insights for targeted policy interventions.

Objectives:
This study addresses that gap by investigating how three AI technologies first Crop Yield Forecasting, Soil Management Systems, and Crop Phenotyping it influences local farmers' intentions for crop yield optimisation (CYO) in the Batticaloa Eravur Pattu Divisional Secretariat Division.

Methods:
A quantitative survey was conducted using a structured questionnaire based on a positivist philosophy and deductive approach. The target population was 11,125 farmers, from which 185 were selected through cluster sampling. Data were successfully collected from 148 farmers. Pearson's Correlation and Multiple Linear Regression analyses were performed to examine the relationships.

Results:
Respondents were predominantly male (87.8%), aged 30–50 (70.9%), with nearly half holding graduate degrees. Pearson's correlations showed strong positive relationships between all three AI technologies and CYO intentions (CYF: $r = 0.834$; SMS: $r = 0.860$; CP: $r = 0.836$; all $p < 0.01$). Multiple regression confirmed significant positive effects, with CP as the strongest predictor ($\beta = 0.382$, $p = 0.004$), followed by CYF ($\beta = 0.330$, $p = 0.003$) and SMS ($\beta = 0.252$, $p = 0.043$). The model explained 81.4% of the variance ($R^2 = 0.814$).

Conclusion:
These findings capture intentions, not actual yield gains, requiring longitudinal validation. CP's dominance suggests visually accessible AI tools may offer a low-cost entry point for adoption. The single-DSD sample ($n = 148$) limits generalisability. Policymakers should prioritise CP-based extension training and establish monitoring frameworks to assess real-world impacts, while adapting strategies cautiously elsewhere.

Keywords: *Artificial Intelligence, Crop Yield Optimisation, Crop Yield Forecasting, Soil Management Systems, Crop Phenotyping*

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EP 32

An Edge-Enabled Passenger Occupancy Monitoring System for Public Buses Using Deep Learning and Geospatial Analytics

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Abstract

Background: Public buses are a primary mode of transportation in Colombo, Sri Lanka, yet transport operators often lack reliable real-time passenger occupancy information. This limitation contributes to overcrowding, inefficient scheduling, and poor resource allocation. Although previous passenger monitoring studies have reported high detection accuracy, few integrate edge computing, geospatial analytics, offline functionality, and cloud analytics within a unified framework for real-time passenger occupancy monitoring in operational public transport environments.

Objective/s: This study develops an edge-enabled passenger density monitoring framework that provides real-time occupancy information by integrating computer vision, Global Positioning System (GPS) tracking, edge computing, and cloud analytics to support transportation planning and operational decision-making.

Methods: An extended and annotated South China University of Technology Head (SCUT-HEAD) dataset was used to train a You Only Look Once Version 11 Nano (YOLOv11n) model for 50 epochs using cloud-based Graphics Processing Unit (GPU) resources. The trained model was deployed on a Raspberry Pi to detect and count passengers. Occupancy data were integrated with GPS coordinates, stored locally during network interruptions, synchronized with the cloud when connectivity was restored, and visualized through a web dashboard.

Results: The prototype achieved a mean Average Precision (mAP@0.5) of 0.924 and a passenger counting accuracy of 96.1%, demonstrating reliable detection and occupancy estimation. Evaluation under real operating conditions, including varying lighting conditions, crowded buses, and moving vehicles, confirmed robust edge performance. The generated occupancy data support demand-based scheduling, fleet allocation, route optimization, and transportation analytics.

Conclusion/s: The proposed framework demonstrates the effectiveness of integrating edge computing, deep learning, geospatial analytics, and cloud technologies for real-time passenger density monitoring. By providing accurate occupancy information, the system supports informed transport planning, improves fleet utilization, enhances commuter experiences, and contributes to future smart mobility initiatives in Sri Lanka.

Keywords: *Edge Computing, Intelligent Transportation Systems, Passenger Density Estimation, Smart Mobility, YOLOv11n*

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EP 33

A SkillMatch: An AI-Assisted Trust-Based Service Marketplace for Enhancing Worker Reliability in Sri Lanka's Blue-Collar Sector

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Abstract

Background: The informal blue-collar labor market in Sri Lanka faces persistent trust and transparency challenges. Customers lack information to evaluate worker credibility before hiring, while skilled workers have limited opportunities to establish verifiable reputations. Existing service marketplace platforms rely on service listings and basic rating mechanisms, providing limited support for intelligent trust assessment and predictive reputation analysis.

Objective/s: This study aims to design and evaluate SkillMatch, an Artificial Intelligence (AI)-assisted service marketplace that improves worker discovery and strengthens trust between customers and service providers through trust scoring and reputation management. Unlike conventional platforms using static ratings, SkillMatch introduces AI-based trust prediction by analysing behavioural and review-based indicators.

Methods: The proposed solution employs a MERN-based web platform integrated with a FastAPI AI service. Approximately 500 review records were collected from a controlled dataset and processed to extract trust-related features, including ratings, review frequency, review recency, communication quality, punctuality indicators, and sentiment measures. A rule-based matching approach was used as a baseline, while a Random Forest (RF) model was trained to predict worker trust scores. Model performance was evaluated using Mean Absolute Error (MAE) on the evaluation dataset, with generated trust scores further validated through system testing.

Results: Experimental findings demonstrated that the RF model achieved an MAE of 0.004306, outperforming the Linear Regression baseline with an MAE of 0.01028. The results indicate improved prediction capability for identifying relationships among trust-related attributes. Integration testing confirmed consistent trust-score generation and system responsiveness through a fallback mechanism during AI service disruptions.

Conclusion/s: The findings indicate that AI-assisted trust evaluation can enhance transparency, worker visibility, and decision-making within digital service marketplaces. SkillMatch provides a scalable approach to support customers in selecting suitable workers while helping service providers establish stronger reputations and employment opportunities. The proposed solution contributes to Sri Lanka's blue-collar workforce transformation by strengthening confidence among marketplace participants.

Keywords: *Artificial Intelligence (AI), Random Forest (RF), Trust Prediction, Service Marketplace, Digital Reputation.*

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EP 34

The Role of Machine Learning in Detecting Financial Fraud in Modern Financial Systems in the Banking Sector: A Study in the Northern Province of Sri Lanka

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Abstract

Background: Financial fraud has become a major challenge for banking institutions due to the rapid growth of digital financial services and increasingly sophisticated cyber threats. Machine learning has emerged as a valuable approach for improving financial fraud detection by identifying suspicious transaction patterns and supporting timely decision-making. However, there is limited empirical evidence on the perceived effectiveness of machine learning-related factors in financial fraud detection within the banking sector.

Objective/s: This study aimed to investigate respondents' perceptions of the effectiveness of machine learning, anomaly detection techniques, and access control mechanisms in enhancing financial fraud detection within the banking sector by examining the relationships between these perceived factors and financial fraud detection effectiveness.

Methods: A quantitative research approach was adopted using a structured questionnaire to collect primary data from 150 respondents with knowledge or experience in the banking, financial, and information technology sectors. The collected data were analysed using descriptive statistics, Spearman's rank correlation, and regression analysis to examine respondents' perceptions of the effectiveness of machine learning-related factors in financial fraud detection.

Results: The findings indicated that respondents generally agreed with the effectiveness of machine learning, anomaly detection techniques, and access control mechanisms in detecting financial fraud. Spearman's rank correlation analysis revealed statistically significant strong positive relationships between machine learning ($\rho = 0.633$), anomaly detection techniques ($\rho = 0.693$), access control mechanisms ($\rho = 0.613$), and financial fraud detection effectiveness ($p < 0.001$). Regression analysis further confirmed that all three independent variables were significant positive predictors of financial fraud detection effectiveness.

Conclusion/s: The study concludes that respondents perceive machine learning, anomaly detection techniques, and access control mechanisms as effective approaches for enhancing financial fraud detection within the banking sector. The findings provide empirical evidence regarding respondents' perceived effectiveness of these machine learning-related technologies and offer useful insights for future research and informed decision-making within financial institutions.

Keywords: *Access Control, Anomaly Detection, Digital Banking, Financial Fraud Detection, Fraud Prevention*

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EP 35

Evaluating the Effectiveness of Machine Learning Models in Predicting Cybersecurity Threats for Banking Sectors in the Northern Region

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Abstract

Background: The banking sector is among the most frequently targeted industries by cybercriminals. Traditional rule-based intrusion detection systems and static firewalls are increasingly inadequate against evolving threats such as zero-day vulnerabilities and advanced persistent threats. Machine Learning (ML) offers adaptive, data-driven capabilities for real-time threat detection, yet empirical evidence on ML effectiveness within Northern Region banking remains limited.

Objective/s: This study analysed cybersecurity professionals' perceptions of how ML adoption improves threat-detection performance within Northern Region banking institutions. Objectives were to: (1) analyse perceptions of performance gains from supervised algorithms, including Random Forest, Support Vector Machines, and Neural Networks; (2) examine perceived capability of unsupervised and deep learning models in detecting zero-day threats; and (3) investigate implementation challenges and ethical considerations of ML deployment.

Methods: A positivist, deductive, mono-method quantitative survey design was adopted. A structured Likert-scale questionnaire was distributed to approximately 150 cybersecurity professionals, IT managers, and system administrators in Northern Region banks, selected via purposive sampling. Secondary data were drawn from peer-reviewed literature and industry reports (IBM, ENISA, Verizon) to contextualise findings. Data were analysed via IBM SPSS using descriptive, correlation, and regression analysis.

Results: Respondents generally perceived supervised ML models, particularly Random Forest and SVM, as improving detection performance for known threats over traditional rule-based systems. Unsupervised and deep learning approaches were perceived as more effective for identifying novel, zero-day threats. Key implementation challenges identified were data privacy, algorithmic bias, deployment costs, and regulatory compliance, viewed as significant barriers to wider adoption.

Conclusion/s: This study found that Northern Region banking professionals generally perceived ML-based approaches as improving threat-detection performance over traditional systems, particularly for known-threat classification and, to a lesser extent, zero-day detection. Findings inform ML model selection for regional banks, support compliance with frameworks such as PCI DSS, and highlight ethical considerations in banking AI adoption.

Keywords: *banking security, cybersecurity threats, intrusion detection, machine learning, Northern Region*

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EP 36

Smart Emergency Response System for Women's Safety Using Artificial Intelligence and Real Time Location Tracking

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Abstract

Background:

Violence, harassment, and personal safety threats against women remain significant global concerns, often resulting in delayed emergency response and limited evidence collection. Existing women's safety applications primarily rely on manual emergency activation and provide limited intelligent threat assessment.

Objectives:

To develop and evaluate an Artificial Intelligence (AI)-powered Smart Emergency Response System that integrates AI-based voice emotion recognition, Global Positioning System (GPS) location tracking, automated emergency alerts, and secure evidence collection to support timely emergency response.

Methods:

A cross-platform mobile application supported by cloud services was developed to integrate AI-based voice emotion recognition, real-time location sharing, emergency notifications, and secure multimedia evidence storage. Unlike conventional safety applications that primarily depend on manual emergency activation, the proposed framework combines proactive distress detection with automated emergency response features. The system was evaluated through functionality testing and AI model validation.

Results:

The emotion recognition model achieved an overall classification accuracy of 70.07% in detecting distress-related emotional states. Functional testing confirmed successful real-time location tracking, emergency alert transmission, and secure evidence preservation. Although the current AI accuracy demonstrates the technical feasibility of AI-assisted distress detection, further improvements are required before practical real-world deployment.

Conclusions:

The proposed framework demonstrates the technical feasibility of integrating AI-assisted distress detection, real-time location tracking, and emergency communication within a unified women's safety system. Since the current evaluation was limited to system testing, future work will include usability evaluation with real users, collecting more diverse real-world voice samples to improve AI accuracy, and integrating wearable and Internet of Things (IoT) technologies to further enhance system effectiveness.

Keywords: *Artificial Intelligence, Emergency Response System, Emotion Recognition, GPS Tracking, Women's Safety.*

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EP 37

AI-Driven Real-Time Cyberbullying Detection and Prevention Framework for Online Gaming Environments

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Abstract

Background:
Cyberbullying in online gaming environments is an increasing cybersecurity concern due to player anonymity, competitive gameplay, and real-time communication features. Existing studies primarily focus on policy enforcement, awareness programmes, educational interventions, and legal approaches to mitigate cyberbullying. However, limited research has proposed integrated Artificial Intelligence (AI)-driven conceptual frameworks for real-time cyberbullying detection and prevention specifically within online gaming environments.

Objective/s:
This study aims to propose a conceptual AI-driven framework for real-time cyberbullying detection and prevention in online gaming environments. The specific objectives are to identify existing cyberbullying prevention approaches, examine research gaps in current literature, explore the role of AI in detecting toxic gaming behaviour, and develop a conceptual framework integrating AI with cybersecurity strategies.

Methods:
This study adopted a qualitative research design based on a literature review and thematic analysis. Peer-reviewed literature retrieved through Google Scholar on cyberbullying in online gaming, AI-based moderation, and cybersecurity strategies was analysed to identify recurring themes, current prevention approaches, and existing research gaps. The Theory of Planned Behaviour (TPB) informed the behavioural perspective of the proposed framework, while the Malaysia Cyber Security Strategy 2020–2024 provided the cybersecurity context for the framework design.

Results:
The findings indicate that current research mainly emphasises awareness programmes, educational initiatives, legal frameworks, and AI-assisted moderation techniques. However, limited evidence was identified of comprehensive conceptual frameworks integrating AI-driven real-time text analysis, behavioural pattern analysis, risk assessment, and automated response mechanisms specifically for cyberbullying prevention in online gaming environments. Based on seven identified research gaps, this study proposes a conceptual framework comprising AI-based cyberbullying detection, behavioural analysis, risk classification, alert generation, and moderation support to strengthen cyberbullying prevention in online gaming platforms.

Conclusion/s:
This study presents a conceptual AI-driven framework intended to support real-time cyberbullying detection and prevention in online gaming environments. The proposed framework extends existing cybersecurity strategies by integrating AI-assisted behavioural analysis with preventive response mechanisms and provides a foundation for future system development and empirical validation. The findings contribute to the advancement of safer online gaming environments for researchers, game developers, policymakers, and cybersecurity professionals.

Keywords: *Artificial Intelligence, Cyberbullying, Cybersecurity, Online Gaming, Real-Time Detection*

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EP 38

AI-Powered Medical Document Processing and Claim Validation System for Insurance Automation

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Background: Medical insurance claim processing in Sri Lanka remains largely dependent on manual document review, causing delays, inconsistent evaluations, and increased administrative effort. Documents such as invoices, prescriptions, medical reports, and bills require individual verification, limiting processing efficiency. Existing automated approaches mainly focus on document digitization rather than integrating intelligent extraction, validation, and decision-support capabilities.

Objective/s: This study aims to develop an Artificial Intelligence (AI)-driven medical insurance claim validation system that improves claim processing efficiency, accuracy, and consistency by integrating automated information extraction and policy-based evaluation.

Methods: The proposed system combines Optical Character Recognition (OCR), Natural Language Processing (NLP), and a rule-based validation framework. A dataset containing 1,200 anonymized claim documents representing realistic insurance claim scenarios, including scanned and digital formats, was used for evaluation. Google Vision OCR extracts relevant information, while NLP techniques identify medical and billing entities. The rule-based engine validates extracted information against predefined insurance conditions, including coverage limits, exclusions, and OPD/IPD policies. The system was implemented using a Laravel-based web application integrated with Python-based AI processing modules.

Results: The system achieved approximately 90% accuracy in claim information extraction and validation, measured based on the correctness of extracted entities and validated claim details against expected outputs. Processing time was reduced by over 60% compared with conventional manual processing. Higher performance was observed for printed documents, while handwritten and low-quality documents resulted in reduced accuracy.

Conclusion/s: The proposed approach advances existing claim automation solutions by combining intelligent document understanding with automated policy validation. The findings demonstrate improved efficiency, consistency, and reduced manual effort in insurance claim processing. Future enhancements may include advanced OCR models and image preprocessing techniques to improve performance for complex document conditions. The system provides a foundation for more reliable digital healthcare insurance operations in Sri Lanka.

Keywords: *Optical Character Recognition, Natural Language Processing, Insurance Claims Automation, Rule-Based Systems, Healthcare Informatics.*

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Full Papers on Economics, Finance, Business, Management, Hospitality and Tourism- Poster Presentations

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EP 01

Leveraging Digital Transformation to Enhance Organizational Efficiency and Sustainability in Sri Lanka

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Abstract

Background:
Organizations in Sri Lanka face increasing pressures to improve operational efficiency while aligning with national digital targets and sustainability goals. However, many legacy institutions face severe structural challenges when trying to effectively integrate digital technologies into their core business processes, leading to operational inefficiencies, workflow fragmentation, and limited strategic impact.

Objective/s:
This study proposes a conceptual framework to examine how digital transformation can be strategically structured to enhance organizational efficiency and support sustainable business practices in Sri Lanka. It focuses on addressing systemic gaps in internal processes, leadership alignment, dynamic capabilities, and sustainable resource management.

Methods:
The study adopts a non-empirical, qualitative conceptual research design. It systematically synthesizes peer-reviewed academic literature and national digital economy strategy documents published between 2018 and 2024. The gap analysis and model formulation are structured using a deductive synthesis mapped across the Technology–Organization–Environment (TOE) Framework and Dynamic Capabilities Theory.

Results:
The conceptual synthesis highlights that technology acquisition alone produces superficial gains and often exacerbates workflow fragmentation when unsupported by organizational readiness. Long-term efficiency and sustainability require a multi-dimensional alignment where dynamic leadership sensing, dynamic reskilling, dynamic governance, and targeted environmental metrics mediate the relationship between digital tool adoption and operational performance.

Conclusion/s:
This manuscript offers a strategic roadmap for organizations in emerging economies like Sri Lanka. It demonstrates that bridging the implementation gap requires moving from isolated software installations to holistic socio-technical integration, providing a foundation for future empirical testing and managerial implementation.

Keywords: *Digital transformation, Emerging economies, Organizational efficiency, Sustainability, Technology adoption.*

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Introduction

Organizations around the world are progressively required to improve operational efficiency while responding to developing sustainability opportunities. In emerging economies such as Sri Lanka, this operational challenge is intensified by unique macroeconomic pressures, volatile resource environments, restricted corporate capital budgets, and the pressing need to remain competitive in a rapidly evolving global digital landscape. As a result, digital transformation has gained significant attention as a pivotal strategic enabler for improving organizational performance, workflow resilience, and long-term environmental and financial sustainability.

Digital transformation refers to the deep integration of digital technologies across all business processes, fundamentally changing how organizations operate, make decisions, and deliver value to stakeholders. It enables organizations to streamline legacy workflows, enhance real-time data-driven decision-making, and significantly elevate stakeholder engagement. However, despite increasing digital investments across South Asia and national initiatives such as Sri Lanka's National Digital Economy Strategy 2030 and Digital Economy Blueprint, many enterprise initiatives struggle to deliver expected returns, exposing a persistent gap between technology acquisition and true operational improvement.

Recent literature highlights that digital transformation fails when treated purely as an IT upgrade rather than an integrated socio-technical restructuring. In many developing contexts, software tools are introduced without aligning them to internal capabilities, resulting in fragmented workflows, isolated data silos, employee change fatigue, and administrative friction. While existing studies document the general advantages of digitalization, there is a distinct lack of actionable, theoretically grounded frameworks showing how organizations in emerging markets like Sri Lanka can systematically bridge this implementation gap.

To address this gap, this manuscript presents a qualitative conceptual framework grounded in two established management theories:

1. The Technology–Organization–Environment (TOE) Framework

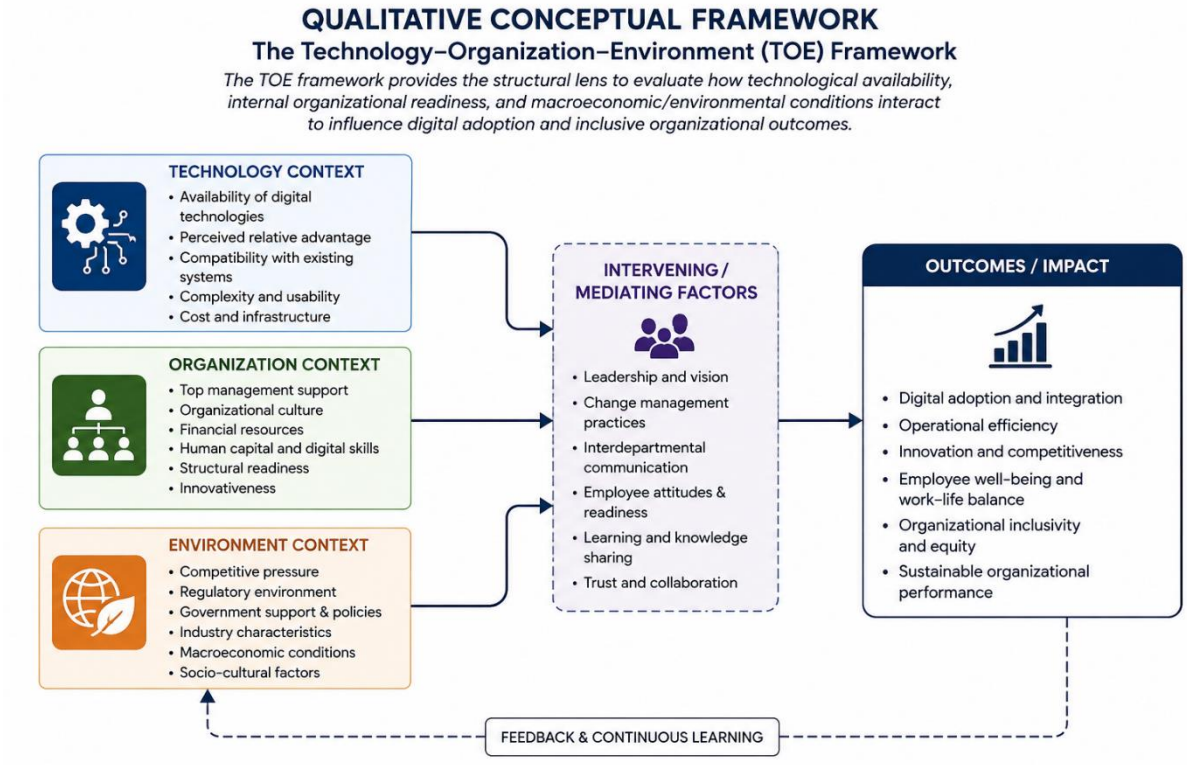

Figure 1: The Technology–Organization–Environment (TOE) Framework

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2. Dynamic Capabilities Theory.

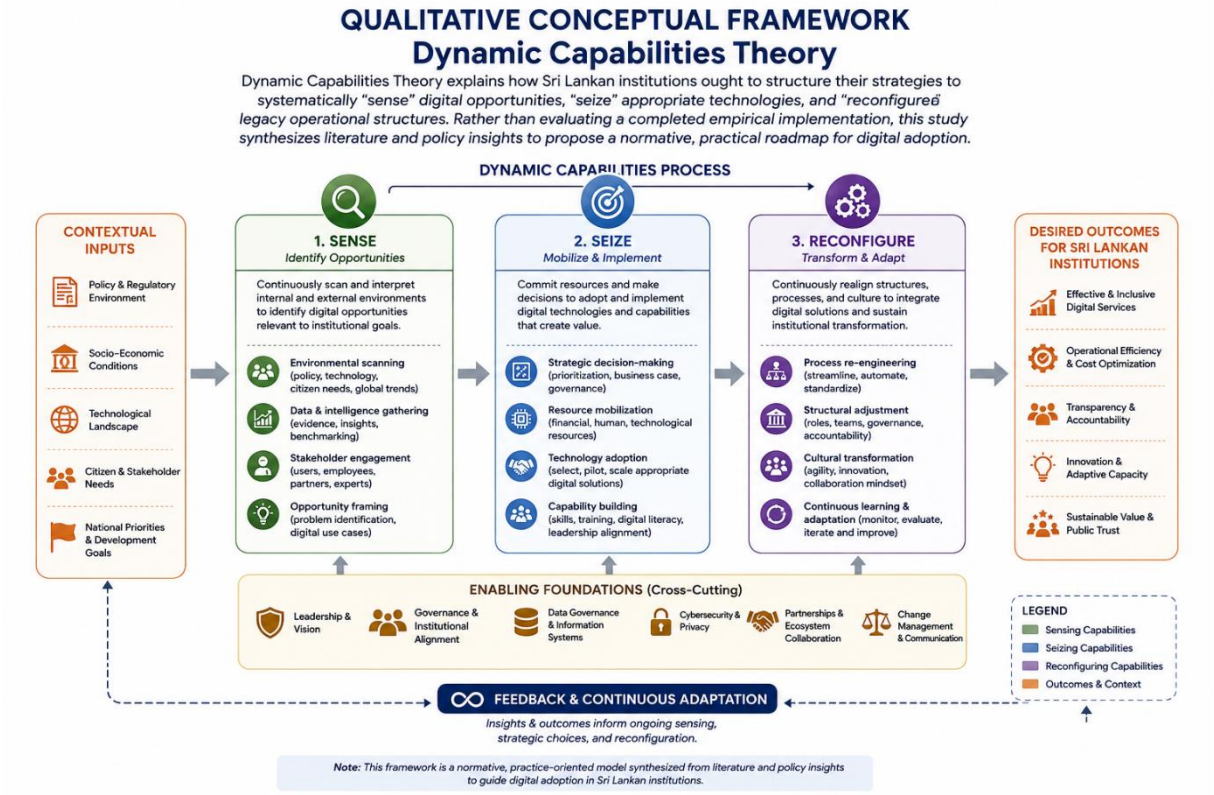

Figure 2: Dynamic Capabilities Theory

Study Objectives

The primary objective of this study is to formulate a conceptual and strategic framework detailing how Sri Lankan organizations can effectively leverage digital transformation to enhance operational efficiency and sustainability. Specifically, this manuscript aims to:

1. Synthesize existing literature and policy frameworks to identify the core systemic gaps and barriers obstructing effective digital adoption in Sri Lanka.
2. Apply the TOE Framework and Dynamic Capabilities Theory to structure an actionable strategic roadmap for organizational digital readiness.
3. Propose granular operational recommendations spanning digital governance, dynamic reskilling, and sustainability metrics to guide future empirical research and real-world managerial practice in emerging economies.

METHODS

This study employs a qualitative conceptual research design and strategic policy synthesis. Rather than evaluating an empirical or post-implementation case study, this manuscript presents a theoretical framework and strategic roadmap designed to address the operational gaps identified in existing literature. The study synthesizes academic research and policy documents to formulate an actionable conceptual approach for Sri Lankan organizations.

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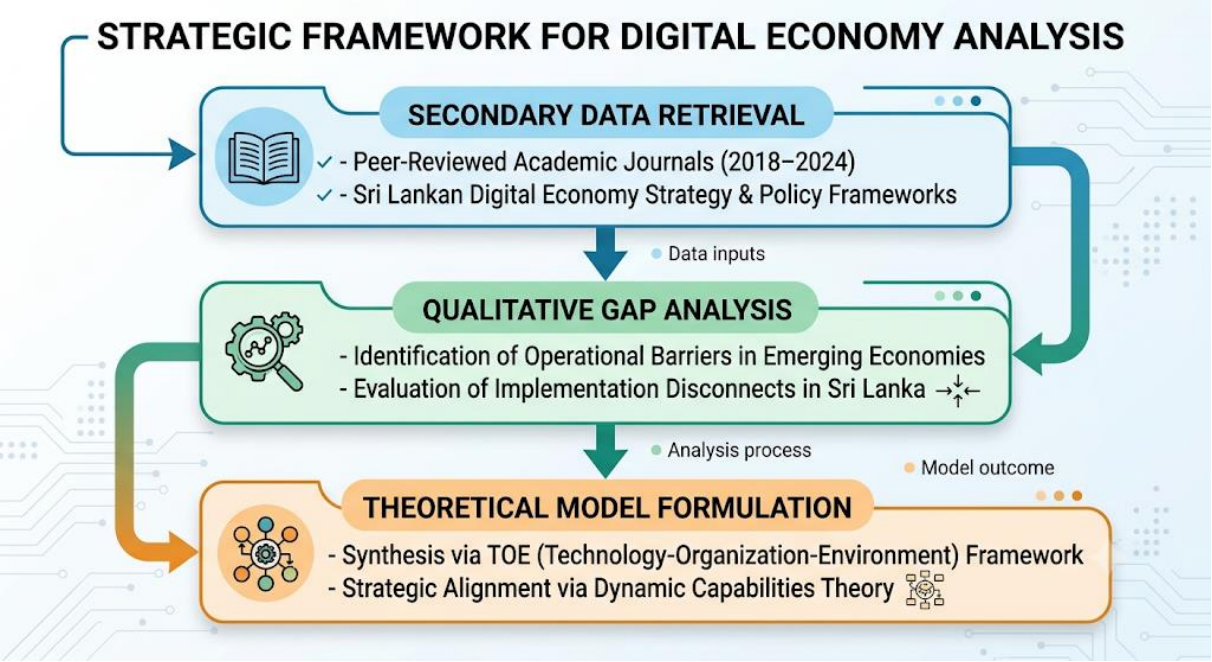

Figure 3: Strategic Framework for Digital Economy Analysis

Study Design and Setting

The study adopts a non-empirical, conceptual formulation approach. It focuses on the macroeconomic and organizational setting of emerging economies, specifically contextualized to the digital modernization challenges faced by institutions in Sri Lanka. The manuscript serves as a strategic proposition, mapping out how organizations can systematically align technology adoption with internal capabilities and policy objectives to prevent workflow fragmentation.

Participant Characteristics/ Material Description

The foundation of this conceptual study relies strictly on secondary documentary evidence, including:

1. Peer-Reviewed Academic Literature: Published conceptual and qualitative studies evaluating digital transformation, workflow efficiency, dynamic capabilities, and organizational change in developing markets.
2. Policy and Strategy Documents: Sri Lankan national digital economy frameworks including the National Digital Economy Strategy 2030 and Sri Lanka Digital Economy Blueprint along with regional development reports evaluating digital infrastructure, SME maturity, and macroeconomic constraints.

Sample Size Calculation

To build a rigorous conceptual foundation, secondary sources were filtered using explicit criteria:

Inclusion Criteria:

1. Peer-reviewed journal articles and official policy frameworks published between 2018 and 2024 focusing on digital strategy, organizational management, operational efficiency, or sustainability.
2. Academic literature and policy report relevant to emerging economies or South Asian economic contexts.
3. Research offers theoretical insights into technology adoption frameworks, leadership readiness, or dynamic organizational capabilities.

Exclusion Criteria:

1. Highly technical or engineering-focused papers lack organizational or managerial relevance.
2. Outdated publications (prior to 2018) that do not reflect modern enterprise software ecosystems.

3. Context-bound empirical studies from advanced, high-income economies whose structural conditions cannot be realistically applied to Sri Lanka.

Procedures, Interventions, and Comparisons

Because this study proposes a conceptual framework rather than analysing primary data, the research followed a three-step analytical protocol:

1. Gap Identification: Systematic review of existing literature to highlight the recurrent disconnect between software acquisition and actual operational efficiency in Sri Lanka.
2. Theoretical Structuring: Mapping identified organizational friction points to the three pillars of the Technology–Organization–Environment (TOE) Framework (Technological readiness, Organizational dynamic capacity, and Environmental/economic pressures).
3. Actionable Strategic Roadmap: Synthesizing Dynamic Capabilities Theory to propose specific steps organizations ought to take (sensing digital needs, seizing appropriate technologies, and reconfiguring internal structures) to achieve sustainable performance.

Statistical Analysis Methods Use

This manuscript does not involve primary empirical testing, field data collection, statistical modelling, or direct site interventions. The analysis is entirely qualitative, theoretical, and normative designed to provide a structured strategic foundation for future empirical research and real-world organizational implementation.

RESULTS

The synthesis of literature and policy frameworks reveals that digital transformation in emerging economies operates as a complex, interdependent system rather than a direct linear progression from technology purchase to performance improvement.

The qualitative synthesis of secondary data establishes four foundational structural findings:

1. System Fragmentations as Primary Barriers: Implementing independent, unintegrated digital platforms (e.g., isolated CRM, legacy databases, or communication software) increases task redundancy and workflow friction. Without centralized enterprise architecture, digital tools create isolated information silos rather than operational speed.
2. Organizational Readiness as a Mediator: Technological availability alone yields negligible performance improvements. High operational responsiveness is achieved only when organizations pair digital deployment with dynamic leadership support, high employee digital literacy, and continuous skill updates.
3. Digital-Sustainability Convergence: Digital transformation supports sustainability goals (such as resource conservation, paperless administration, and reduced carbon footprints) only when environmental Key Performance Indicators (KPIs) are explicitly embedded into business process workflows.
4. Policy-Execution Gap in Sri Lanka: While Sri Lanka's national strategy outlines ambitious targets for digital government and trade, organizational execution is restricted by low corporate web/database presence (under 20% among local enterprises), resource limitations, and resistance to change among senior personnel.

Conceptual Transformation Architecture Matrix

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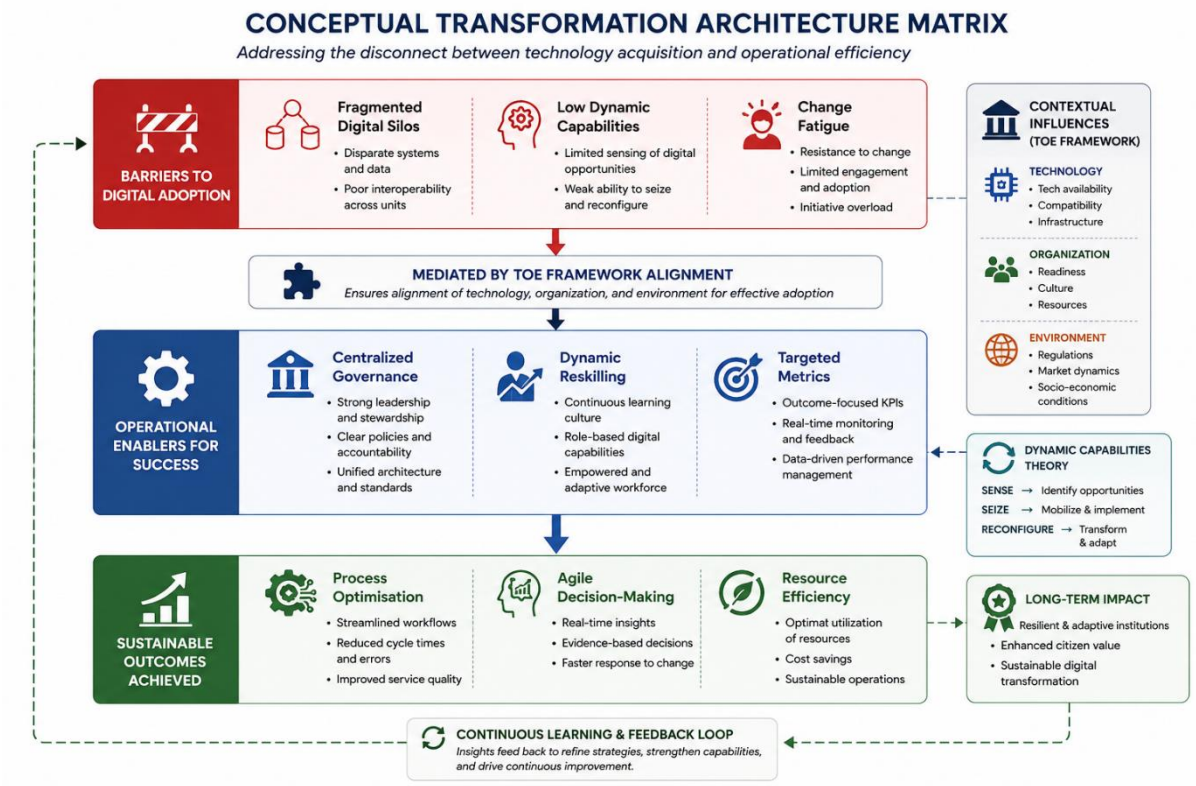

Figure 4: Conceptual Transformation Architecture Matrix

DISCUSSION

The conceptual findings of this study reinforce that digital transformation is a fundamental socio-technical restructuring rather than a simple IT deployment. While organizations frequently prioritize software acquisition, sustained operational gains depend on how effectively technology is integrated into existing workflows and supported by corporate culture.

Theoretical Integration: TOE and Dynamic Capabilities

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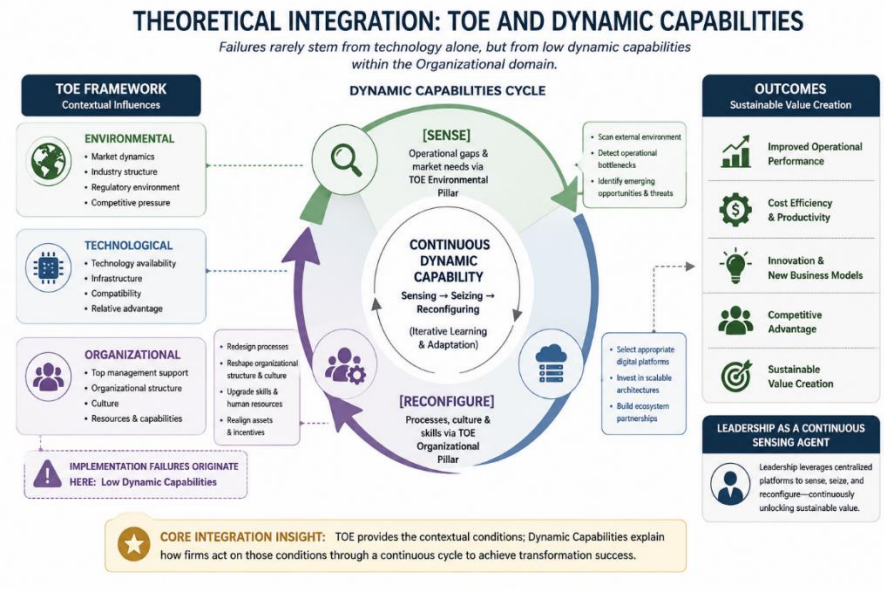

Figure 5: Theoretical Integration: TOE and Dynamic Capabilities

Analysing digital transformation through the TOE Framework demonstrates that implementation failures rarely stem from technological flaws alone. Instead, failures originate within the Organizational domain specifically, low dynamic capabilities that prevent firms from reconfiguring asset structures when new platforms are deployed. According to Dynamic Capabilities Theory, sustainable value is unlocked when leadership acts as a continuous sensing agent, using centralized platforms to detect operational bottlenecks, seize appropriate software architectures, and reconfigure human resource capabilities.

Contextual Relevance To Sri Lanka

In Sri Lanka, the urgency for structured digital transformation is exacerbated by macroeconomic recovery challenges and severe capital constraints. At the national policy level, initiatives such as the *Sri Lanka Digital Economy Blueprint* and the *National Digital Economy Strategy 2030* spearheaded by the Information and Communication Technology Agency of Sri Lanka (ICTA) aim to achieve a fivefold expansion in the digital economy, targeting a $15 billion economic valuation by 2030 (increasing its GDP contribution from approximately 3.5% to 12%) (1).

However, enterprise-level digital adoption remains severely constrained across the broader domestic economy. Micro, Small, and Medium Enterprises (MSMEs), which according to the Department of Census and Statistics (DCS) represent over 75% of total business establishments and contribute 52% to national Gross Domestic Product (GDP), face acute digital operational deficits. (2) Enterprise surveys by global development institutions highlight that despite ubiquitous informal messaging tool usage, fewer than 19% of local MSMEs utilize structured, formal enterprise databases or maintain active corporate web presences. (3)

Furthermore, public and private sector institutions encounter acute internal operational friction, including senior personnel resistance, fear of job displacement, digital literacy gaps, and politically or economically volatile operating environments. Simply acquiring software without restructuring underlying operational workflows leads to sub-optimal outcomes, task redundancy, and isolated data silos. To build long-term operational resilience, Sri Lankan organizations must leverage cloud-native, low-capital enterprise architectures that align directly with emerging national Digital Public Infrastructure (DPI) initiatives such as national digital identity projects and unified digital payment systems allowing local firms to minimize heavy capital outlays while enhancing supply chain adaptability, regulatory compliance, and operational visibility

Practical Implications for Industry Leaders

To operationalize this conceptual framework, corporate managers should execute three core strategic actions:

- *Digital Governance & Maturity Assessment:* Conduct structured digital maturity audits prior to tool procurement to ensure seamless interoperability across ERP and CRM systems, avoiding data fragmentation.

- *Change Management and Dynamic Reskilling:* Implement continuous learning pathways to address digital literacy gaps and minimize employee change fatigue, fostering a resilient workforce.

- *Sustainability Metrics Integration:* Explicitly link enterprise software outputs to environmental performance indicators, such as reduced paper consumption, minimized electronic waste, and optimized resource routing.

Limitations

To maintain academic rigor, several limitations of this conceptual study must be acknowledged:

1. *Reliance on Secondary Sources:* The study depends on secondary literature and policy documents, which may inherit historical reporting biases.

2. *Absence of Primary Empirical Data:* The framework lacks quantitative or statistical validation from field sites.

3. *Contextual Specificity:* While tailored to Sri Lanka, the framework's applicability to advanced economies with mature digital infrastructure may be limited.

4. *Lack of Sector Stratification:* The proposed model provides a high-level organizational perspective without differentiating between manufacturing, services, or small-to-medium enterprises (SMEs).

Future Research Directions

To build upon the conceptual framework established in this study and address its inherent limitations, future research should explore several key empirical and thematic avenues:

1. **Quantitative Validation:** Future studies should empirically test and validate the proposed TOE–Dynamic Capabilities model using quantitative approaches, such as Partial Least Squares Structural Equation Modelling (PLS-SEM), across Sri Lankan enterprise environments.
2. **Sector-Specific Digital Transformation & Comparative Industry Analysis:** Research should investigate how digital adoption varies across distinct economic sectors, such as apparel manufacturing, financial services, agriculture, and tourism to analyse industry-specific regulatory, operational, and structural dynamics.

3. **SME Digital Maturity:** Dedicated empirical investigations are needed to evaluate low-cost, cloud-native adoption models and digital maturity pathways tailored specifically to the capital and resource constraints of Micro, Small, and Medium Enterprises (MSMEs).

4. **Longitudinal Organizational Change:** Multi-year longitudinal studies should be conducted to track how dynamic capabilities, employee change fatigue, and corporate culture evolve throughout the full life cycle of enterprise digital restructuring.

5. **AI-Enabled Digital Transformation:** Future research should examine how emerging technological enablers, such as Artificial Intelligence (AI), Machine Learning (ML), and predictive analytics, can be integrated into the sensing and reconfiguring phases of dynamic enterprise capabilities to drive real-time operational efficiency and automated sustainability tracking.

Conclusions

This conceptual study addresses the persistent disconnect between digital technology acquisition and genuine operational performance in emerging economies, with a specific focus on the macroeconomic landscape of Sri Lanka. By synthesizing secondary literature and national policy frameworks through the complementary lenses of the Technology–Organization–Environment (TOE) Framework and Dynamic Capabilities Theory, this research moves beyond descriptive evaluations of digitalization to formulate an actionable strategic roadmap.

The primary conclusion drawn from this synthesis is that technology procurement, when isolated from structural readiness, yields merely superficial gains while actively exacerbating workflow fragmentation, administrative friction, and data isolation. Achieving meaningful operational efficiency requires a shift toward socio-technical integration, wherein digital tool adoption is explicitly mediated by dynamic leadership capabilities, continuous workforce reskilling, and centralized governance structures. Furthermore, for local enterprises particularly Micro, Small, and Medium Enterprises (MSMEs) navigating severe resource constraints long-term operational resilience depends on leveraging cloud-native architectures aligned with national Digital Public Infrastructure (DPI) objectives, while embedding measurable environmental key performance indicators directly into enterprise workflows.

The significance of this study lies in both its theoretical and practical contributions to management literature in developing economic contexts. Theoretically, the manuscript bridges a notable gap by demonstrating how environmental pressures, organizational readiness, and technological capabilities interact dynamically within volatile market environments, thereby expanding the applicability of established adoption frameworks beyond high-income economies.

On a practical level, the proposed framework provides industry leaders and corporate decision-makers with a practical, step-by-step approach to evaluating digital maturity, mitigating employee change fatigue, and aligning digital investments with broader sustainability metrics. From a policy perspective, the study highlights the internal operational barriers obstructing Sri Lanka's national target of building a $15 billion digital economy, underscoring the necessity of targeted enterprise reskilling and accessible digital infrastructure. Ultimately, this manuscript establishes a theoretical foundation for future empirical investigation, offering a conceptual model suitable for field testing, quantitative validation, and cross-sectoral comparative research across South Asia

References

1. Information and Communication Technology Agency of Sri Lanka, (ICTA). *National Digital Economy Strategy 2030 & Digital Economy Blueprint.* Colombo : Ministry of Technology, 2024.

2. Department of Census and Statistics, DCS. *Survey to Assess the Impact of the Economic Crisis on Micro, Small and Medium Enterprises (MSMEs) in Sri Lanka.* Colombo : Ministry of Finance, Economic Stabilization and National Policies, 2023.

3. World Bank Group. *MSMEs and Digital Technology Integration in South Asia: Country Profile Sri Lanka. Washington (DC).* s.l. : World Bank, 2023.

4. *Understanding Digital transformation: a Review and a Research Agenda.* Gregory Vial. 2, 2019, The Journal of Strategic Information Systems, Vol. 28, pp. 118-144.

5. *Open Innovation in Multinational companies' subsidiaries: the Role of Internal and External Knowledge.* Ferraris, A, Santoro, G and Bresciani, S. 4, 2017, European J of International Management, Vol. 11, p. 452.

6. *Digital Transformation and Sustainable Business Models.* Katsamakas, E. 11, 2022, Sustainability, Vol. 14, p. 6414.

7. *Digital Sustainability and Entrepreneurship: How Digital Innovations Are Helping Tackle Climate Change and Sustainable Development.* George, G, Merrill, RK and Schillebeeckx, SJD. 5, 2021, Entrepreneurship Theory and Practice, Vol. 45, pp. 999-1027.

8. *Digital Transformation in Business and Management reseArch: an Overview of the Current Status Quo.* Kraus, S, et al. 4, 2022, International Journal of Information Management, Vol. 63, pp. 1-18.

9. *Emergent Digital Strategies and Networks: Advancements to Service Management Research.* Reis, J, Amorim, M and Melão, N. 2020, Journal of Reviews on Global Economics, Vol. 8, pp. 1689-708.

10. *Digital Transformation Strategies.* Matt, C, Hess, T and Benlian, A. 339-43, 2015, Business & Information Systems Engineering, Vol. 5, p. 57.

11. *Visions and Voices on Emerging Challenges in Digital Business Strategy.* Bharadwaj, A, et al. 2, 2013, MIS Quarterly, Vol. 37, pp. 61-663.

12. *Organizing for a Digital Future: Opportunities and Challenges.* Soule, DL, et al. 3, 2014, SSRN Electronic Journal, Vol. 55, pp. 1-6.

13. *Building Dynamic Capabilities for Digital transformation: an Ongoing Process of Strategic Renewal.* Warner, KSR and Wäger, M. 3, 2019, Long Range Planning., Vol. 52, pp. 49-326.

14. *Accelerating Digital Innovation inside and out: Agile teams, ecosystems, and Ethics.* Kane, GC, et al. 1-14, 2019, MIT Sloan Management Review, Vol. 60, p. 4.

15. *Digital transformation: a Multidisciplinary Reflection and Research Agenda.* Verhoef, PC, et al. 122, 2021, Journal of Business Research, Vol. 122, pp. 889-901.

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EP 02

Evaluating the Influence of AI Chatbot on Customer Satisfaction in Sri Lankan E-commerce Industry

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Background: The increasing adoption of artificial intelligence (AI) chatbots in e-commerce has transformed customer service by providing instant responses, personalized assistance, and continuous service availability. However, limited research has examined how AI chatbot characteristics influence customer satisfaction within the Sri Lankan e-commerce industry.
Objective/s: This study aimed to investigate the influence of perceived usefulness, perceived ease of use, anthropomorphism, and perceived security on customer satisfaction in the Sri Lankan e-commerce industry, with consumer trust acting as a mediating variable.
Methods: A quantitative cross-sectional research design was employed. Data were collected from 193 online shoppers aged 18–45 years who had experience using AI chatbots on Sri Lankan e-commerce platforms. Participants were selected using stratified random sampling from six districts, and data were collected through a structured online questionnaire. The data were analyzed using SPSS 25 through descriptive statistics, reliability analysis, correlation analysis, and regression analysis.
Results: All measurement scales demonstrated acceptable reliability, with Cronbach's alpha values exceeding 0.7. The findings revealed significant positive relationships between AI chatbot characteristics, consumer trust, and customer satisfaction. Perceived security showed the strongest relationship with customer satisfaction ($r = 0.952$), followed by consumer trust ($r = 0.927$). Furthermore, perceived usefulness, ease of use, anthropomorphism, and perceived security significantly influenced customer satisfaction. Consumer trust positively mediated the relationship between AI chatbot characteristics and customer satisfaction.
Conclusion: AI chatbot characteristics significantly influence customer satisfaction in the Sri Lankan e-commerce industry. Perceived security emerged as the strongest influencing factor, while consumer trust played a significant mediating role. The findings highlight the importance of developing AI chatbots that are useful, easy to use, human-like, and secure to enhance customer experiences, strengthen consumer trust, and improve overall customer satisfaction.

Keywords: Artificial Intelligence, AI Chatbots, Customer Satisfaction, Consumer Trust, E-commerce, Sri Lanka

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Introduction

AI chatbots in the global e-commerce sector can optimize customer interactions and improve service accessibility and efficiency, and most online retail platforms use these tools to provide instant responses, personalized recommendations, and 24/7 customer service. Digital commerce in Sri Lanka is growing rapidly, so local businesses have successively introduced these systems to upgrade their services. However, customer satisfaction is fundamentally shaped by users' perceptions and trust in the technology.

Existing research has identified four core influencing characteristics on customer satisfaction such as perceived usefulness, perceived ease of use, anthropomorphism, and perceived security [1,2]. Perceived usefulness refers to the ability of chatbots to help customers effectively complete their tasks and obtain relevant information, while ease of use focuses on the simplicity and convenience of chatbot interactions [3,4]. Anthropomorphism, which includes human-like communication and emotional interaction, has also been found to positively influence customer experiences and trust [5,6]. In addition, perceived security plays a major role in building customer confidence by assuring users that their personal information and and online transactions are protected [7,8].

When it comes to trust, its like the bridge that connects all these chatbot qualities to how satisfied customers end up feeling. Research points out that if a chatbot seems useful, simple, secure, and a bit human-like, customers are more likely to trust it, and that trust pushes satisfaction higher, especially in online shopping setups [2,6].

But in Sri Lanka, theres not much work done on this for e-commerce, even though international studies cover it plenty. Most local research sticks to banks or government services, not really diving into retail online [9]. And quantitative researches linking chatbot features to satisfaction through trust, aimed at Sri Lankan shoppers, is limited [10]. So, theres a significant research gap that needs filling, to see how these things actually work here.

This study is to check out how features like usefulness, ease of use, anthropomorphism, and perceived security affect satisfaction in Sri Lankas e-commerce world, with trust in the middle as the mediator. That seems key, since the local scene might handle it differently.

Methods

Research Approach and Population

This study basically went with a quantitative research approach, with a cross-sectional time horizon to find out how AI chatbot features influence customer satisfaction in Sri Lankas e commerce industry with consumer trust acting as a mediator. The main things focused on were perceived usefulness, ease of use, anthropomorphism, and perceived security, all tying into satisfaction. The target population were online shoppers from Sri Lanka, ages 18 to 45, who had actually used AI chatbots on sites like Daraz, Wasi.lk, or Kapruka. Respondents were selected from districts such as Colombo, Gampaha, Kandy, Galle, Jaffna, and Batticaloa.

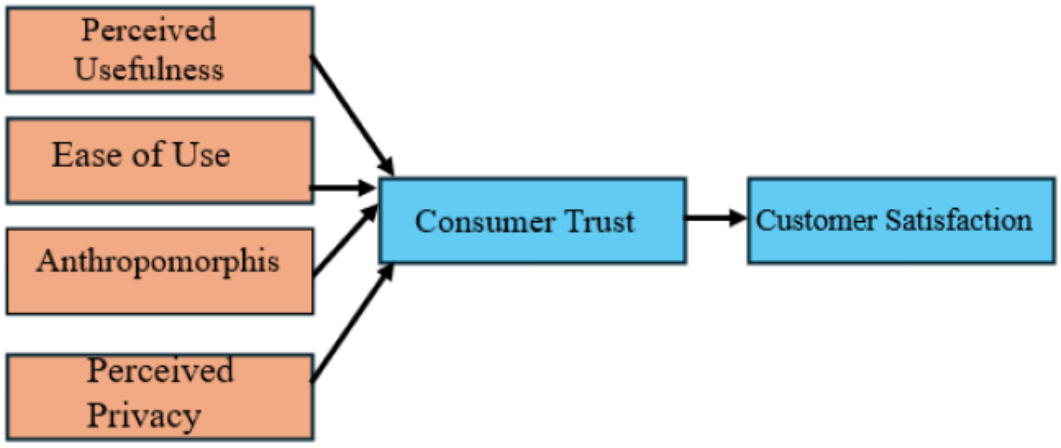

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Figure 1: Conceptual Framework

Sampling Techniques and Data Collection

The sample size was determined using the finite population correction formula with 95% confidence level and 5% margin of error. And 193 respondents were selected from a total target population of 385 online shoppers. Stratified random sampling helped was used to ensure proper representation from all selected districts and reduce sampling bias.

Primary data were collected through a structured online questionnaire consisting of close-ended questions related to perceived usefulness, ease of use, anthropomorphism, perceived security, consumer trust and customer satisfaction. The measurement items were developed based on previous literature related to AI chatbot usage and customer satisfaction in digital service environments [1-4].

Data Analysis

The collected data were analysed using SPSS 25. Descriptive and inferential statistical techniques were used to examine demographic characteristics, reliability, correlations, and the relationship between variables. Reliability analysis was conducted using Cronbach's Alpha, where all variables recorded values above 0.7, confirming acceptable reliability levels.

Ethical Considerations

On ethics, everything stayed confidential and anonymous for participants. Participation was voluntary, and data only went toward this academic work. This research also maintained transparency, minimized bias during analysis, and ensured ethical use of AI-related content.

Results

Demographic Profile of Respondents

The questionnaire was distributed among a sample of 193 respondents who had already experienced AI chatbots on Sri Lankan e-commerce platforms. The majority were aged between 18 - 25, and it was observed that this age group had a higher preference for using AI-powered chatbots. A stratified random sampling technique was adopted to select the participants and to cover six districts, namely Colombo, Gampaha, Kandy, Galle, Jaffna, and Batticaloa, ensuring representation from different geographical regions of Sri Lanka.

Reliability Analysis

Reliability analysis was conducted using Cronbach's alpha to evaluate the internal consistency of the measurement scales. All variables recorded Cronbach's Alpha values above the acceptable threshold of 0.7, confirming that the research instrument was reliable for statistical analysis.

Table 1: Reliability Analysis

Variable	Cronbach's Alpha Value	Decision Criteria
Perceived Usefulness	0.731	Acceptable
Ease of Use	0.815	Good
Anthropomorphism	0.899	Good
Perceived Security	0.869	Good
Consumer Trust	0.882	Good
Customer Satisfaction	0.904	Excellent

Source: (Survey Data)

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Correlation Analysis

The correlation analysis indicated a positive relationship between AI chatbot features and customer satisfaction. Perceived usefulness and ease of use showed strong positive relationships with consumer trust and customer satisfaction. Meanwhile, it further shows that anthropomorphism positively influenced customer interaction and engagement, while perceived security improved customer confidence regarding online transactions and information privacy.

Table 2: Correlation Analysis

Variables	PU	EOU	ANTH	PS	CT	CS
Perceived Usefulness (PU)	1					
Ease of Use (EOU)	.790**	1				
Anthropomorphism (ANTH)	.877**	.858**	1			
Perceived Security (PS)	.870**	.889**	.936**	1		
Consumer Trust (CT)	.798**	.855**	.935**	.942**	1	
Customer Satisfaction (CS)	.860**	.834**	.918**	.952**	.927**	1
****. Correlation is significant at the 0.01 level (2-tailed).**						

Source: Survey Data

The correlation analysis revealed strong positive correlations between AI chatbot features and consumers' trust and satisfaction. Perceived security had the strongest connection with customer satisfaction at r = 0.952. Likewise, consumer trust had a strong positive connection with customer satisfaction at r = 0.927. All relationships were statistically significant at the 0.01 level.

Regression Analysis

The analysis has also proven that perceived usefulness, ease of use, anthropomorphism and perceived security significantly influenced customer satisfaction among online shoppers. Regression analysis also demonstrated that consumers' trust positively mediated the relationship between AI chatbot features and customer satisfaction.

Among the independent variables, perceived security had the strongest influence on customer satisfaction, as it is shown that customers place more emphasis on the privacy protection and transaction safety as well as the trustworthiness when they are interacting with AI chatbot systems. Anthropomorphism also has a strong positive influence on improving user engagement and creating a more humanized interaction during their online shopping experiences. Finally, perceived usefulness and ease of use have both positively contributed to the improvement of convenience and accessibility and efficiency of the customers' interactions with AI chatbots in regards to customer service.

Table 3: Regression Analysis Summary

Variable	Standardized Influence on Customer Satisfaction (β)	Significance (p-value)
Perceived Usefulness	Positive	$p < 0.05$
Ease of Use	Positive	$p < 0.05$
Anthropomorphism	Positive	$p < 0.05$
Perceived Security	Strong Positive	$p < 0.05$
Consumer Trust	Positive Mediating Influence	$p < 0.05$

Source: Survey Data*Hypotheses Testing*

The results showed that every hypothesis were supported. Perceived usefulness, ease of use, anthropomorphism, and perceived security demonstrated significant positive influence on customer satisfaction within the Sri Lankan e-commerce industry. Among these variables, perceived security showed the strongest influence on customer satisfaction. And consumer trust significantly mediated the relationship between AI chatbot features and customer satisfaction, showing that consumer trust plays an important role in enhancing positive customer experiences with AI chatbot technologies.

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Table 4: Hypotheses Test Summary

Hypotheses	Result
H1: Perceived usefulness positively influences consumer trust	Accepted
H2: Ease of use positively influences consumer trust	Accepted
H3: Anthropomorphism positively influences consumer trust	Accepted
H4: Perceived Security positively influences consumer trust	Accepted
H5a: Consumer trust mediates the relationship between perceived usefulness and customer satisfaction.	Accepted
H5b: Consumer trust mediates the relationship between ease of use and customer satisfaction.	Accepted
H5c: Consumer trust mediates the relationship between anthropomorphism and customer satisfaction.	Accepted
H5d: Consumer trust mediates the relationship between perceived security and customer satisfaction.	Accepted
H6: Consumer Trust Has a significant positive impact on customer satisfaction.	Accepted

Discussions

Perceived Usefulness and Ease of Use

The results of this study demonstrated that customer satisfaction in Sri Lanka's e-commerce sector is significantly influenced by perceived usefulness and ease of use. When AI chatbots offered quick responses, precise information, and practical customer support during online shopping activities, customers were more satisfied. Strong positive correlations between perceived usefulness, ease of use, and customer satisfaction were also found in the correlation analysis. The findings showed that user-friendly chatbots enhance consumer interactions and promote favorable perceptions of AI technologies. These findings are consistent with previous studies which highlighted that useful and easy to use AI systems positively influence customer acceptance and satisfaction [1,3,4].

Anthropomorphism and Perceived Security

The study also showed that anthropomorphism enhances user engagement and emotional interaction with AI chatbots, which in turn improves customer satisfaction. Personalized interactions, conversational responses, and human-like communication methods all helped to improve customer satisfaction. Similarly, of all the independent variables, perceived security showed the strongest influence on customer satisfaction. Customer satisfaction and perceived security had a very significant positive relationship, according to the correlation study ($r = 0.952$). Customers expressed increased confidence and trust in AI chatbots that guaranteed secure online transactions and privacy protection. These results are aligned with previous studies highlighting the enhancement of customer trust and satisfaction in digital commerce environments through human-like chatbot interactions and security assurance [5–8].

Consumer Trust and Customer Satisfaction

The findings also demonstrated that the relationship between AI chatbot features and customer satisfaction is substantially mediated by consumer trust. Customer satisfaction and consumer trust have a strong positive relationship, according to the correlation analysis ($r = 0.927$). Customers were more likely to develop positive attitudes toward AI chatbot services when the systems were perceived as useful, secure, reliable, and interactive. And, the regression analysis verified that every independent variable had a significant impact on consumer satisfaction. These results are consistent with previous research that found that customer acceptance of AI technology in online service environments is significantly influenced by trust [2,6].

Limitations and Future Research

Despite the positive findings, this study had a number of limitations. Only respondents between the ages of 18 and 45 were included in the study, which was restricted to a few districts in Sri Lanka. Also, the study focused on four AI chatbot features and ignored other Behavioural or technological aspects that may influence consumer satisfaction. Therefore,

future research studies can expand the sample size, cover more areas, and look into more AI-related elements influencing consumer experiences in Sri Lanka's e-commerce industry.

Conclusion

According to the study's findings, customer satisfaction in Sri Lanka's e-commerce industry is significantly influenced by AI chatbot features. Customer satisfaction was positively impacted by perceived usefulness, ease of use, anthropomorphism, and perceived security, however, the relationship between AI chatbot features and customer satisfaction was significantly mediated by consumer trust. Perceived security was the independent variable that had most significant influence on customer satisfaction, highlighting the significance of transaction security, privacy protection, and consumer confidence in AI chatbot systems.

Customers are satisfied when AI chatbots offer precise information, quicker responses, user-friendly interactions, and human-like communication experiences, according to the survey. Strong positive correlations between AI chatbot features, customer satisfaction, and consumer trust were also shown by the correlation and regression analysis. So, the results show that implementing AI chatbots effectively can enhance customer experiences and strengthen customer relationships in Sri Lanka's e-commerce industry.

By offering actual data from the Sri Lankan e-commerce sector, where limited prior research has been done, this study adds to the quantity of knowledge already available on AI chatbot technologies. Through safe, dependable, and engaging chatbot services, the results may help e-commerce companies improve AI chatbot performance, build consumer confidence, and raise overall customer satisfaction.

The study was restricted to specific districts and respondents between the ages of 18 and 45, despite the encouraging results. Future research can therefore broaden the geographic scope, boost the sample size, and look at other AI-related elements that may influence consumer satisfaction in digital commerce environments.

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References

Eren, B. A., 2021. Determinants of customer satisfaction in chatbot use: evidence from a banking application in Turkey. International Journal of Bank Marketing, 39(2), pp. 294-311.

Lie, D., Sudirman, A., E. & Butarbutar, M., 2019. Analysis of Mediation Effect Of Consumer Satisfaction On The Effect Of Service Quality, Price and Consumer Trust On Consumer Loyalty. *INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH,* 8(8), pp. 421-428.

Guo, L. & Cai, Y., 2023. An analysis of the impact of text-based AI chatbot on consumer purchase intentions in online shopping platforms. International Journal of Sociologies and Anthropologies Science, 4(6), p. 399–416.

Nguyen, V. T. & Nguyen, C. T., 2022. The Effect of Structural Equation Modeling on Chatbot Usage: An Investigation of Dialogflow. International Journal of Applied Information Technology, 6(1), pp. 1-12.

Klein, K. & Martinez, L. F., 2022. The impact of anthropomorphism on customer satisfaction in chatbot commerce: an experimental study in the food sector. Electronic Commerce Research, 23(4), p. 2789–2825.

Ding, Y. & Najaf, M., 2024. Interactivity, humanness, and trust: a psychological approach to AI chatbot adoption in e-commerce. BMC Psychology, 12(595), pp. 1-14.

Nordheim, C. B., Følstad, A. & Bjørkli, A. C., 2019. An initial model of trust in chatbots for customer service—Findings from a questionnaire study. Interacting with Computers, 31(3), p. 317–335.

Al-Oraini, B. S., 2025. Chatbot dynamics: trust, social presence and customer satisfaction in AI-driven services. Journal of Innovative Digital Transformation, pp. 1-22.

Rathnayake, A. S., Nguyen , T. D. H. N. & Ahn, Y., 2025. Factors Influencing AI Chatbot Adoption in Government Administration: A Case Study of Sri Lanka's Digital Government. Administrative Sciences, 15(4), p. 157.

Rajapaksha, S. & Chandrasiri, S., 2023. The impact of AI on customer experience: an exploration of how AI-powered chatbots and virtual assistants have transformed customer experience in the last decade.. Journal of Digital Customer Experience.

Wilson, N., Keni , K. & Tan, P. . H. P., 2021. The Role of Perceived Usefulness and Perceived Ease-of-Use Toward Satisfaction and Trust which Influence Computer Consumers' Loyalty in China. Gadjah Mada International Journal of Business, 23(3), pp. 262-294.

Munawar, F. et al., 2023. The Impact of Anthropomorphism, Consumer Trust, And Consumer Attitude on Purchase Decisions of Environmentally Friendly Products. Enrichment: Journal of Management, 13(1), pp. 214-223.

Farhat, K., Arif, I., Aslam, W. & Hussain, A., 2019. Underlying Factors Influencing Consumers' Trust and Loyalty in Ecommerce. Business Perspectives and Research, 8(2), pp. 186-204.

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EP 03

Determinants of Textile and Garment Exports in Sri Lanka: 1995–2025

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Abstract

Background: The textile and garment industry is a major contributor to Sri Lanka's economy, providing export revenue and employment. Understanding the drivers of these exports helps policymakers support the sector.

Objectives: The main objective of this study is to analyse the determinants of Sri Lanka's textile and garment exports from 1995 to 2025. The first specific objective is to examine the long-term growth trajectory of textile and garment exports, and the second is to evaluate the influence of key macroeconomic variables, including the exchange rate, female labor force participation, government expenditure, and foreign direct investment (FDI).

Methods: This study analysed secondary data covering a 31-year period (1995–2025) sourced from the Central Bank of Sri Lanka. Descriptive statistics and multiple regression analysis were employed using SPSS to examine the data. Model validity was assessed using econometric diagnostic tests.

Results: Exports ranged from 1,092 to 5,952 units, with a mean of 3,780.37. The regression model explained 89.0% of the variation in exports (R Square = 0.890). Female labor force participation ($\beta_1 = 159.208$, $p = 0.007$) and the exchange rate ($\beta_2 = 9.258$, $p < 0.001$) had significant positive effects. Government expenditure showed a significant negative effect ($\beta_3 = -157.268$, $p < 0.001$). FDI was not significant ($p = 0.696$). Diagnostic tests indicated that the regression model satisfied the required assumptions.

Conclusions: Sri Lanka's textile and garment exports from 1995 to 2025 show a positive long-term growth trajectory. Exchange rate depreciation and female labor force participation strongly and positively influence export performance, whereas higher government expenditure reduces exports and foreign direct investment has no statistically significant effect. Policymakers should therefore focus on exchange rate management and support for women's employment to enhance export competitiveness, sustain long-term growth, and ensure the continued strategic contribution of the apparel industry to Sri Lanka's economic development. Future research should employ panel data, sector-specific FDI, dynamic econometric models, and export competitiveness measures.

Keywords: *Exchange rate, exports, female labour force, foreign direct investment, government expenditure, textile industry*

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Introduction

The textile and garment industry constitutes Sri Lanka's most significant export sector, serving as the primary generator of foreign exchange, a major source of direct and indirect employment, and a crucial driver of industrial development. Over the past four decades, Sri Lanka has earned global recognition as a reliable, ethical, and sustainable manufacturing hub, supplying high-quality apparel to renowned international brands such as Victoria's Secret, GAP, Nike, Marks & Spencer, H&M, and Uniqlo. The industry offers a diversified product range including sportswear, lingerie, workwear, swimwear, and children's clothing. It has transformed from basic cut-and-sew operations into a knowledge-driven, innovation-oriented sector supported by advanced research and development facilities, green manufacturing practices, and the internationally acclaimed "Garments Without Guilt" initiative. These attributes have strengthened its competitive position within global value chains. Despite these strengths, the sector's export performance remains highly sensitive to macroeconomic fluctuations, including exchange rate volatility, labour market conditions, and overall economic growth. Consequently, to sustain growth and reinforce competitiveness amid increasing global pressures, it is essential to empirically assess how key macroeconomic indicators influence export outcomes.

The study is grounded in International Trade Theory, Comparative Advantage Theory, Export-Led Growth Theory, and Global Value Chain (GVC) Theory. These frameworks explain how comparative advantage, export-led growth, and global production networks influence textile and garment exports, providing the theoretical basis for selecting the study's macroeconomic determinants.

The determinants of export performance in the textile and garment industry have been extensively studied, providing a robust theoretical and empirical foundation for analysing the Sri Lankan case. The exchange rate is a primary determinant of price competitiveness in international trade. Economic theory posits that depreciation of the domestic currency enhances export price competitiveness, thereby boosting export volumes (7). This relationship is particularly pronounced in labour-intensive sectors such as garments. Empirical studies on developing Asian economies confirm this finding; for instance, Hossain and Mitra (3) identified a significant positive impact of real exchange rate depreciation on Bangladesh's garment export growth. In Sri Lanka, research by Weerasinghe and Perera (8) identifies the exchange rate as a pivotal factor, suggesting that policies preventing real appreciation have been crucial for the apparel sector's competitiveness.

The link between gross domestic product and export performance is more complex. For highly globalized industries integrated into global value chains, export performance is driven more by external demand and sector-specific factors than by the domestic business cycle (1). This resonates in Sri Lanka, where Kelegama (6) described the garment industry as operating as an "enclave," with growth reliant on global partnerships rather than domestic fluctuations. As a labour-intensive industry, the garment sector's health is closely tied to labour market conditions. High unemployment may signal structural issues such as skill mismatches or social unrest, which can hinder production capacity (4). Gereffi and Frederick (2) emphasise that competitive advantage stems from a stable, skilled, and productive labour force. For Sri Lanka, which competes on ethical compliance under the "Garments Without Guilt" banner, labour market weaknesses threaten this premium positioning (5). While individual effects have been explored, an updated integrated analysis for Sri Lanka covering 1995 to 2025 is needed. **Furthermore, the existing literature has not systematically addressed econometric issues such as stationarity, autocorrelation, and multicollinearity in the Sri Lankan context, which this study aims to address.** Accordingly,

The main objective is

to analyse the determinants of Sri Lanka's textile and garment exports.

The specific objectives,

1. to examine the long-term growth trajectory of textile and garment exports
2. to evaluate the influence of exchange rate, female labour force participation, government expenditure, and foreign direct investment on exports.

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Methods

This study adopted a quantitative research design, which is appropriate for measuring and testing the statistical relationships between numerical variables. The time frame of the study covered 31 consecutive years, from 1995 to 2025. This paper used secondary data from the Central Bank of Sri Lanka.

To analyse the first objective, descriptive statistics were first calculated for the export variable. These included the minimum value, the maximum value, the mean, and the standard deviation. A graph was also generated using SPSS to analyse the trend in Sri Lanka's textile and garment exports.

Multiple linear regression was performed to analyse the second specific objective. The dependent variable in this study was the annual value of textile and garment exports (USD Mn). The independent variables included four key macroeconomic factors, which are the exchange rate (Sri Lankan rupees per US dollar), the female labour force participation rate (percentage of the total female working-age population), government expenditure (percentage of GDP), and foreign direct investment (USD Mn). The variables were selected based on international trade theory, empirical evidence, and their policy relevance to Sri Lanka. They capture export competitiveness, labour market conditions, fiscal policy, and the role of foreign investment in the textile and garment sector.

The multiple regression model is as follows:

$$\text{Textile and Garment Exports} = \beta_0 + \beta_1(\text{Female Labour}) + \beta_2(\text{Exchange Rate}) + \beta_3(\text{Government Expenditure}) + \beta_4(\text{FDI}) + \varepsilon$$

In this equation, β_0 represents the intercept or constant term (the expected level of textile and garment exports when all independent variables are zero), β_1 through β_4 represent the regression coefficients (each indicating the expected change in exports for a one-unit change in the respective independent variable, holding all other variables constant), and ε represents the error term (capturing the influence of other factors not included in the model).

To ensure the validity of the OLS regression model, several econometric diagnostic tests were conducted. The Augmented Dickey–Fuller (ADF) test assessed stationarity, Variance Inflation Factors (VIF) examined multicollinearity, the Durbin–Watson statistic tested for autocorrelation, the Breusch–Pagan–Godfrey (BPG) test evaluated heteroscedasticity, and the Jarque–Bera (JB) test assessed the normality of residuals. These tests were performed to verify that the regression model satisfied the underlying econometric assumptions and produced reliable estimates.

All statistical analyses were conducted using the specialized statistical software SPSS. Statistical significance was determined at a threshold of $p < 0.05$, indicating that any association with a less than 5% probability of occurring by chance was deemed statistically significant.

Results

Descriptive Statistics: Long-Term Growth Trajectory of Textile and Garment Exports

To address the first specific objective, which was to examine the long-term growth trajectory of textile and garment exports, descriptive statistics were computed for the export variable over the 31-year period from 1995 to 2025.

Table 01 - Descriptive Statistics of Textile and Garment Exports in Sri Lanka

	N	Minimum	Maximum	Mean	Std. Deviation
Exports	31	1092	5952	3780.37	1289.107
Valid N (listwise)	31				

Source : Author's calculations using SPSS based on data from the Central Bank of Sri Lanka Annual Reports (1995-2025)

As presented in Table 1, textile and garment exports ranged from a minimum of 1,092 (USD Mn) to a maximum of 5,952 (USD Mn). The mean export value was 3,780.37 (USD Mn), with a standard deviation of 1,289.107. The relatively large

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standard deviation indicates considerable year-to-year fluctuations in export performance over the study period. A graphical representation of the trend is provided in Figure 1.

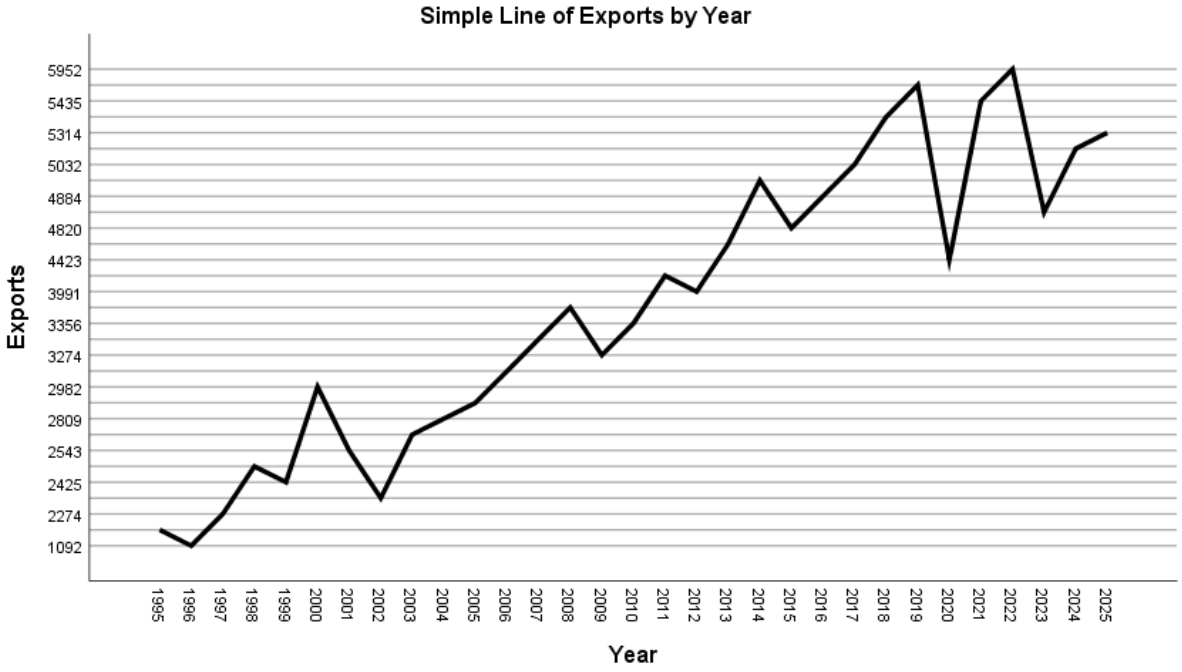

Figure 01 - Trend of Textile and Garment Exports in Sri Lanka (1995–2024)
Source : Author's calculations using SPSS based on data from the Central Bank of Sri Lanka Annual Reports (1995-2025)

The export trend shows an overall upward trajectory with notable fluctuations influenced by major economic events. Key factors include the expiry of the Multi Fibre Arrangement (2005), the Global Financial Crisis (2008–2009), the COVID-19 pandemic (2020), Sri Lanka's economic crisis (2022), and the restoration of GSP+ trade concessions, all of which affected export performance.

Regression Analysis: Influence of Macroeconomic Factors on Exports

To address the second specific objective, which was to evaluate the influence of exchange rate, female labour force participation, government expenditure, and foreign direct investment (FDI) on textile and garment exports, a multiple linear regression analysis was conducted. The dependent variable was textile and garment exports (USD Mn), while the independent variables were exchange rate (Sri Lankan rupees per US dollar), female labour force participation rate (percentage of total female working-age population), government expenditure (percentage of GDP), and FDI (USD Mn).

Model Summary

As shown in Table 2, the multiple regression model demonstrated a strong relationship between the independent variables and textile exports. The R Square value was 0.890, meaning that the four independent variables collectively explained 89.0% of the variation in textile and garment exports. The adjusted R Square was 0.873, which accounts for the number of predictors in the model.

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Table 2 - Model Summary

Model	R	R Square	Adjusted R Square	STd. Error of the Estimate
1	.943[a]	.890	.873	459.6852

Source : Author's calculations using SPSS based on data from the Central Bank of Sri Lanka Annual Reports (1995-2025)

ANOVA Results

The ANOVA results, presented in Table 3, confirmed that the regression model was statistically significant ($F = 52.482$, $p < 0.001$). This indicates that the independent variables collectively predict textile and garment exports at a highly significant level.

Table 3 - ANOVA Results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	44359901.952	4	11089975.488	52.482	.000[b]
	Residual	5494072.610	26	211310.485		
	Total	49853974.562	30			

Source : Author's calculations using SPSS based on data from the Central Bank of Sri Lanka Annual Reports (1995-2025)

Regression Coefficients with Diagnostic Statistics

Table 4 presents the unstandardized coefficients (β), standardized coefficients (Beta), t-values, and significance levels, **95% confidence intervals, and Variance Inflation Factors (VIF)** for each independent variable.

Table 4 - Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.			
	B	Std. Error	Beta			Lower Bound	Upper Bound	
(Constant)	665.130	2314.739		.287	.776	-4094.4	5424.717	
Female Labour	159.208	54.118	.223	2.942	.007	48.135	270.281	2.102
Exchange Rate	9.258	1.551	.557	5.969	.000	6.071	12.445	2.856
Government Expenditure	-157.268	31.131	-.466	-5.05	.000	-221.158	-93.378	2.798
FDI	-.031	.078	-.029	-.394	.696	-.192	.130	1.547

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a. Dependent Variable: Textile Exports			

Source : Author's calculations using SPSS based on data from the Central Bank of Sri Lanka Annual Reports (1995-2025)

All VIF values were below 5, indicating no multicollinearity among the independent variables. The 95% confidence intervals indicate the likely range of the true population coefficients.

Female labour force participation exerted a statistically significant positive influence on textile and garment exports (β = 159.208, $p = 0.007$). Specifically, a one-unit increase in the female labour force participation rate was associated with an approximate rise of 159.21 units in export value, ceteris paribus. The exchange rate demonstrated the strongest positive effect among all predictors ($\beta = 9.258$, $p < 0.001$). This finding indicates that depreciation of the Sri Lankan rupee against the United States dollar, reflected by a higher exchange rate, leads to a substantial increase in textile and garment exports. Government expenditure expressed as a percentage of gross domestic product revealed a significant negative relationship with exports ($\beta = -157.268$, $p < 0.001$). An expansion in government spending as a proportion of GDP was correlated with a decline in textile and garment exports. Conversely, foreign direct investment did not exhibit a statistically significant effect on export performance ($p = 0.696$). Accordingly, based on the empirical evidence, foreign direct investment was not a meaningful predictor of textile and garment exports throughout the study period.

The diagnostic tests confirmed that the regression model satisfied the key econometric assumptions, although the ADF test indicated potential non-stationarity in some variables.

Discussion

This study pursued two principal objectives. The first was to examine the long-term growth trajectory of textile and garment exports in Sri Lanka. The second was to evaluate the influence of exchange rate, female labour force participation, government expenditure as a percentage of GDP, and foreign direct investment on textile and garment export performance.

Concerning the first objective, the descriptive statistics revealed considerable volatility in textile and garment exports over the 31-year period from 1995 to 2025. Export values ranged from 1,092 USD Mn to 5,952 USD Mn, with a mean of 3,780.37 USD Mn and a standard deviation of 1,289.107. This substantial variation indicates that the sector has experienced alternating phases of expansion and contraction. The fluctuations in export performance reflect major external shocks, including the expiry of the Multi Fibre Arrangement (2005), the Global Financial Crisis, the COVID-19 pandemic, Sri Lanka's 2022 economic crisis, and the restoration of GSP+ concessions.

The uneven trajectory can be attributed to multiple exogenous shocks. Notwithstanding these fluctuations, the overarching trend suggests gradual secular expansion, reinforcing the sector's status as an indispensable contributor to the national economy.

Regarding the second objective, the regression model demonstrated substantial explanatory power, with the four independent variables collectively accounting for 89.0 per cent of the variance in exports (R Square = 0.890, adjusted R Square = 0.873). The model was statistically significant ($F = 52.482$, $p < 0.001$). The exchange rate exerted the strongest positive influence ($B = 9.258$, $p < 0.001$), aligning with international trade theory which posits that domestic currency depreciation enhances export price competitiveness (7). This finding corroborates empirical evidence from other developing Asian economies, including Bangladesh (3), and earlier Sri Lankan studies (8). Maintaining a competitive real exchange rate appears paramount for preserving global market share. However, given the observational nature of this study and the potential non-stationarity indicated by the ADF test, these findings should be interpreted as associational rather than causal.

Female labour force participation also exhibited a significant positive effect ($\beta = 159.208$, $p = 0.007$). The textile industry has historically been a primary employer of women in Sri Lanka. An expansion in female labour force participation enlarges the available worker pool, enabling higher production capacity. This finding underscores the importance of policies facilitating women's workforce entry, including safe transportation, childcare provisions, and equitable remuneration (2, 4). The positive and significant coefficient aligns with both Comparative Advantage Theory, which emphasizes labour-intensive production, and Export-Led Growth Theory, which highlights the role of labour supply in sustaining export expansion.

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Government expenditure revealed a significant negative relationship ($\beta = -157.268$, $p < 0.001$). The negative association between government expenditure and exports may reflect higher production costs or counter-cyclical fiscal responses during economic downturns rather than a direct adverse effect on exports.

Elevated government spending may precipitate inflationary pressures or higher interest rates, both of which undermine export competitiveness by escalating production costs. Excessive fiscal expansion may also generate macroeconomic uncertainty, deterring investment in tradable sectors.

Foreign direct investment did not demonstrate a statistically significant effect ($p = 0.696$). The insignificant effect of FDI may be due to aggregate FDI including non-tradable sectors rather than textile and apparel investments. Additionally, FDI impacts may occur with time lags. Future studies should consider sector-specific FDI and lagged effects for deeper insights.This study is limited by its observational nature, potential non-stationarity, and omitted variables such as global demand, trade conditions, wages, inflation, and political factors. Future research should address these limitations for stronger analysis.

This unexpected result may be attributed to temporal lags in FDI impact, inadequate capture of spillover effects, or the possibility that FDI inflows were directed toward non-tradable sectors rather than textiles. Further investigation with disaggregated data is warranted.

Conclusions

The historical trend analysis of Sri Lanka's textile and garment exports from 1995 to 2025 reveals a positive long-term growth trajectory. This growth, however, has been punctuated by significant fluctuations linked to major historical events including the MFA expiry, the Global Financial Crisis, the COVID-19 pandemic, and Sri Lanka's domestic economic crisis.

The econometric evaluation concludes that exchange rate depreciation and female labour force participation are the strongest positive determinants of export performance, while higher government expenditure as a percentage of GDP exhibits a negative influence, and foreign direct investment shows no statistically significant impact. In conclusion, the key determinants of Sri Lanka's textile and garment exports are the exchange rate and female labour force participation, both exerting a strong positive influence. Higher government expenditure reduces exports, and the sector's growth trajectory remains vulnerable to external shocks. Therefore, policymakers should prioritise exchange rate management and women's employment support through skills training and workplace safety measures, while exercising fiscal caution to sustain long-term export growth and reinforce Sri Lanka's position as an ethical apparel manufacturing hub. Given the observational nature and potential non-stationarity of the data, the findings should be interpreted as associations rather than causal relationships. Policy measures should extend beyond exchange rate management to include productivity enhancement, technological upgrading, workforce skills development, export diversification, value-chain upgrading, and sustainable apparel manufacturing. Supporting women's employment, maintaining fiscal discipline, and promoting ethical manufacturing practices are essential for strengthening Sri Lanka's export competitiveness. Future research should apply dynamic econometric models, panel data analysis, sector-specific FDI measures, and export competitiveness indices to provide more comprehensive insights.

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References

1. Athukorala P. Sri Lanka’s Trade Policy: Reverting to Dirigisme? The World Economy. 2014;37(11):1557–1576. doi:10.1111/twec.12213

2. Gereffi G, Frederick S. The Global Apparel Value Chain, Trade and the Crisis: Challenges and Opportunities for Developing Countries. In: Cheng W, Jomo KS, Ma SM, editors. Development after the Global Financial Crisis. Cambridge University Press; 2019. doi:10.1017/9781108550316.008

3. Hossain MS, Mitra R. Determinants of Ready-Made Garments Exports from Bangladesh: A Dynamic Panel Data Analysis. J Dev Areas. 2018;52(4):63–77. Available from: https://www.jstor.org/stable/26415752

4. International Labour Organization (ILO). The Future of Work in the Textile, Clothing, Leather and Footwear Industry. Geneva: International Labour Office, Sectoral Policies Department; 2019. Available from: https://www.ilo.org/sector/resources/publications/WCMS_735327/lang--en/index.htm

5. Jayasuriya S, Knight-John M. Sri Lanka's Apparel Industry: A Story of Sustained Competitive Advantage. In: Competitiveness Strategies of Developing Countries. Abingdon: Routledge; 2018. Available from: https://www.routledge.com/9781138558937

6. Kelegama S. Ready-Made Garment Industry in Sri Lanka: Preparing to Face the Global Challenges. Asia-Pacific Trade and Investment Review. 2005;1(1):51–74. Available from: https://repository.unescap.org/handle/20.500.12870/1206

7. Krugman PR, Obstfeld M. International Economics: Theory and Policy. 6th ed. Boston: Addison-Wesley; 2003. Available from: https://www.pearson.com/en-us/subject-catalog/p/international-economics-theory-policy/P200000005845/9780137546332

8. Weerasinghe WGP, Perera WAS. Impact of Real Effective Exchange Rate on Export Performance: Evidence from Sri Lanka. Sri Lankan J Appl Stat. 2020;21(2):1–15. doi:10.4038/sljastats.v21i2.7991

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EP 04

Determining Factors Oo Business Viability for Technology-Integrated Vertical Columbarium Services at Jayaratne Funeral Directors

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Abstract

Traditional cemeteries in urban Sri Lanka face increasing challenges due to limited land availability, rising real estate costs, and burial-related environmental concerns. Although indoor vertical columbarium systems successfully optimize urban space in other countries, Sri Lanka lacks sufficient empirical research on introducing such innovative services through private funeral homes. Therefore, this empirical study determined the key factors affecting the long-term business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors in Borella, Colombo. The study comprehensively examined four independent variables: cultural acceptance, infrastructure, perceived financial affordability, and technological integration capability. This study was developed using Saunders' Research Onion as the guiding framework. A quantitative approach and deductive method were applied, and primary data was collected via a structured questionnaire distributed among 103 participants included 35 employees of Jayaratne Funeral Directors, 40 potential customers, 10 religious leaders, 8 urban planners, and 10 policymakers/government representatives according to Morgan table. The findings revealed that the proposed framework significantly explains the business viability of technology-integrated vertical columbarium services. Among the examined factors, financial affordability and infrastructure were identified as significant positive determinants of long-term business sustainability, while cultural acceptance and technological integration showed positive but statistically insignificant relationships. Overall, the study provides practical insights for Jayaratne Funeral Directors in developing affordable, sustainable, and commercially viable memorial solutions that address urban land challenges in Sri Lanka.

Keywords: *business viability, columbarium, customer relations, Land shortage, operational readiness*

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Introduction

"As cities continue to grow and land becomes increasingly limited, even spaces of remembrance are forced to evolve. The need to honor human memory with dignity, sustainability, and innovation has become more important than ever in modern urban society.". This socio-spatial evolution is visually conceptualized in Figure 1.1, illustrating the paradigm shift from traditional urban landscapes to modernized, space-optimized memorial architecture.

Figure 1- Conceptual framework of technology-integrated vertical columbarium services by author

Background of the Land Shortage Crisis and legal and financial pressures.

Sri Lanka's cemeteries are facing a serious national challenge due to a growing shortage of burial land. Rapid urbanization has increased demand for housing and commercial development, leaving limited space for cemetery expansion. As a result, local authorities face rising land conflicts and environmental concerns within surrounding communities.

A clear example is seen in the Oddamavadi area of the Batticaloa District, where 21.5 acres of land were allocated for mass burials. Many local residents, including families previously displaced by war, lost land that supported their housing, agriculture, and livelihoods (1). This highlights the social and economic impact of poor cemetery management, which becomes more severe in highly urbanized cities like Colombo.

The issue is further intensified by outdated colonial-era regulations and high costs. Under the Cemeteries and Burial Grounds Ordinance, burials are prohibited within 50 feet of residences (2), and closed burial grounds cannot be repurposed without ministerial approval. Although Colombo Municipal Council waives basic burial fees for residents, non-residents must still pay charges (3). More importantly, private burial space is scarce, forcing families into the secondary market where prices range from Rs. 5 million to over Rs. 7.5 million, making traditional burial unaffordable.

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Shifting Towards Vertical Columbariums

To address these challenges, Sri Lanka must adopt space-efficient solutions such as vertical columbariums. The term columbarium originates from the Latin columba, meaning dove (4), and refers to structures with niches for storing cremated remains. These facilities are found in cemeteries, temples, and memorial buildings and also function as spaces for remembrance. Their vertical design significantly reduces land usage, making them suitable for dense urban areas.

Significance of the Study

Although vertical columbarium systems are widely used in countries such as Hong Kong, China, Singapore, and Japan, Sri Lanka still lacks sufficient empirical research on their adoption in private funeral services.

Therefore, this study examines the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors in Borella, Colombo. It focuses on four factors: cultural acceptance, infrastructure, financial affordability, and technological integration, providing insights into their commercial and cultural feasibility in the Sri Lankan context.

Profile of Jayaratne Funeral Directors

Established in 1952, Jayaratne Funeral Directors is one of Sri Lanka's leading death-care organizations (5), headquarters in Borella, Colombo. It provides professional funeral services, making it a suitable setting to evaluate the viability of vertical columbarium systems. Its long-standing operations allow assessment of key factors: cultural acceptance through its diverse clientele, infrastructure through operational capacity, financial affordability through service structure, and technological integration through its ability to adopt modern memorial systems.

Literature Review.

Business Viability.

In corporate strategy and entrepreneurship literature, business viability refers to the long-term ability of a business model to sustain operations, remain competitive, generate consistent revenue, and create continuous value. Unlike operational feasibility, which focuses on whether a service can be practically implemented, viability emphasizes long-term sustainability, adaptability, financial performance, and commercial success under changing market conditions (6). In this study, business viability is operationalized as the perceived long-term commercial potential of technology-integrated vertical columbarium services and is measured through respondents' perceptions of future growth potential, customer demand, revenue sustainability, competitiveness, and overall suitability as a sustainable memorial solution. Therefore, it is distinguished from customer acceptance, which reflects stakeholder willingness to adopt the service, and financial affordability, which represents the perceived cost accessibility of the service.

In the funeral industry, land scarcity and the shift toward space-efficient memorial systems increasingly influence business viability. Research shows that columbarium-based services provide land and cost advantages compared with traditional burials, while affordability, cultural readiness, and digital innovation contribute to long-term sustainability (7,8).

Cultural Acceptance.

In academic literature, the long-term viability of a death-care innovation depends on its alignment with cultural traditions, religious beliefs, and evolving lifestyles. Historically, societies have placed significant importance on funeral rites and preserving the memory of the deceased. In Sri Lanka, final dispositions mainly consist of burials and cremations, with 80%–90% of urban communities choosing cremation. Following cremation, families often seek closure through permanent memorial spaces that preserve identity and family legacy (9).

However, modern urban youth are increasingly affected by "hurry sickness," a condition characterized by constant time pressure and fast-paced lifestyles (10). This limits their ability to regularly visit and maintain distant, overcrowded cemeteries. At the same time, rising social isolation and concerns about lonely deaths have increased the desire for meaningful and accessible forms of remembrance (9,10). To address these changes, many individuals are adopting practices such as "death cleaning," where they proactively organize their belongings and plan their final rites in advance.

A technology-integrated vertical columbarium responds to these changing cultural patterns by providing an accessible urban memorial space while supporting dignified and lasting remembrance. Therefore, cultural acceptance is a key determinant of the business viability of such services at Jayaratne Funeral Directors.

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Infrastructure

In municipal public works, infrastructure refers to the fundamental physical and structural systems required for community survival, public health, and long-term operational continuity. For an infrastructure project to achieve viability, its design must address logistical deficits while remaining financially, environmentally, and structurally sustainable (11). The progression towards vertical columbaria directly reflects this viability. Rapid urban population growth and land scarcity have led to spatial exhaustion in traditional cemeteries, causing overcrowding and high real estate costs. Transitioning to vertical interment systems conserves land, improves economic efficiency, and supports sanitation requirements while addressing community needs (12).

The viability of contemporary columbarium infrastructure depends on balancing engineering durability with the creation of a spiritual, comforting, and peaceful environment. This is reflected in practices at Jayaratne Funeral Directors, where infrastructure is designed for both functional efficiency and emotional comfort during bereavement (11,12). This balance requires strong structural design based on Ultimate Strength Design (USD) to ensure safety under dead and seismic loads. Features such as natural ventilation, daylight optimization, and rainwater harvesting further enhance sustainability, reduce costs, and support a calm memorial environment consistent with Jayaratne Funeral Directors' standards.

Financial Affordability.

Financial affordability refers to the ability of consumers to access funeral and memorial services without excessive financial burden. In public infrastructure planning, financial viability is influenced by "form follows finance," where rising land costs drive a shift away from costly single-story developments (13). Traditional in-ground burials involve long-term costs such as burial plots, vaults, headstones, and land maintenance. Studies show that they require approximately 5.4 m^2 per plot including access to infrastructure, making them increasingly unaffordable for middle- and low-income groups as urban land prices rise (14). Municipalities also face financial strain as cemetery maintenance depends on one-time plot sales.

To address this, literature highlights multi-story columbaria as a cost-effective solution. Vertical niche stacking allows hundreds of urns to be accommodated within a small footprint, significantly reducing land use and capital costs per unit (15). It also lowers maintenance and labour expenses through prefabricated above-ground systems (15). As a result, columbarium services offer a more affordable and sustainable alternative to traditional burial systems. In the context of Jayaratne Funeral Directors, affordability remains a key factor influencing the business viability of technology-integrated vertical columbarium services.

Technological Integration.

The transition toward vertical columbaria has expanded beyond space-saving to include Internet of Things (IoT) hardware and digital communication systems, leading to "smart cemeteries" (16). Modern infrastructure increasingly links physical memorial spaces with cloud-based digital archives to meet expectations for digital connectivity (17). A key innovation is the Automatic Conveyor-belt Columbarium (ACC), which integrates robotic automation with digital displays. In these systems, conveyor mechanisms retrieve urns from secure storage and deliver them to viewing areas upon visitor authentication, while screens display photographs and genealogical information of the deceased.

Recent studies also highlight the use of NFC tags and QR codes embedded in niche facades. When scanned, they connect users to digital memorial platforms containing biographies, family trees, and video tributes (16,17). Additionally, sensor-based systems monitor temperature and humidity in columbarium structures, reducing moisture damage and maintenance costs. In the context of Jayaratne Funeral Directors, these technologies improve efficiency, user experience, and modernization. Therefore, technology integration is a key determinant of business viability in vertical columbarium services.

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Conceptual Framework.

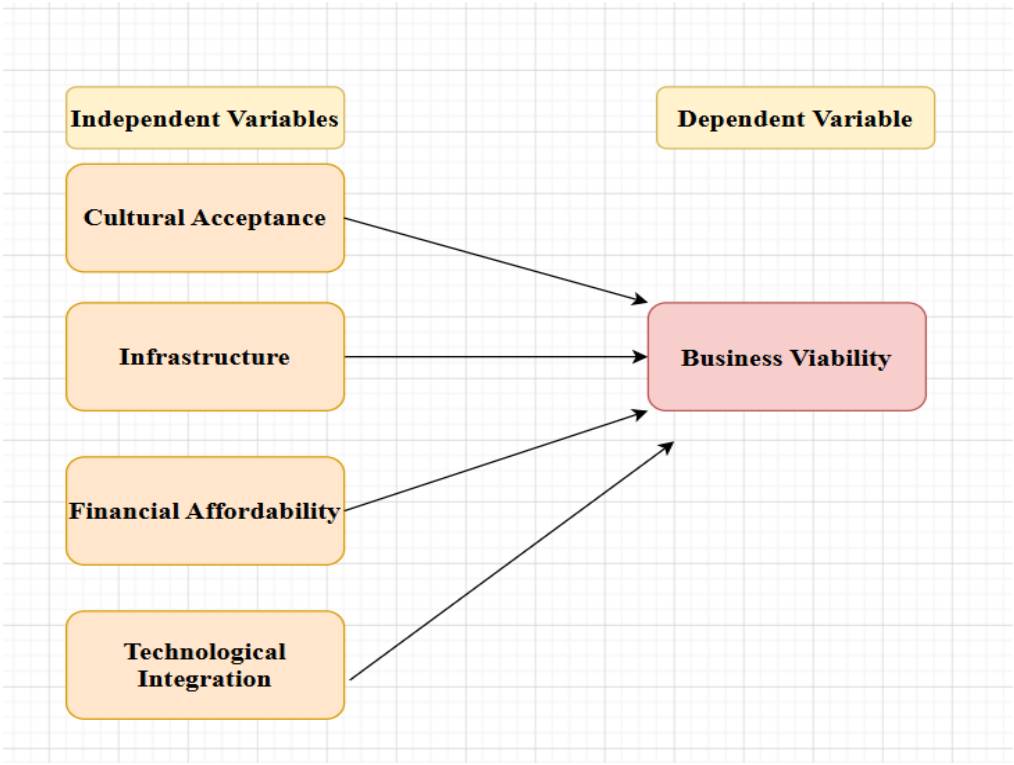

Figure 2: Conceptual Framework

According to figure 02 The conceptual framework is supported by the Resource-Based View (RBV) and Technology Acceptance Model (TAM). RBV explains that business success depends on valuable organizational resources and capabilities, therefore, infrastructure readiness and technological integration are considered important factors influencing service viability. TAM and Perceived Value Theory explain that market acceptance of innovative services depends on stakeholder acceptance and perceived benefits compared with costs. Therefore, cultural acceptance and financial affordability are included as demand-side factors affecting the adoption and long-term success of vertical columbarium services. In this study, viability is assessed through four determinants: cultural acceptance, infrastructure readiness, financial affordability, and technology integration.

Differentiation of Technology-Integrated Vertical Columbarium Services from Existing Memorial Services.

Table 1: Conceptual Novelt

Aspect	Traditional Cemetery	Technology-Integrated Vertical Columbarium (Proposed Study)
Land Utilization	Requires large land areas	Maximizes land use through vertical design, addressing urban land scarcity
Technology	Minimal or no technology	Integrates digital memorials, QR codes, online visitation, digital records, and automated management systems
Cultural Considerations	Strongly aligned with traditional burial customs	Requires greater cultural acceptance due to the integration of modern technology with memorial practices

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Cost	High long-term land and maintenance costs	Designed to provide an affordable and sustainable memorial solution while reducing land-related costs
Infrastructure	Basic cemetery infrastructure	Requires advanced infrastructure, digital systems, security, and technological support
Long-Term Sustainability	Limited by land availability and urban expansion	Supports sustainable business growth through efficient land use, technological innovation, and scalable operations

Table 1 demonstrates the conceptual novelty of the proposed technology-integrated vertical columbarium by comparing it with traditional memorial services. Unlike traditional burial practices, the proposed model combines technology with space-efficient infrastructure to address urban land scarcity and improve operational efficiency. Therefore, cultural acceptance, infrastructure, financial affordability, and technological integration provide a comprehensive framework for evaluating the business viability of the proposed service.

Main Research Objective

To determine the factors affecting the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors.

Specific Research Objectives

• RO1 – To determine the effect of cultural acceptance on the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors.

• RO2 – To determine the effect of infrastructure on the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors.

• RO3 – To determine the effect of financial affordability on the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors.

• RO4 – To determine the effect of technology integration on the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors.

This study is expected to provide a clear understanding of how cultural acceptance, infrastructure readiness, financial affordability, and technology integration collectively influence the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors. The findings will help identify the most significant factors affecting adoption and sustainability, and will contribute to developing practical recommendations for implementing modern, space-efficient memorial solutions in urban Sri Lankan contexts.

Methods of the Research

Research Design

This study was developed using Saunders' Research Onion as the guiding framework. A positivist philosophy was adopted to collect objective and measurable data on the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors. A quantitative method was used to gather numerical data, and a deductive approach was applied to test theories from the literature. A descriptive research design was used to examine the influence of cultural acceptance, infrastructure, financial affordability, and technological integration on business viability.

Participant Characteristics

The study involved 103 respondents from key stakeholder groups. The participants included 35 employees of Jayaratne Funeral Directors, 40 potential customers, 10 religious leaders, 8 urban planners, and 10 policymakers/government representatives. These groups were selected due to their relevant knowledge and perspectives on funeral services, acceptance, infrastructure, affordability, and technology adoption.

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Sample Size and Inclusion Criteria

The sample size of 103 respondents was determined using the Krejcie and Morgan (1970) sample size table. The study included relevant stakeholders such as employees, customers/potential customers, religious leaders, urban planners, and policymakers, while respondents without relevant knowledge were excluded.

Data Collection Procedure

Data were collected using a structured questionnaire with 25 items, five for each variable: cultural acceptance, infrastructure, financial affordability, technology integration, and business viability. A five-point Likert scale (Strongly Disagree to Strongly Agree) was used. Questionnaires were distributed to selected employees and responses were collected for analysis.

Statistical Analysis Methods

Data were analysed using SPSS. Descriptive statistics (mean and standard deviation) summarized responses. Reliability was tested using Cronbach's Alpha. Correlation examined relationships between variables and comparisons, and multiple regression assessed their impact on business viability.

Results.

This section presents the findings of the study based on the collected data and statistical analysis.

Demographic Information.

Table 2: Demographic info

Variable	Category	Frequency	Percentage%
Gender	Male	60	58.3
	Female	43	41.7
Participant Group	Employees (Jayarathne Funeral Directors)	35	34.0
	Customers / Potential Customers	40	38.8
	Religious Leaders	10	9.7
	Urban Planners	8	7.8
	Policymakers / Government Representatives	10	9.7

The demographic analysis shows that the study included 103 respondents, with males representing 58.3% (60 respondents) and females representing 41.7% (43 respondents). Among the participant groups, customers/potential customers formed the largest proportion (38.8%), followed by employees of Jayarathne Funeral Directors (34.0%), while religious leaders, urban planners, and policymakers contributed 9.7%, 7.8%, and 9.7% respectively.

Descriptive analysis of study variables.

Descriptive analysis is a statistical method used to summarize the main features of a dataset, such as mean, median, standard deviation, range.

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Statistics

		A1	A2	A3	A4	A5
N	Valid	103	103	103	103	103
	Missing	0	0	0	0	0
Mean		3.98	4.19	4.42	4.40	4.32
Median		4.00	4.00	4.00	4.00	4.00
Mode		4	4	4[a]	4[a]	4
Std. Deviation		.656	.768	.619	.616	.645
Sum		410	432	455	453	445

a. Multiple modes exist. The smallest value is shown

Statistics

		B1	B2	B3	B4	B5
N	Valid	103	103	103	103	103
	Missing	0	0	0	0	0
Mean		4.20	4.30	4.17	4.46	4.32
Median		4.00	4.00	4.00	5.00	4.00
Mode		4	4	5	5	5
Std. Deviation		.746	.654	.833	.653	.717
Sum		433	443	430	459	445

Figure 3: Business Viability and Cultural Acceptance- Descriptive analysis

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Statistics

		C1	C2	C3	C4	C5
N	Valid	103	103	103	103	103
	Missing	0	0	0	0	0
Mean		4.21	4.17	4.27	4.41	4.35
Median		4.00	4.00	4.00	5.00	4.00
Mode		5	4	4	5	5
Std. Deviation		.800	.810	.744	.678	.724
Sum		434	430	440	454	448

Statistics

		D1	D2	D3	D4	D5
N	Valid	103	103	103	103	103
	Missing	0	0	0	0	0
Mean		4.31	4.29	4.37	4.34	4.43
Median		4.00	4.00	4.00	4.00	4.00
Mode		4	4	4[a]	4	5
Std. Deviation		.627	.620	.642	.650	.604
Sum		444	442	450	447	456

a. Multiple modes exist. The smallest value is shown

Figure 4: Infrastructure and Financial Affordability - Descriptive Analysis

Statistics

		E1	E2	E3.	E4	E5
N	Valid	103	103	103	103	103
	Missing	0	0	0	0	0
Mean		4.38	4.45	4.46	4.36	4.35
Median		4.00	5.00	4.00	4.00	4.00
Mode		4	5	5	4[a]	4
Std. Deviation		.612	.653	.574	.669	.652
Sum		451	458	459	449	448

a. Multiple modes exist. The smallest value is shown

Figure 5: Technology Integration - Descriptive Analysis

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Table 3: Descriptive Analysis

Variable	Items	Number	Mean Range	St. Deviation Range	Interpretation
Business Viability	A1 – A5 Question 01 - 05	103	3.98 – 4.42	0.616 – 0.768	Positive
Cultural Acceptance	B1 – B5 Question 05 - 10	103	4.17 – 4.46	0.653 – 0.833	Positive
Infrastructure	C1 – C5 Question 10 - 15	103	4.17 – 4.41	0.678 – 0.810	Positive
Financial Affordability	D1 – D5 Question – 15 - 20	103	4.29– 4.43	0.678 – 0.810	Positive
Technological Integration	E1 – E5 Question 20 - 25	103	4.35 – 4.46	0.574 – 0.669	Positive

Table 3 shows the descriptive statistics indicate that all study variables recorded mean values above 3.5, suggesting generally positive perceptions among respondents. Standard deviation values remain moderate, indicating acceptable response consistency across all constructs. Overall, the findings suggest favorable attitudes toward business viability and its influencing factors.

Reliability Statistics of Business Viability Project.

Table 4: Reliability Statistics

Scale	Cronbach's Alpha	No. of items	Interpretation
Overall Scale	0.855	25	Good reliability
Business Viability	0.760	5	Acceptable
Cultural Acceptance	0.759	5	Acceptable
Infrastructure	0.783	5	Acceptable
Financial Affordability	0.776	5	Acceptable
Technological Integration	0. 719	5	Acceptable

Table 4 shows the reliability analysis indicates that the overall questionnaire achieved good internal consistency, with a Cronbach's Alpha value of 0.855 across 25 items. All individual variables demonstrated acceptable reliability, with Cronbach's Alpha values ranging from 0.719 to 0.783, confirming that the measurement scales were consistent and suitable for further analysis.

Correlation Analysis between Variables and Business Viability.

Table 5: Correlation Analysis

Independent Variable	Pearson Correlation	Sig. (p-value)	Relationship
Cultural Acceptance	0.461	P<0.001	significant moderate positive
Infrastructure	0.507	P<0.001	significant moderate positive
Financial Affordability	0.512	P<0.001	significant moderate positive
Technological Integration	0.390	P<0.001	weak to moderate positive relationship

Table 5 presents the results of the Pearson correlation analysis between the independent variables and business viability. All four independent variables had significant positive relationships with business viability ($p<0.001$). Financial Affordability ($r=0.512$) had the strongest moderate positive correlation, followed by Infrastructure ($r=0.507$) and Cultural Acceptance

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(r=0.461), while Technological Integration (r=0.390) showed a weak to moderate positive relationship with business viability.

Multiple Regression Analysis Results.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.614[a]	.377	.351	.321	.377	14.798	4	98	<.001	1.984

a. Predictors: (Constant), Technologicalintegration, Infrastructure, FinancialAffordability, CulturalAcceptance

b. Dependent Variable: BusinessViability

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.116	4	1.529	14.798	<.001[b]
	Residual	10.126	98	.103		
	Total	16.242	102			

a. Dependent Variable: BusinessViability

b. Predictors: (Constant), Technologicalintegration, Infrastructure, FinancialAffordability, CulturalAcceptance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	1.157	.430		2.689	.008	.303	2.012		
	CulturalAcceptance	.119	.097	.130	1.220	.225	-.074	.312	.563	1.776
	Infrastructure	.217	.078	.272	2.773	.007	.062	.373	.660	1.516
	FinancialAffordability	.297	.101	.285	2.925	.004	.095	.498	.671	1.490
	Technologicalintegration	.085	.098	.085	.868	.387	-.109	.279	.666	1.502

a. Dependent Variable: BusinessViability

Figure 6: Model Summary, Anova, Coefficients

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Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	CulturalAcceptance	Infrastructure	FinancialAffordability	Technological integration
1	1	4.980	1.000	.00	.00	.00	.00	.00
	2	.008	25.759	.12	.00	.83	.02	.06
	3	.005	31.575	.23	.59	.08	.13	.11
	4	.004	34.191	.03	.22	.08	.43	.52
	5	.003	37.854	.62	.19	.00	.42	.31

a. Dependent Variable: BusinessViability

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.38	4.75	4.26	.245	103
Residual	-1.018	.909	.000	.315	103
Std. Predicted Value	-3.606	1.979	.000	1.000	103
Std. Residual	-3.168	2.829	.000	.980	103

a. Dependent Variable: BusinessViability

Figure 7: Collinearity, Residual Statistics

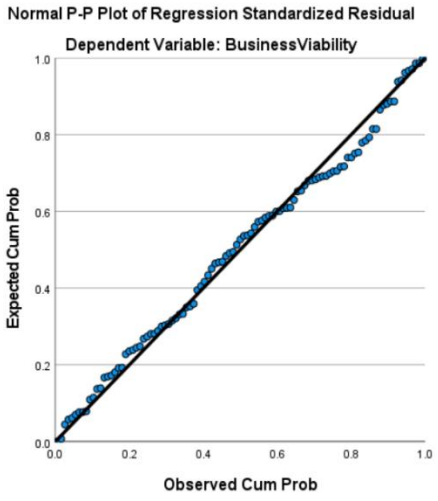

Figure *8:* P - P Plot

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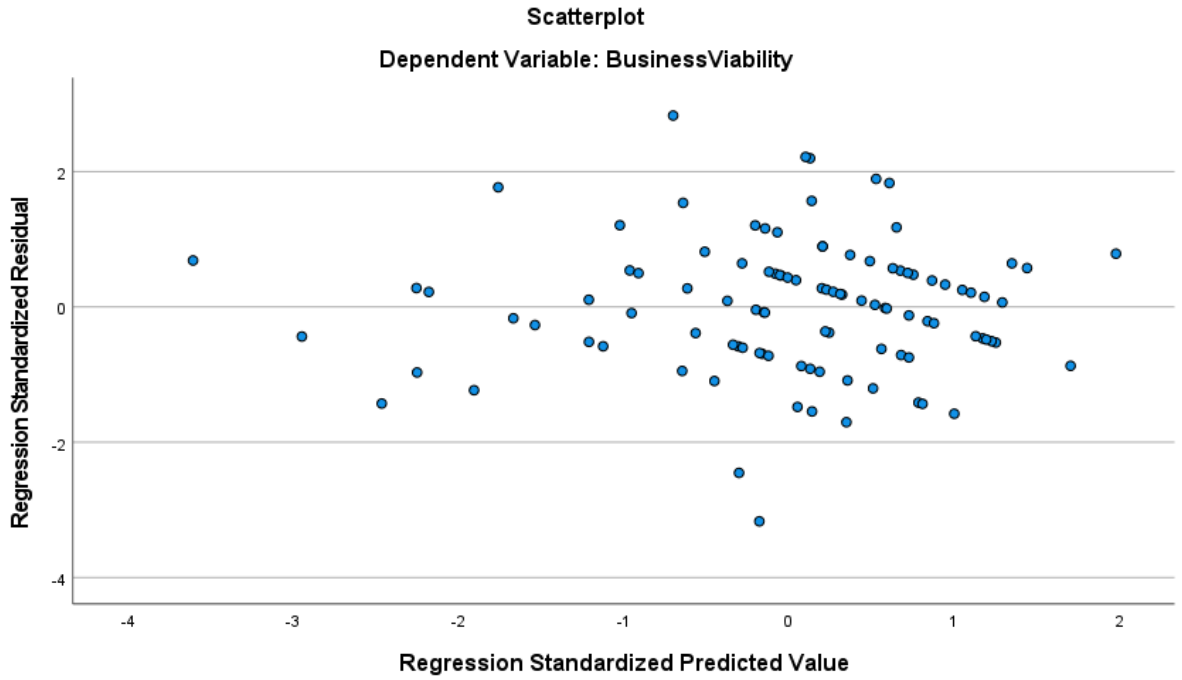

Figure 9- homoscedasticity

Figures 6,7 and 8 shows the multiple linear regression model was statistically significant, indicating that the four independent variables significantly predict Business Viability (F (4,98) =14.798, p<0.001). The model recorded an R value of 0.614, while the R Square value of 0.377 indicates that the predictors explain 37.7% of the variation in business viability (Adjusted R^2=0.351).
The regression assumptions were satisfied, with a Durbin-Watson value of 1.984 confirming independence of residuals and the residual scatterplot confirming homoscedasticity. Financial Affordability had the strongest effect on business viability (β=0.285, 95%CI [0.095,0.498]), followed by Infrastructure (β=0.272, 95%CI [0.062,0.373]). However, Cultural Acceptance and Technological Integration were positive but not significant predictors, as their confidence intervals included zero. Furthermore, the collinearity statistics (Tolerance > 0.10, VIF < 5) indicate that multicollinearity is not a concern, confirming the suitability of the regression model for analysis.

Discussion

This section discusses the study findings in relation to existing literature and their implications for the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors. The results show that the framework significantly explains business viability (R^2=0.377, F=14.798, p<0.001), with regression assumptions satisfied, including independence of residuals (Durbin-Watson = 1.984) and confirmed homoscedasticity. Based on the Resource-Based View, Financial Affordability (B=0.297, p=0.004) and Infrastructure (B=0.217, p=0.007) were the only significant positive factors influencing long-term sustainability. This highlights the importance of cost efficiency, effective land use, and organizational capabilities in developing a viable vertical columbarium service (12,11) . These findings support the potential of vertical columbaria to address urban land scarcity by improving space efficiency and reducing costs compared with traditional burial methods.

Although Cultural Acceptance (p=0.225) and Technological Integration (p=0.387) showed positive relationships, their effects were not statistically significant. This suggests that stakeholder familiarity and acceptance of technology-based memorial services may require further awareness and gradual adoption within the Sri Lankan context. Based on these findings, Jayaratne Funeral Directors should priorities affordable prefabricated vertical columbarium designs, durable

infrastructure, and sustainable features such as natural ventilation and daylighting. Additionally, practical technologies such as QR-based digital memorials, online records, Internet of Things (IoT) hardware and digital communication systems and Automatic Conveyor-belt Columbarium (ACC) systems (16,17) can be gradually introduced to improve customer experience and operational efficiency while maintaining affordability.

Conclusion

This study examined the factors influencing the business viability of technology-integrated vertical columbarium services at Jayaratne Funeral Directors. The findings revealed that the proposed framework significantly explains business viability, with all four independent variables showing positive relationships. However, Financial Affordability and Infrastructure were identified as significant factors influencing long-term business sustainability, highlighting the importance of cost efficiency, space optimization, and operational readiness in developing vertical columbarium services.

Although Cultural Acceptance and Technological Integration showed positive relationships, their effects were not statistically significant, suggesting that these factors may require further consideration as the concept develops within the Sri Lankan context. Overall, the study concludes that technology-integrated vertical columbarium services have potential as a sustainable alternative to traditional burial practices by addressing urban land limitations and improving resource efficiency. For successful implementation, Jayaratne Funeral Directors should priorities affordable designs, strong infrastructure development, and gradual adoption of customer-focused technologies to enhance long-term commercial viability.

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I would like to express my sincere gratitude to my lecturer, Mrs. Shashika Korelage, for her continuous guidance and support throughout this study. I also extend my thanks to ESOFT Metro Campus Galle and Jayaratne Funeral Directors for their cooperation and assistance in completing this research. Finally, I would like to express my appreciation to all the respondents who took the time to complete the survey, as their valuable participation made this study possible.

References

1. Mirror D. Double trouble in city of burial. [Online].; 2021 [cited 2026 05 28. Available from: HYPERLINK "https://www.dailymirror.lk/plus/Double-trouble-in-city-of-burial/352-227853" https://www.dailymirror.lk/plus/Double-trouble-in-city-of-burial/352-227853 .

2. PUBLISHING B. CEMETERIES AND BURIAL GROUNDS ORDINANCE. [Online].; 2019 [cited 2026 05 28. Available from: HYPERLINK "https://www.srilankalaw.lk/c/147-cemeteries-and-burial-grounds-ordinance.html" https://www.srilankalaw.lk/c/147-cemeteries-and-burial-grounds-ordinance.html .

3. DailyMirror. Death becomes a costly affair for Colombo dwellers. [Online].; 2026 [cited 2026 05 28. Available from: HYPERLINK "https://www.dailymirror.lk/breaking-news/Death-becomes-a-costly-affair-for-Colombo-dwellers/108-276486" https://www.dailymirror.lk/breaking-news/Death-becomes-a-costly-affair-for-Colombo-dwellers/108-276486 .

4. Juan J. COLUMBARIUM': FRACTURE THRESHOLD The Curation of Transformation Through Retention and Relinquishment. Pratt Institute ProQuest, Interior Design; 2025 May.

5. Ltd. JGoC. About us. [Online].; 2026 [cited 2026 05 28. Available from: HYPERLINK "https://lk.linkedin.com/company/jayaratne-group-of-companies-ltd" https://lk.linkedin.com/company/jayaratne-group-of-companies-ltd .

6. Austin D'Souza HVJCWGH. A business model design framework for viability: a business ecosystem approach. Journal of Business Models. 2015 May; 3: 1 - 29.

7. Wenzel M,WHT,&KJ. he Funeral Industry and the Internet: On the Historical Emergence and Destabilization of Strategic Paths. In.: European Journal of Information Systems; 2017. p. 361- 378.

8. Wong CK,&AAR. Start-up Business Plan in Chinese Race Funeral Services Industry: Eternal Life Care. Research in Management of Technology and Business. 2023 Nov; 04(02): 804–816.

9. U M. The Management of Death in Sri Lanka and Potential Solutions for the Future. 2023 Dec; 35(02): 5-11.

10. Ding E. Turning a Maze into a Labyrinth: Hurry Sickness, Technology, and the Creative Process. 2023 May.

11. T. S. Death beyond the means: Funeral overspending and its government regulation around the world. 2021 Feb; 33(3).

12. H. J. Operating Profit Analysis of Jeju Special Self-Governing Province's Funeral Facilities Using Cost Analysis. 2024; 47(3): 23-35.

13. WP H. Vertical Cemetery. Procedia Engineering. 2015 May; 118: 201- 2014.

14. Elizabeth Kwoh HA. The sacred and secular: Design analysis on Chinese Culture Columbaria in this modern era. 2026 Jan; 11(01).

15. Ravende K. Value Engineering and Reason of Unnecessary Cost in Construction Industry. Australian journal of applied and basic sciences. 2014 Aug; 8(13): 583 - 588.

16. D. c. The essence of the “smart cemetery” concept: New methods for processing personal data in public spaces. Problems of Information Society. 2022; 13(02): 88–95.

17. Partos KG. Smart Columbarium Navigation: Enhancing Grave Mapping with Geographical Information System (GIS) and Fuzzy Logic Algorithm for the Garden of the Divine Word Columbary. 2024 Dec.

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EP 05

The Role of Artificial Intelligence (Ai) On Customer Relationship Management; with Reference to Commercial Bank of Ceylon, Sri Lanka; Employee's Perspective

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Abstract

The integration of Artificial Intelligence (AI) into Customer Relationship Management (CRM) has emerged as a transformative force in the global banking industry. AI technologies enable banks to enhance personalization, predictive capabilities, automation, and operational efficiency while improving customer satisfaction and loyalty. In Sri Lanka, despite notable digital advancements by leading institutions such as Commercial Bank of Ceylon (CBC), challenges including low national AI readiness (ranked 95th globally), infrastructure limitations, data privacy concerns, resistance to change, and uneven implementation across branches continue to hinder the full realization of AI's potential in CRM practices. This study investigates the role of AI in enhancing CRM from the employees' perspective at selected branches of Commercial Bank of Ceylon.

The primary objective of this research is to identify the role of overall AI in CRM practices at CBC, Sri Lanka. The specific objectives are to examine the influence of four key AI components such as AI-Powered Customer Insights, AI-Based Chatbots and Virtual Assistants, Predictive Analytics for Customer Behaviour, and AI-Driven Personalization on CRM effectiveness. This study followed a positivist philosophy and deductive approach using a quantitative survey strategy. Primary data was collected through a structured questionnaire distributed via Google Forms to 90 employees at selected CBC branches. Stratified and simple random sampling techniques were employed. Data analysis was conducted using SPSS software, incorporating descriptive statistics, Pearson correlation analysis, and multiple regression analysis to test the research hypotheses. The findings revealed a strong positive and statistically significant overall relationship between AI and CRM. AI-Based Chatbots and Virtual Assistants and AI-Driven Personalization demonstrated strong significant correlations and regression impact. In contrast, AI-Powered Customer Insights and Predictive Analytics for Customer Behaviour did not show statistically significant relationships in this context. The study concludes that AI significantly enhances CRM effectiveness at CBC, particularly through chatbots and virtual assistants and personalization strategies. Banks should prioritize investment in these high-impact areas while improving implementation maturity of chatbots and personalization tools. The findings provide practical recommendations for optimizing AI-CRM integration within Sri Lanka's banking sector and contribute to academic literature on AI adoption in emerging markets.

Keywords: *Artificial Intelligence, Customer Relationship Management, Commercial Bank of Ceylon, Predictive Analytics, Personalization.*

Acknowledgment: Management and employees of CBC of KCC and Peradeniya branches

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Introduction

Customer Relationship Management (CRM) has become a significant aspect in the banking sector where Artificial Intelligence (AI) integration is transforming service delivery and customer engagement [18]. AI simulates human intelligence processes performed by machines, enabling data-driven decision-making, automation, and personalization. Globally, banks are increasingly adopting AI to enhance CRM effectiveness. In Sri Lanka, Commercial bank of Ceylon (CBC) stands out with its digital innovations such as ComBank Digital App where customers to perform banking transactions anytime and anywhere [4] [5] [6]. Furthermore, CBC has introduced AIPARA (AI-Powered Annual Report Assistant) to enable stakeholders to access information from annual reports through artificial intelligence, improving accessibility and user experience [11].

This research aims to understand the role of AI on CRM effectiveness at CBC with special reference to employees' perspective at Kandy City Centre branch and Peradeniya Branch. Further, it has determined the greatest influence factors of specific AI components on CRM effectiveness and the practical implications for banking institutions.

Sri Lanka's banking sector faces challenges in AI-CRM integration despite global advancements. Limited customer awareness and trust in AI tools persist, with many clients preferring traditional methods [7]. Similarly, [25] mentions that resistance to change among older demographics and some staff, uneven implementation across branches, restricted internal data access, language barriers, and staff shortages complicate adoption. Further it highlights that high implementation costs, regulatory compliance on data privacy by the Central Bank of Sri Lanka, and low national AI readiness (95th globally) add further constraints.

CBC as the largest private commercial bank in Sri Lanka, has made notable strides in digital transformation, including investments in AI-based data analysis, robotic process automation, CRM systems, and an AI-powered SME Credit Underwriting Solution reference to [4] [11]. Further it states that the bank has also implemented AI chatbots for 24/7 customer support too. However, challenges such as integration issues, workforce resistance, and uneven maturity levels across operations persist, limiting the full realization of AI's potential in enhancing CRM effectiveness [1] [3]. On the other extreme, AI preparedness analysis of Sri-Lanka shows that the country occupies the 95th place among 193 countries in the Government AI Readiness Index, and the infrastructure and data availability scores are very low, which means that the country is highly challenged to implement AI in accordance with [17]. Therefore, this study investigates the role of AI in CRM effectiveness reference to CBC.

The main objective of this study is to examine the influence of overall Artificial Intelligence in CRM in the banking sector from an employee perspective. Accordingly, the study aims to achieve the following objectives too.

- To examine the influence of AI-based chatbots and virtual assistants on CRM effectiveness
- To examine the influence of AI-powered customer insights on CRM effectiveness.
- To examine the influence of AI-driven personalization on CRM effectiveness.
- To examine the influence of predictive analytics on CRM effectiveness.

The importance of the study is emphasized through the focus on the increasing relevance of the application of artificial intelligence in transforming customer relationship management. In terms of theory contribution, the research helps fill gaps in the literature in relation to AI adoption and CRM by providing empirical data about the role of different AI solutions such as AI chatbots, AI-powered customer insights, AI-based personalization, and AI predictive analytics. As opposed to many previous research papers which mainly focus on the perspectives of employees, this research highlights the opinions of employees.

In terms of practical significance, the conclusions provide useful recommendations for bank managers and decision makers regarding AI-based CRM strategy design. Thus, banks can apply the results of the paper to choose AI investments that will be more beneficial for employees and customers. This study also highlights the need for active participation of employees in implementing AI systems in organizations. To successfully use AI technologies, it is crucial for employees to be aware about the existence of these technologies, to undergo proper training, to be ready for the application of technology and to have organizational support. That is why banks must not only implement AI tools but also ensure that there are necessary skills for their proper application. Besides, this paper is important for the banking industry of developing countries, where digital transformation becomes crucial for competitiveness.

Limitations of the study could be mainly identified as the sample size because it was conducted using data collected from 90 employees of only two branches of a commercial bank namely Kandy City Centre and Peradeniya branches. Thus, the

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results might not accurately reflect the experiences and opinions of employees in all branches of the banking sector. The branches in different geographic regions may have different organizational cultures, management procedures, and employee readiness and technology adoption methods. For example, branches located in urban commercial areas might have more exposure to digitally savvy customers, sophisticated technological infrastructure and a higher usage of AI enabled banking solutions when compared to branches located in semi-urban or rural areas. Therefore, the identified relationships between AI-driven factors and CRM effectiveness may differ across various banking environments with a different level of technological readiness. In this regard, this study provides substantial proof on AI-enabled CRM practices in the selected banking context; however, it needs to be exercised when generalizing the findings to the wider banking sector. Future research could address this limitation by using larger and more diverse commercial banks as well as from the perspective of customers as well.

Litrreature review can be explained below for the identified independent variables.

AI-based chatbots and virtual assistants

AI-Based Chatbots and Virtual Assistants are automated systems that provide 24/7 customer support, handle routine queries, and improve response times. [16] explores the economic and managerial implications of AI-driven chatbots in CRM, noting their role in enhancing customer interactions and streamlining business processes. CBC successfully implemented AI chatbots for customer support, contributing to operational efficiency [4]. According to, these tools minimize wait times and allow employees to focus on complex issues, thereby improving overall service quality [13]. In the Sri Lankan context, such tools help address high-volume queries while facing challenges related to local language support and customer trust [7]. Studies indicate that while chatbots boost accessibility, their effectiveness in building emotional connections remains limited compared to human interaction [24].

AI-powered customer insights

AI-Powered Customer Insights refer to the use of advanced data analytics and machine learning techniques to process large volumes of structured and unstructured customer data, generating actionable intelligence on preferences, behaviours, and emerging needs [14] . According to [18] based applications significantly improve the quality of customer service and promote long-term customer relations through deep insights. Similarly, [19] highlights that AI enables firms to gather, store, and analyses consumer activity information in real-time, leading to better interpretation and action on customer behaviours. In the Sri Lankan banking context, CBC leverages AI for customer data analysis to enhance decision-making and personalization [6].These insights allow banks to move from reactive to proactive CRM strategies, identifying pain points and opportunities before customers explicitly express them [19]. However, challenges such as data quality and integration with legal systems remain critical barriers in emerging markets [23] [25].

AI-driven personalization

AI-Driven Personalization involves using algorithms to deliver tailored products, services, recommendations, and experiences based on individual customer profiles. [21] reveals that 71% of consumers expect personalized interactions, with AI-powered systems enabling hyper-personalization on a scale. [19] [9] emphasize that machine learning creates detailed micro-segments from Behavioural data, supporting focused marketing messages. In Sri Lankan banking, institutions like CBC applies AI for personalized financial advice and targeted campaigns [6]. [18] notes that this capability directly enhances customer loyalty and engagement. Nevertheless, concerns around data privacy, ethical use of personal information, and potential bias in algorithms require careful governance [7] [15].

Predictive analytics for customer Behaviour

Predictive Analytics for Customer Behaviour utilizes historical data and machine learning algorithms to forecast customer actions, such as churn risk, purchase likelihood, and lifetime value [12]. [24] states that integrating AI into CRM systems provides decision-makers with tools to better understand consumer conduct, leading to improved business efficiency. At Commercial Bank of Ceylon, predictive models support proactive retention strategies and personalized offerings [3]. [20] argues that predictive analytics enables organizations to intervene at critical points in the customer lifecycle, offering retention deals before dissatisfaction escalates. However, in developing markets like Sri Lanka, limitations in data availability and model accuracy due to fragmented customer profiles pose significant challenges [17 [25].

Customer Relationship Management

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CRM is a strategy and technology used by businesses to manage interactions with current and potential customers, aiming to improve satisfaction, loyalty, and long-term profitability [14]. [19] defines CRM as procedures, tactics, and tools to track and evaluate consumer data across the customer lifecycle. [16] highlights that CRM enables personalized services, boosts retention, and enhances operational effectiveness through data analysis. In the banking sector, AI integration transforms traditional CRM into a smarter, proactive system [21]. CBC utilizes CRM systems enhanced by AI to strengthen customer relationships and competitive positioning [6]. However, successful implementation depends on overcoming organizational, technological, and cultural barriers, particularly in emerging economies [7].

Methods

Epistemologically, the study uses positivism with a deductive approach to examine the theories already in existence. The survey method is used to obtain quantitative data. The population includes all employees of CBC who worked in banking activities that utilize the use of technology. Ninety employees were chosen for the survey from the branches of Kandy City Centre and Peradeniya. These employees consisted of people with different levels of experience and exposure to the use of digital banking technologies, hence providing an overall view of AI usage in the banking environment. The stratified and simple random sampling methods were used. Primary data was collected through the use of questionnaires using Google Forms and was analysed using descriptive statistics, Pearson correlation, and multiple regression analysis.

The following figure shows the conceptual framework of the study with the support of Technology Acceptance Model (TAM) by Fred Davis [9].

Validity of TAM

This research makes the best fit from the theoretical perspective by focusing on AI implementation and usage among the bank's personnel and evaluating how the usage of AI applications affects the effectiveness of CRM. The study specifies that the employees' perception towards technology is influenced by two key elements such as Perceived Usefulness (PU) and Perceived Ease of Use (PEOU)[9]. As the effectiveness of CRM based on AI technologies is not only dependent on technological aspects but also on the usage of such technologies among employees, TAM can be applied in order to identify the influence of PU and PEOU on employees' Behaviour. Thus, the effective use of AI-based CRM tools by the employees depends on their interaction with these technologies.

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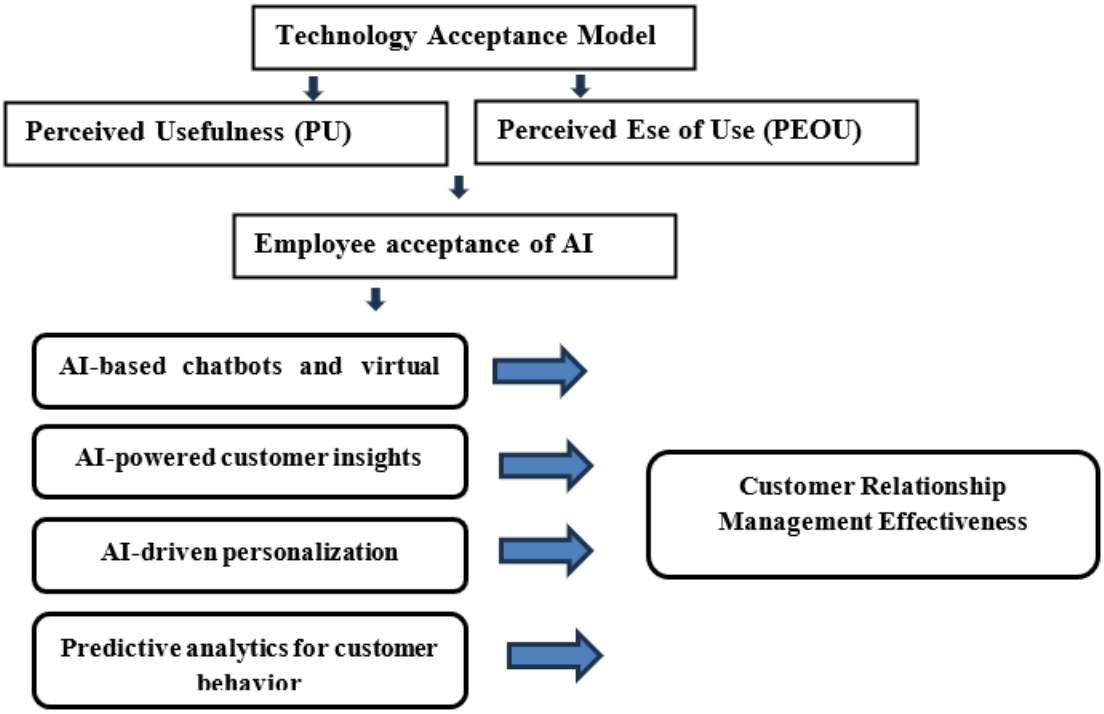

Figure 1: Conceptual framework based on TAM [9]

H1

- $H1_0$: AI-Based Chatbots and Virtual Assistants do not play a positive role in Customer Relationship Management at CBC.
- $H1_1$: AI-Based Chatbots and Virtual Assistants play a positive role in Customer Relationship Management at CBC.

H2

- $H2_0$: AI-Powered Customer Insights do not play a positive role in Customer Relationship Management at CBC.
- $H2_1$: AI-Powered Customer Insights play a positive role in Customer Relationship Management at CBC.

H3

- $H3_0$: AI-Driven Personalization do not play a positive role in Customer Relationship Management at CBC.
- $H3_1$: AI-Driven Personalization plays a positive role in Customer Relationship Management at CBC.

H4

- $H4_0$: Predictive Analytics for Customer Behaviour do not play a positive role in Customer Relationship Management at CBC.
- $H4_1$: Predictive Analytics for Customer Behaviour play a positive role in Customer Relationship Management at CBC.

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Results

Table 2: Model summary (survey data)

R	R Square	Adjusted R Square	Std. Error of the Estimate	F-value	Sig.
0.512	**0.262**	**0.226**	**0.421**	**7.53**	**0.000**

The regression model indicates that the selected AI-driven factors collectively explain 26.2% of the variation in CRM effectiveness among employees in the banking sector. The adjusted R^2 value of 22.6% indicates that the model maintains reasonable explanatory power after considering the number of independent variables. The overall regression model is statistically significant ($F = 7.53$, $p < 0.001$), confirming that AI-related factors jointly contribute to predicting CRM effectiveness.

Regression co-efficient

Table 3: Summary of regression co-efficient (survey data)

Independent Variable	Unstandardized Coefficient (B)	Std. Error	Standardized Beta (β)	t-value	Sig. (p-value)	Interpretation
Constant	2.145	0.412	—	5.206	0.000	—
AI-Based Chatbots and Virtual Assistants	0.214	0.106	0.218	2.019	0.043	Significant positive predictor
AI-Powered Customer Insights	0.097	0.125	0.089	0.776	0.361	Positive but statistically insignificant predictor
AI-Driven Personalization	0.235	0.150	0.241	2.317	0.026	Strongest significant positive predictor
Predictive Analytics CB	0.163	0.119	0.151	1.372	0.124	Positive but statistically insignificant predictor

The regression analysis reveals that AI-based personalization proves to be the strongest predictor of CRM success ($\beta = 0.241$, $p = 0.026$). It means that individualized recommendations provided by AI, communication based on AI, and service experience personalized due to AI increase the effectiveness of CRM for employees. Furthermore, the role of AI-based chatbots and virtual assistants proves to be quite high ($\beta = 0.218$, $p = 0.043$). It means that employees consider AI-based conversational agents to be useful instruments of increasing efficiency and reactivity of service.

Even though the use of AI technologies for generating insights about customers ($\beta = 0.089$, $p = 0.361$) and for predicting customer Behaviour ($\beta = 0.151$, $p = 0.124$) appears to be positively correlated with CRM effectiveness, these relations are statistically insignificant. That implies that while employees recognize the value that can be created through the implementation of these technologies, the actual effect might be affected by other variables, including data quality, competence of the workforce, integration issues, etc. Even though AI-driven customer insights and predictions are highly valuable capabilities of CRM systems globally, the effectiveness of these technologies depends significantly on how well

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they can be embedded into business practices. Previous literature reveals that AI technologies provide any value only if there is an appropriate environment in terms of data infrastructure, analytical skills, workforce competence, and implementation practices [21] [22]. The above regressions support the earlier correlations analysis in which positive significant correlation was found for chatbot technologies and AI-enabled personalization technologies whereas positive but insignificant correlation was observed for customer insights and predictive analytics.

Correlation analysis

Table 4: Summary of correlation analysis (survey data)

Variables	CRM Effectiveness	AI Chatbots & Virtual Assistants	AI Customer Insights	AI Personalization	Predictive Analytics
CRM Effectiveness	1.000				
AI Chatbots & Virtual Assistants	0.214*	1.000			
AI Customer Insights	0.097	0.312**	1.000		
AI Personalization	0.235*	0.354**	0.291**	1.000	
Predictive Analytics	0.163	0.276**	0.338**	0.365**	1.000

From the correlation analysis, it can be indicated that all AI-driven factors are positively related to CRM effectiveness, meaning that an increase in the use of AI results in more effective CRM. Of all the predictor variables, the highest correlation between the AI-driven personalization factor and CRM effectiveness was found to be $r = 0.235$ ($p<0.05$), while for the chatbots/virtual assistants' factor, it is $r = 0.214$ ($p<0.05$). On the other hand, there exists a positive but weak relationship for the factors AI-driven customer insights ($r = 0.097$) and AI-based prediction of customer Behaviour ($r = 0.163$).

Discussion

Key research objective: To identify the role of overall Artificial Intelligence in Customer Relationship Management practices at CBC.

The main objective of this research is to examine the effect of AI technologies on the efficiency of CRM practices based on the perspective of bank workers. It can be stated that the regression shows that AI variables as a whole have a significant effect on the efficiency of CRM practices, as the model is statistically significant ($F = 7.53$, $p < 0.001$). From the results obtained, it can be said that AI technologies increase the efficiency of CRM practices through support of the customer interaction process, efficient service, and personalized customer experience. However, it should be noted that $R^2 = 0.262$ shows that there are other factors, besides AI technologies, which affect CRM practices.

- $H1_1$: AI-Based Chatbots and Virtual Assistants play a positive significant role in Customer Relationship Management at CBC.

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The results provide support for H1, as AI-based chatbots and virtual assistants demonstrated a significant positive effect on CRM effectiveness ($\beta = 0.218$, $p = 0.043$). The correlation analysis further supports this relationship, showing a significant positive association between chatbots and CRM effectiveness ($r = 0.214$, $p < 0.05$). This finding indicates that employees perceive AI-powered conversational tools as valuable mechanisms for improving customer service delivery. Chatbots and virtual assistants can reduce response times, provide consistent customer support, and assist employees by handling routine customer inquiries. In the banking sector, where timely and accurate responses are critical for customer satisfaction, AI-enabled communication platforms can strengthen customer engagement and improve operational efficiency. The finding is consistent with previous research suggesting that AI-based service automation enhances customer experience by increasing accessibility and responsiveness.

- $H2_1$: AI-Powered Customer Insights play a positive significant role in Customer Relationship Management at CBC.

While there was a positive relationship between AI-generated customer insights and CRM effectiveness ($\beta = 0.089$; $r = 0.097$), the association was not statistically significant ($p = 0.361$). Thus, H2 is not validated. This means that although the employees realize the potential value of customer insights from AI analysis, without the necessary capability of turning data into strategy, such insights will not be helpful in improving CRM effectiveness. It is clear from the results that availability of customer data by itself does not necessarily mean that customer relationships would improve. The results show that for AI-generated customer insights to have any effect on CRM effectiveness, banks need to have quality data, capable analytics tools, and skilled employees. Without these conditions, the insights generated using AI will not be utilized and therefore will not have any effect on daily CRM practices. Thus, it is not enough for banks to just develop AI analytics tools; they need to train their employees. The Technology Acceptance Model [9] suggests that perceived usefulness and ease of use have an important impact on technology acceptance. Employees' infrequent interactions with predictive analytics tools and inadequate training for understanding AI recommendations can reduce their perceived value as a part of CRM performance.

- $H3_1$: AI-Driven Personalization plays a positive significant role in Customer Relationship Management at CBC.

The findings absolutely validate Hypothesis 3 with AI-based personalization turning out to be the strongest determinant of CRM effectiveness ($\beta = 0.241$, $p = 0.026$). Similarly, correlation analysis also suggests that personalization is the best factor correlated with CRM effectiveness among all the AI factors being considered ($r = 0.235$, $p < 0.05$). This finding demonstrates that there is great value added using personalized AI technologies because this helps banks know the preferences of individual customers and provide services accordingly. Recommendations from AI, communication based on it and solutions tailored to the customer help the bank personnel build stronger relationships and offer better service. This finding is consistent with the recent trend of focusing on customer-oriented strategies by the banks. Today's customers expect relevant services, and AI technologies help move away from the old paradigm of standard service provision to a newer approach of personalized relationship management [11].

- $H4_1$: Predictive Analytics for Customer Behaviour play a positive significant role in Customer Relationship Management at CBC

The results show that predictive analytics has a positive effect on CRM effectiveness ($\beta = 0.151$; $r = 0.163$). The effect is statistically insignificant ($p = 0.124$). H4 is not supported. Predictive analytics gives organizations the ability to predict customer behaviour, discover potential needs and facilitate proactive decision-making, but the findings show that these benefits may not be fully leveraged by employees yet. This may be due to data availability, analytical ability, system integration, or employee confidence in using predictive outputs. This finding underlines the need to develop organizational readiness before expecting predictive analytics to deliver measurable CRM improvements. Banks need to ensure that their predictive models have reliable customer data, the right technology infrastructure, and training programs for their employees. Research by [22] highlights that the success of customer analytics depends heavily on effective data management practices. In developing markets, including Sri Lanka, challenges such as fragmented customer databases, inconsistent data collection practices, and limited integration between banking systems may reduce the effectiveness of predictive analytics applications.

This finding also aligns with [14] argument that AI should be viewed as an enhancement tool for human decision making, not a replacement of human expertise. The contribution of AI systems to CRM outcomes can be limited if they are not well integrated with employee knowledge and customer relationship skills. Therefore, the insignificance effect found in this study could be due to the present state of execution, staff participation and organizational readiness rather than the lack of value of AI-powered customer insights and predictive analytics in the Sri Lankan banking environment.

Conclusions

The study aimed at investigating the effect of AI-driven technologies on Customer Relationship Management (CRM) effectiveness from the point of view of employees in the banking sector. The results confirm the positive effect of AI technologies on CRM effectiveness and the regression model indicates a significant overall effect ($F = 7.53$, $p < 0.001$), explaining 26.2% of the variation in CRM effectiveness. AI-driven personalization was the strongest predictor of CRM effectiveness ($\beta = 0.241$, $p = 0.026$) among the AI applications, highlighting the importance of AI-driven personalization in providing personalized customer experiences and enhancing service quality. AI-based chatbots and virtual assistants also had a significant positive impact ($\beta = 0.218$, $p = 0.043$) through improved service efficiency and assistance to employees in customer interactions. AI-powered customer insights and predictive analytics were found to have positive but statistically insignificant relationships with CRM effectiveness, indicating their success is contingent on organizational readiness, data quality, employee skills, and effective system integration. The study highlights the importance of an employee-centreed approach to adoption of AI in banking CRM, recommending that banks focus on AI-driven personalization and communication tools, alongside investments in employee training, data management, and system integration. Therefore, the study confirms that AI is a valuable enabler of CRM effectiveness and offers practical guidance for successful AI-driven CRM implementation in the banking sector.

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References

1. Adam M, Wessel M, Benlian A. AI-based chatbots in customer service and their effects on user compliance. Electron Mark. 2021;31(2):427-445.
2. Arora N, Dreze X, Ghose A, Hess JD, Iyengar R, Jing B, et al. Putting one-to-one marketing to work: Personalization, customization and choice. Mark Lett. 2008;19(3-4):305-321.
3. Chandrima S, Manish G. The role of artificial intelligence in banking for leveraging customer experience. Australas Account Bus Finance J. 2022;16(5):89-105.
4. Commercial Bank of Ceylon PLC. Annual report 2024. Colombo: Commercial Bank of Ceylon PLC; 2024.
5. Commercial Bank of Ceylon PLC. ComBank Digital [Internet]. Colombo: Commercial Bank of Ceylon PLC; 2025 [cited 2026 Jun 11]. Available from: https://www.combank.lk/services/combank-digital
6. Commercial Bank of Ceylon PLC. ComBank unveils ComBank Digital with US-based Fiserv [Internet]. Colombo: Commercial Bank of Ceylon PLC; 2025 [cited 2026 Jun 11]. Available from: https://www.combank.lk/news/news-events/combank-unveils-combank-digital-with-us-based-fiserv
7. Darshana D. Navigating the digital revolution: how Sri Lanka's banking sector is transforming [Internet]. LinkedIn; 2025 [cited 2026 May 11]. Available from: https://www.linkedin.com/pulse/navigating-digital-revolution-how-sri-lankas-banking-dr-dharshana-g0xoc
8. Davenport T, Guha A, Grewal D, Bressgott T. How artificial intelligence will change the future of marketing. J Acad Mark Sci. 2020;48(1):24-42.
9. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* 1989;13(3):319–340.
10. Dwivedi YK, Hughes L, et al. Artificial intelligence (AI): multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. Int J Inf Manage. 2021;57(1):102994.
11. Echelon Sri Lanka. Commercial Bank revolutionizes annual report culture with AI [Internet]. Colombo: Echelon Media; 2024 [cited 2026 Jun 10]. Available from: https://echelon.lk/commercial-bank-revolutionizes-annual-report-culture-with-ai
12. Hamed A, et al. Predictive analytics in customer Behaviour: anticipating trends and preferences. Results Control Optim. 2024;17:100450.
13. Imthiyas A, et al. The impact of artificial intelligence chatbots on customer satisfaction and retention in digital banking sectors in Sri Lanka. Innovative Academy Res J. 2024;1(1):33-39.
14. Jarrahi MH. Artificial intelligence and the future of work: Human-AI symbiosis in organizational decision making. *Bus Horiz.* 2018;61(4):577–586

15. Kalaiyarasan K, Gurumoorthy P, Kamalakannan R. AI-driven customer relationship management (CRM): a review of implementation strategies. In: Proceedings of the International Conference on Computing Paradigms (ICCP 2023). 2023;7(9):1-183.
16. Khneyzer C, Zaher B, Jean D. AI-driven chatbots in CRM: economic and managerial implications across industries. Adm Sci. 2024;14(8):1-16.
17. Ministry of Technology. Artificial Intelligence White Paper [Internet]. Colombo: Ministry of Technology; 2024 [cited 2026 May 21]. Available from: https://mot.gov.lk/assets/files/AI%20White%20Paper%20March%202024-c09aa49f7990358ad1442103b804511d.pdf
18. Ledro C, Nosella A, Pozza ID. Integration of AI in CRM: challenges and guidelines. J Open Innov Technol Mark Complex. 2023;9(4):1-13.
19. Ledro NV. Artificial intelligence in customer relationship management: literature review and future research directions. J Pers Sell Sales Manag. 2022 Mar 30;42(1):63-80.
20. Manju S, et al. AI-powered CRM and predictive analytics: a new paradigm for customer-centric industries. Adv Consum Res J. 2025;2(4):1045-1052.
21. Minh N, Trn T. A strategic analysis of AI-driven customer relationship management systems in enhancing personalization and retention in financial institutions. Orient J Emerg Paradigms Artif Intell Auton Syst. 2024;14(9):1-8.
22. Munira MSK, Juthi S, Begum A. Artificial intelligence in financial customer relationship management: a systematic review of AI-driven strategies in banking and FinTech. Am J Adv Technol Eng Solut. 2025;1(1):20-40.
23. Ngai EWT, Xiu L, Chau DCK. Application of data mining techniques in customer relationship management: A literature review and classification. *Expert Syst Appl.* 2009;36(2 Pt 2):2592–2602.
24. Penubelli R. AI-driven personalization in CRM marketing: revolutionizing customer engagement at scale. Int J Adv Res Emerg Trends. 2024;1(2):14-27.
25. Raj FK, H R. Artificial Intelligence Driven Customer Relationship Management: Harnessing the power of technology to improve business efficiency. Int J Commun Netw Inf Secur [Internet]. 2024 [cited 2026 Jun 11]. Available from: https://ijcnis.org/index.php/ijcnis/article/view/6849
26. Uddeniye Gedara D, Herath NB. Unveiling the future: how Sri Lanka's banking sector is leveraging AI-powered applications for enhancing customer experience [Internet]. 2024 [cited 2026 Jun 11]. Available from: https://www.theseus.fi/handle/10024/862408
27. Wedel M, Kannan PK. Marketing analytics for data-rich environments. J Mark. 2016;80(6):97-121

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EP 06

The Impact of Social Media Influencers on Consumer Purchase Intention in the Fashion Retail Industry: A Study of Students at ESOFT Metro Campus

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Abstract

Background:
Social media influencers have become an important marketing tool in the fashion retail industry, influencing consumer attitudes and purchasing decisions through digital platforms such as Instagram, TikTok, Facebook, and YouTube. University students are among the most active social media users and are highly exposed to influencer-generated fashion content.

Objective/s:
This study aimed to investigate the impact of social media influencers on consumer purchase intention in the fashion retail industry among students at ESOFT Metro Campus. Specifically, the study examined the influence of trustworthiness, expertise, similarity, familiarity, and likeability on purchase intention.

Methods:
A quantitative research approach was adopted using a cross-sectional survey design. Primary data were collected from 120 students at ESOFT Metro Campus through a structured questionnaire based on a five-point Likert scale. Convenience sampling was used to select respondents. Data were analysed using the Statistical Package for Social Sciences (SPSS), employing descriptive statistics, reliability analysis, Pearson correlation analysis, and multiple regression analysis.

Results:
The findings revealed that all five influencer characteristics positively and significantly influence consumer purchase intention. Likeability emerged as the strongest predictor ($\beta = 0.324$), followed by trustworthiness ($\beta = 0.256$), expertise ($\beta = 0.181$), familiarity ($\beta = 0.166$), and similarity ($\beta = 0.142$). The regression model explained 76.2% of the variation in purchase intention ($R^2 = 0.762$), indicating a strong predictive relationship between influencer characteristics and consumer purchasing Behaviour.

Conclusion/s:
The study concludes that social media influencers significantly affect fashion-related purchase intentions among university students. Fashion retailers should collaborate with credible, knowledgeable, relatable, and likeable influencers to enhance marketing effectiveness and strengthen consumer engagement among young audiences.

Keywords: *Consumer Behaviour, Fashion Retail Industry, Purchase Intention, Social Media Influencers, Sri Lanka, University Students*

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Introduction

In today's digital world, social media is one of the most powerful communication and marketing tools available. Social platforms like Instagram, TikTok, Facebook, and YouTube have drastically changed the way consumers engage with brands and their buying decisions. In the fashion retail sector, social media marketing is being used more and more to market products, create brand awareness and reach young consumers through the use of social media influencers. They can influence consumer attitudes through product reviews, fashion content, lifestyle videos, and engaging with their audience in an interactive way [1].

It has been observed that with the hunger to go online, the penetration of smart phones has led to social media adoption becoming more common amongst the youth in Sri Lanka, and among the university students in particular. DataReportal shows that there were around 8.2 M people using social media in Sri Lanka in 2025, which is equivalent to 35.4% of the Sri Lankan population [2]. Additionally, Instagram is among the most popular apps of the young generation, with over 2.3 million users in Sri Lanka, with the maximum user age group between 18-24 years [2]. Most of these are students in university and Generation Z consumers who are active followers of fashion influencers, online trends and digital content creators.

Since the COVID-19 outbreak, Sri Lankan fashion retail has undergone significant digitalization. Today, numerous fashion labels have tapped into the power of social media influencers as a way to promote their fashion lines and engage online shoppers. A number of previous studies in Sri Lanka have confirmed that the social media elements of influencer credibility, online reviews, consumer trust and consumer engagement positively correlate with purchase intention in the fashion industry [3–5]. But there have also been worries about unethical influencer marketing methods, concealed sponsorships, and false endorsements among customers, which has raised doubts about the authenticity of influencers and transparency in their marketing [6].

University students are very open to the influencer marketing because they spend a great amount of time on social media platforms and are greatly influenced by fashion trends, recommendations from their peers and comments on the internet. Students in ESOFT Metro Campus interact with fashion brands and influencers' content on social media. Although influencer marketing has come into existence as a significant marketing trend, there is not much empirical studies that specifically focus on the impact of a social media influencer on purchase intentions by students in private higher education institutes in Sri Lanka. Hence, this study is focused on examining the effect of social media influencers on the purchase intention of consumers in the fashion retail industry among the students of ESOFT metro campus.

The main aim of this research is to explore the effects of social media influencers on consumer purchase intention in the fashion retail industry for students in ESOFT Metro Campus. In particular, the research examines the role of the following characteristics of influencers on students' purchase intention for fashion products via social media, which includes trustworthiness, expertise, similarity, familiarity, and likability. In addition, the study aims to discover the primary reasons for which the student buys online clothes based on social media influencers.

Social media influencer marketing is a crucial factor of the digital marketing techniques, especially for the fashion retail sector. Social media influencers are people with the power to shape the attitude, perception and buying choices of their followers through content posted on the social media platforms Instagram, TikTok, Facebook and YouTube. Influencers are generally seen as more authentic, relatable and trustworthy than traditional celebrity endorsements, making them extremely powerful in driving consumer actions [1].

The reputation is one of the most crucial traits of an influencer. Ohanian [2] determined that one of the most essential aspects of source credibility is trustworthiness and that trustworthiness has a positive impact on customer attitudes and purchasing decisions. Likewise, Djafarova and Rushworth [3] reported that consumers are more inclined to buy products that are recommended by influencers that they believe to be honest and reliable. Trust can ease the fear of the unknown and boost confidence when transactions are conducted online.

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Another factor that influences consumer purchase intention is expertise. Ohanian [2] defines expertise as the perceived knowledge, experience and competence of an influencer on a given product category. An influencer who has a good understanding of a product has more credibility and consumer trust. Teng et al. [4] also found that the knowledgeable influencers have a positive effect on the consumer's willingness to buy.

Other factors that can influence consumer Behaviour include similarity and familiarity. The audience will resonate more with the influencer when they share comparable lifestyles, interests, and values [5]. The more an individual encounters influencer content, the more familiar they will be with the influencer and the stronger the emotional bond between the influencer and follower will become [6]. This makes consumers more open to influencers' recommendations.

Likability is defined by consumers' personality, appearance, and communication towards an influencer. Colliander and Dahlén [7] found that “likable” influencers stimulate positive emotions, which leads to better engagement and transaction of the consumer. Besides, Lou and Yuan [1] found that both influencer credibility and message value have significant influences on consumer trust and purchase intention.

Overall, literature shows that being trustworthy, knowledgeable, similar, familiar, and liked are important influencer attributes that positively affect consumer purchase intention especially among the young consumer in fashion retail sector.

The research is important as it contributes to the understanding of the influence of social media influencers on the purchase intention of university students in Sri Lanka. University students, as one of the most active user groups on social media are greatly influenced by digital marketing content, online fashion trends and recommendations by influencers. This study examines the influence of trustworthiness, expertise, similarity, familiarity and likability on the buying process of students and provides a contribution to the identification of a set of critical factors that influence students' buying Behaviour. Moreover, the study fills the gap in the literature by tackling the under-researched field of influencer marketing in the private higher education field in Sri Lanka. The results will prove helpful to the fashion retailers, marketers, and business organizations while formulating strategies to attract young people as customers and boost sales. Furthermore, the research could be a valuable resource for future scholars, students, and practitioners in the field of digital marketing, consumer Behaviour, and the fashion retail sector.

Methods

The quantitative research method was used to explore the influence of social media influencers on purchase intention of fashion retailers among the students of ESOFT Metro Campus. The choice of the quantitative approach was justified by the fact that it is suitable for collecting numerical data, which is required to determine the relationship between social media influencer characteristics and consumer purchase intention by applying statistical methods.

In spite of the valuable insights that this study brings to the consumer purchase intention and how social media influencers affect it, there are some limitations to note. The first factor is that the study has a convenience sampling method, consisting of 120 students of a single private higher education institution (ESOFT Metro Campus). As such, the results might not be representative of the university students or the population of Sri Lankans. The gender gap in purchasing behaviours might exist between public university students, students from other private institutions and working adults, because of differences in demographic characteristics, socioeconomic background and consumer experiences. Future studies would therefore benefit from the use of probability sampling techniques and from having respondents from a wider range of universities and from a variety of consumer groups to ensure the findings are more externally valid and can be generalised.

The present study postulates that the interaction between the credibility-related characteristics (trustworthiness and expertise) and attractiveness-related characteristics (similarity, familiarity and likeability) are both positively predictive of consumer purchase intention in the fashion retail sector. Based on a review of relevant theories, the conceptual framework for the proposed study is created and hypotheses are explored that will be examined with students at ESOFT Metro Campus.

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Conceptual Framework

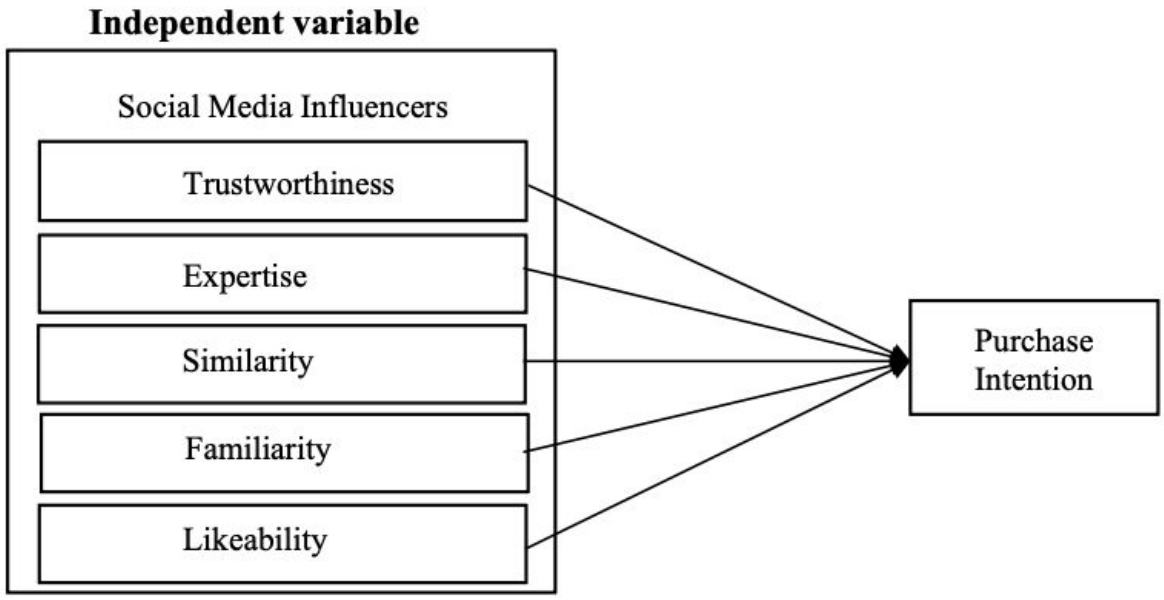

Figure 1: Conceptual Framework

Students who actively use social media platforms (Instagram, Facebook, TikTok, YouTube) and face fashion-related content from influencers were selected. The target population comprised students at ESOFT Metro Campus who use social media platforms (Instagram, Facebook, TikTok, YouTube) and are exposed to fashion-related content from influencers. The number of students that met these criteria was not known so the population was unknown. Hence, a non-probability sampling technique called "convenience sampling" was used to select the respondents in the study. The sample was 120 students because they were accessible, available and the number was appropriate for quantitative research.

Primary data was gathered using a physical questionnaire with a structure that was given to the students of ESOFT Metro Campus. Questionnaire comprised two parts. The first section captured demographic data including gender, age and social media usage while the second captured the independent variables of trustworthiness, expertise, similarity, familiarity, and likability and the dependent variable of purchase intention by consumers. A five-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree" was used to measure respondents' perceptions. Physical questionnaires were individually sent to students who returned the questionnaires personally for a higher response rate and accurate data collection.

The secondary data were gathered from academic journals, books, conference papers, research papers and reliable online sources related to social media influencers, consumer Behaviour and fashion retail industry. The literature review and the theoretical foundation of the study were fed from these sources.

The collected data were analysed with SPSS (Statistical Package for Social Sciences). The data were summarized using descriptive statistics including frequencies, percentages, means and standard deviations for the respondent characteristics. Further, correlation analysis was carried out to explore the relationships between the dimensions of social media influencers and the purchase intention, and multiple regression analysis was performed to find out how much purchase intention was explained by trustworthiness, expertise, similarity, familiarity, and likability.

Efforts were made for ethical compliance with respondents informed of the purpose of the study and participation was voluntary. Confidentiality and anonymity of the respondents was ensured during the research process; the respondents' data were only used for academic research within the framework of the research project on the EICON 2026 conference.

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Descriptive Statistics

Table 1: Descriptive Statistics of Study Variables

Variable	Mean	Std. Deviation
Trustworthiness	4.12	0.68
Expertise	4.05	0.71
Similarity	3.98	0.74
Familiarity	4.08	0.69
Likeability	4.15	0.66
Purchase Intention	4.10	0.72

The descriptive statistics indicate that all study variables recorded mean values above 3.90, demonstrating positive perceptions among ESOFT Metro Campus students regarding social media influencers and their impact on fashion purchasing decisions. Likeability recorded the highest mean value (M = 4.15, SD = 0.66), suggesting that students highly value influencers with attractive personalities and communication styles. Consumer purchase intention also recorded a high mean value (M = 4.10), indicating a strong tendency among students to purchase fashion products recommended by influencers.

Reliability Analysis

Table2 : Reliability Statistics

Variable	Cronbach's Alpha
Trustworthiness	0.823
Expertise	0.846
Similarity	0.801
Familiarity	0.834
Likeability	0.851
Purchase Intention	0.873

The reliability analysis confirmed acceptable internal consistency for all constructs. Cronbach's Alpha values ranged from 0.801 to 0.873, exceeding the recommended threshold of 0.70. Therefore, the questionnaire items used to measure each construct were considered reliable and suitable for further statistical analysis.

Correlation Analysis

Table 3: Pearson Correlation Analysis

Variables	TW	EX	SI	FA	LI	PI
Trustworthiness	1					
Expertise	.642	1				
Similarity	.598	.611	1			
Familiarity	.628	.585	.607	1		
Likeability	.675	.651	.633	.648	1	
Purchase Intention	.748	.721	.694	.702	.781	1

Note: $p < 0.01$

The correlation analysis revealed significant positive relationships between all influencer characteristics and consumer purchase intention. Likeability showed the strongest association with purchase intention ($r = 0.781$, $p < 0.01$), followed by trustworthiness ($r = 0.748$, $p < 0.01$). These findings suggest that students are more likely to purchase fashion products when they perceive influencers as trustworthy, knowledgeable, familiar, relatable, and likeable.

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Model Summary

Table 4: Model Summary

R	R Square	Adjusted R Square	Std. Error
.873	.762	.752	.359

The model summary indicates a strong relationship between the independent variables and consumer purchase intention. The R Square value of 0.762 implies that 76.2% of the variation in purchase intention is explained by trustworthiness, expertise, similarity, familiarity, and likeability. This demonstrates the substantial influence of social media influencers on students' purchasing decisions.

ANOVA Analysis

Table 5: ANOVA Results

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	48.327	5	9.665	74.985	.000
Residual	14.691	114	0.129		
Total	63.018	119			

The ANOVA results show that the regression model is statistically significant ($F = 74.985$, $p < 0.001$). Since the significance value is below 0.05, the model adequately explains the relationship between social media influencer characteristics and consumer purchase intention.

Multiple Regression Analysis

Table 6: Regression Coefficients

Variables	Beta (β)	t-value	Sig.
Trustworthiness	0.256	4.712	.000
Expertise	0.181	3.526	.001
Similarity	0.142	2.784	.006
Familiarity	0.166	3.102	.002
Likeability	0.324	5.891	.000

Regression Equation

Purchase Intention = 0.324(Likeability) + 0.256(Trustworthiness) + 0.181(Expertise) + 0.166(Familiarity) + 0.142(Similarity)

The regression analysis revealed that all five influencer characteristics significantly influence consumer purchase intention. Likeability emerged as the strongest predictor ($\beta = 0.324$, $p < 0.001$), indicating that students are highly influenced by influencers they find attractive and appealing. Trustworthiness was the second strongest predictor, followed by expertise, familiarity, and similarity. Therefore, all independent variables positively and significantly affect consumer purchase intention.

Hypothesis Testing

Table 7: Summary of Hypothesis Testing

Hypothesis	Decision
Trustworthiness positively influences purchase intention	Supported
Expertise positively influences purchase intention	Supported

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Similarity positively influences purchase intention	Supported
Familiarity positively influences purchase intention	Supported
Likeability positively influences purchase intention	Supported

The findings confirm that all social media influencer characteristics significantly influence consumer purchase intention among ESOFT Metro Campus students. Among the examined factors, likeability demonstrated the strongest impact, highlighting the importance of selecting influencers who can create positive emotional connections with their audience.

Discussion

Based on the results of this study, it can be concluded that the factors of social media influencers do have a significant impact on the purchase intentions of students at ESOFT Metro Campus. All the five independent variables (trustworthiness, expertise, similarity, familiarity and likeability) proved to be positively and significantly influence the Purchase intention, thereby supporting all the proposed hypotheses. The present results align with those of other studies that found that both a brand's credibility and attraction drives consumer attitudes and influence their purchasing decisions in digital marketing [6,10,15].

Of the five influencer dimensions, the likeability had the highest coefficient of regression, which is purchase intention (β = 0.324). The discovery indicates that university students have a higher chance in purchasing fashion products when they are recommended by a fashion influencer that is attractive, engaging, relatable to them. Generation Z consumers often create emotional relationships with influencers through social media interaction platforms, like Instagram or TikTok, that they follow on an ongoing basis. The study corresponds with Colliander and Dahlén [3] and Lou and Yuan [10] who reported positive co-relation between likability of influencers and engagement of consumers and between the credibility and the value of messages and the trust and inclination to purchase of consumers.

The second most significant determinant of purchase intention was trustworthiness, which refers to the trustworthiness of the influencers' recommendations made by the students. The second most important predictor of purchase intention is trustworthiness, meaning that students highly value the trustworthiness of the influencers' recommendation. Likewise, experience had a substantial positive impact, showing that a consumer does' value the owner who has enough knowledge and experience on the fashion products. The findings corroborate Ohanian [15] and Djafarova and Rushworth [6] claims that celebrities or influencers who are authoritative and credible build consumer confidence and trust in purchase.

In addition, purchase intentions were also significantly and positively related to familiarity and similarity. The more consumers are exposed to influencer material, the more they are familiar with the content, build emotional connection and build trust in the influencer's suggestions. Similarly, perceived similarity fosters a greater degree of identification with influencers which boosts the chance that their followers will accept their product endorsements. The outcomes presented in this study agree with earlier studies in social media and consumer Behaviour [1,3,10].

Conclusion

The idea behind the research was to determine the influence of a social media influencer on the purchase intention of a consumer in the fashion retail industry towards the student population of ESOFT Metro campus. The paper aimed at the 5 characteristics of an influencer that comprise of trustworthiness expertise similarity, familiarity, and likeability. The results in this study indicated that all the 5 elements are directly and positively related to the customer's purchase intention.
The data also revealed that the students purchase Behaviour is more influenced by likeability Quite a bit than the other four, Trustworthiness expertise familiarity in descending order and similarity in next descending order. These results point out that students may make a purchase only based on their liking for the influencers who exhibit attractiveness reliability knowledge, relatability, and also familiarity. Also, we haven't disregarded Really the statistical assessments have further backed up the notion that these 5 influencers' attributes explain the majorities of the variance in the buyers' purchase intention.
Based on the above results, some implications can be highlighted for the practice of fashion retailers and digital marketers in Sri Lanka. Social media organisations should identify social media influencers by taking audience engagement rates,

instead of follower numbers, into account. Engaged audiences are the ones who bring a sense of trust and the feeling to buy a product from the influencers with high following who have less influential audience base.
Secondly, brands should give the influencers suggestions to keep them being authentic and transparent in their fashion product promotion. It is important that sponsored content is clearly noted and influencers can be sure to give honest feedback resulting from their experiences. Waiting until the last minute to convey the message can weaken consumer trust, and disingenuous messaging can make an influencer marketing campaign look less trustworthy.
Thirdly, fashion retailers must focus on partnerships with influencers in the longer term, not promoting one-off campaigns. Regular partnerships can contribute to better brand awareness, deepening the understanding of the brand, and stimulating long-lasting relationships between followers and influencers.
Moreover, organisations will need to think about working with micro-influencers, usually with a smaller, but much more engaged audience. This is because those with micro-followers tend to have more interactions, authenticity and consumer trust, which makes them a powerful option for fashion retailers targeting Generation Z consumers.

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References

Bandara RM. Impact of social media advertising on consumer buying behaviour toward fast fashion products in Sri Lanka. Colombo: University of Colombo; 2021.

Beldad A, De Jong M, Steehouder M. How shall I trust the faceless and the intangible? A literature review on the antecedents of online trust. Comput Hum Behav. 2010;26(5):857-869.

Colliander J, Dahlén M. Following the fashionable friend: The power of social media. J Advert Res. 2011;51(1):313-320.

DataReportal. Digital 2025: Sri Lanka [Internet]. Singapore: DataReportal; 2025. Available from: https://datareportal.com/reports/digital-2025-sri-lanka

DataReportal. Social media statistics in Sri Lanka 2025 [Internet]. Singapore: DataReportal; 2025. Available from: https://datareportal.com

Djafarova E, Rushworth C. Exploring the credibility of online celebrities' Instagram profiles in influencing purchase decisions among young female users. Comput Hum Behav. 2017; 68:1-7.

Holt DB. Why do brands cause trouble? A dialectical theory of consumer culture and branding. J Consum Res. 2002;29(1):70-90.

Kaluarachchi P, Jayasuriya S. Impact of firm-created and user-generated social media communication on purchase intention in Sri Lanka's fashionwear industry. J Bus Manag. 2024;12(1):33-49.

Lee E, Yurchisin J. Social media and consumer decision making in apparel retailing. Int J Retail Distrib Manag. 2011;39(4):265-282.

Lou C, Yuan S. Influencer marketing: How message value and credibility affect consumer trust and purchase intention. J Interact Advert. 2019;19(1):58-73.

McGuire WJ. Attitudes and attitude change. In: Lindzey G, Aronson E, editors. Handbook of Social Psychology. 3rd ed. New York: Random House; 1985. p. 233-346.

Muda M, Musa R, Mohamed RN. Celebrity entrepreneur endorsement and advertising effectiveness. Procedia Soc Behav Sci. 2014;130:11-20.

Narayana D, Dissanayaka D. Impact of social media influencers on consumer purchase intention in the fashion retail industry in Sri Lanka. Sri Lanka J Mark. 2022;8(2):45-61.

Nejad MG, Sherrell DL, Babakus E. Influencer expertise and consumer trust in social media environments. J Bus Res. 2014;67(8):1572-1580.

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ISBN: 978-624-6610-01-2
Proceedings of the ESOFT International Conference 2026
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Ohanian R. Construction and validation of a scale to measure celebrity endorsers' perceived expertise, trustworthiness, and attractiveness. J Advert. 1990;19(3):39-52.

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Abstracts on Economics, Finance, Business, Management, Hospitality and Tourism - Poster Presentations

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EP 07

Authentic Leadership, Organisational Identification, and Organisational Citizenship Behaviour: Evidence from Private Higher Education Institutions in Northern Sri Lanka

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Abstract

Background: This study examined the impact of authentic leadership (AL) on organisational citizenship behaviour (OCB), with organisational identification (OI) as a mediator, among employees in private higher education institutions in Northern Sri Lanka. The study is grounded in Social Identity Theory and authentic leadership theory, which explain how leadership influences employees' psychological attachment and discretionary behaviours. Organisational citizenship behaviour is important in higher education as it enhances cooperation and institutional effectiveness beyond formal job roles.

Objective/s: The study aimed to examine: (1) the impact of AL on OCB, (2) the impact of AL on OI, (3) the impact of OI on OCB, and (4) the mediating effect of OI on the relationship between AL and OCB.

Methods: A positivist research philosophy and a deductive, quantitative explanatory design were adopted. Data were collected from 196 academic and non-academic employees using a structured questionnaire. Simple random sampling was employed by randomly selecting eligible employees from institutional staff lists, after which the questionnaire was distributed to the selected participants via Microsoft Forms. The findings represent the combined sample, and no subgroup analysis was conducted by academic versus non-academic status. Data were analysed using SPSS version 25, including descriptive statistics, reliability, factor analysis, correlation, regression, and mediation analysis, with Hayes' PROCESS Macro Model 4 (version 4.2) with 5,000 bootstrap samples.

Results: The findings indicated strong reliability and validity of the measurement scales ($\alpha > 0.86$; KMO > 0.84). Correlation analysis revealed strong positive relationships among AL, OI, and OCB. Regression results showed that AL significantly predicted OCB ($\beta = 0.825$, $R^2 = 0.680$, $p < 0.001$) and OI ($\beta = 0.9209$, $R^2 = 0.774$, $p < 0.001$). OI significantly predicted OCB ($\beta = 0.3014$, $p < 0.001$). Mediation analysis confirmed that OI partially mediated the relationship between AL and OCB, with a significant indirect effect (0.2776, 95% CI [0.1894, 0.3611]). These findings suggest that fostering authentic leadership can strengthen employees' organisational identification and organisational citizenship behaviour, providing practical guidance for higher education administrators to enhance employee engagement.

Conclusion/s: The study concludes that AL enhances employees' OI, thereby promoting OCB. The findings contribute to leadership and organisational behaviour literature, and this study provides practical implications for enhancing employee engagement. Strengthening authentic leadership may contribute to improved institutional performance in higher education institutions.

Keywords: *Authentic Leadership, Higher Education Institutions, Organisational Citizenship Behaviour, Organisational Identification, Sri Lanka.*

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EP 08

Role of Microfinance Factors on Performance of Women Entrepreneurs: An Evidence from Mannar, Sri Lanka

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Abstract

Background: Microfinance has been widely recognized as an effective mechanism for promoting financial inclusion, poverty alleviation, and women entrepreneurship in developing countries. In Sri Lanka, microfinance institutions provide financial and non-financial services to women entrepreneurs, particularly in rural and post-conflict regions. Despite the expansion of these services, limited empirical evidence exists regarding their effectiveness in enhancing the business performance of women entrepreneurs especially in Mannar, a region characterized by post-war socio-economic challenges.

Objective/s: This study aimed to examine the role of microfinance factors on the performance of women entrepreneurs in Mannar. Specifically, it sought to determine the effects of access to credit and training and capacity-building services on women entrepreneurs' performance.

Methods: The study was quantitative in nature. Data were collected from 100 women entrepreneurs who are microfinance customers of a leading private bank in Mannar. Respondents were selected randomly from the list obtained from the institution and structured questionnaires comprising demographic information and variables based on a five-point Likert scale were administered to collect data. Data were analysed descriptively and inferentially using SPSS. Multiple linear regression was employed to assess the relationships between microfinance factors and entrepreneurial performance. Cronbach's alpha was used to check the internal consistency.

Results: Many respondents were aged 36–40 years (33%), possessed Advanced Level education qualifications (68%), engaged in cake-making businesses (31%), and had 6–10 years of business experience (40%). Reliability analysis indicated strong internal consistency, with Cronbach's alpha values exceeding 0.80. The regression model explained 45.3% of the variance in women entrepreneurs' performance (Adjusted $R^2 = 0.453$). Both access to credit ($p=0.000$) and training and capacity building ($p=0.001$) significantly influenced entrepreneurial performance. Access to credit emerged as the strongest predictor ($\beta = 0.512$) followed by training and capacity building services ($\beta = 0.274$).

Conclusion/s: Microfinance services significantly contribute to improving the performance of women entrepreneurs in Mannar. Enhanced access to credit and entrepreneurial training can strengthen the performance of women entrepreneurs and thus business growth and sustainability, supporting women's economic empowerment and regional development in post-conflict communities. Since the study is limited to a particular institution in Mannar, the findings lack generalizability, and more generalizable findings would obtain when all post-conflict regions are incorporated in the study.

Keywords: *Access to credit, Microfinance, Training and Capacity building, Women entrepreneurs' performance*

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EP 09

AI-Powered Tools and Inventory Management Optimization: Evidence from Selected Supermarket Outlets in Galle District, Sri Lanka

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Abstract

Background - Artificial intelligence (AI) is increasingly transforming retail supply chain operations by improving inventory visibility, demand forecasting, stock replenishment, and wastage control. Although previous international studies have demonstrated the benefits of AI in inventory management, empirical evidence from Sri Lankan supermarket operations remains limited. This study addresses this gap by examining how AI-powered tools contribute to inventory management optimization in selected supermarket outlets in the Galle District, Sri Lanka.

Objectives - The study aimed to examine the effect of real-time inventory tracking, AI-based demand forecasting, automated stock replenishment, and inventory wastage reduction on inventory management optimization.

Methods - The study adopted a positivist research philosophy and a deductive approach following Saunders' Research **Onion**. A descriptive quantitative research design was employed. Primary data were collected through a structured five-point Likert scale questionnaire administered to 36 employees selected using simple random sampling from selected supermarket outlets. Secondary data was obtained from relevant academic and industry sources. Data was analysed using SPSS Version 26 through reliability testing, descriptive statistics, and Pearson correlation analysis.

Results - The questionnaire demonstrated excellent internal reliability (Cronbach's Alpha = 0.949). All four AI dimensions showed statistically significant positive relationships with inventory management optimization ($p < 0.001$). AI-based demand forecasting recorded the strongest relationship ($r = 0.876$), followed by real-time inventory tracking ($r = 0.825$), inventory wastage reduction ($r = 0.813$), and automated stock replenishment ($r = 0.741$). These findings indicate that AI-powered tools improve stock visibility, forecasting accuracy, replenishment efficiency, and wastage control, leading to enhanced operational performance and inventory optimization.

Conclusions - The findings confirm that AI-powered tools significantly improve inventory management performance in Sri Lankan supermarkets, with AI-based demand forecasting emerging as the strongest contributor. The results suggest that retailers can achieve greater operational efficiency, better stock control, and reduced inventory wastage by strengthening AI integration, improving data quality, and enhancing employees' capability to effectively utilize AI-driven inventory systems.

Keywords: *Artificial Intelligence, Demand Forecasting, Inventory Management, Stock Replenishment, Retail Supply Chain.*

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EP 10

Climate Financing and Developing Economies: A Case Study of Barriers and Strategies in Sri Lanka

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Abstract

Background:
Climate finance is a critical development challenge for vulnerable economies, where limited fiscal space and institutional constraints can slow adaptation and mitigation. Although previous studies have identified Sri Lanka's climate-finance constraints, fewer have synthesised the barriers and strategy options alongside recent policy developments, leaving an important gap in the literature.

Objective/s:
This study aims to examine the major barriers to climate financing in Sri Lanka and identifies strategies that may improve access to domestic and international climate finance.

Methods:
The study used a qualitative secondary-data case study design based on approximately 15 peer-reviewed studies, policy documents, and reports from national and international institutions. A thematic content analysis was conducted to identify recurring evidence on climate finance needs, barriers, financing instruments, and policy responses.

Results:
The literature indicates a substantial climate finance gap in Sri Lanka. A recent critical review, drawing on the Climate Prosperity Plan and related policy sources, reports that the country requires approximately USD 26.5 billion by 2030 for climate actions, while green lending accounts for only 1.4% of the banking sector portfolio. The thematic analysis shows that the main barriers are inadequate domestic funding, limited project readiness, weak institutional capacity, and restricted access to external finance. Recent policy developments, including the National Climate Finance Strategy (2025–2030), identify green bonds, public-private partnerships, carbon markets, and disaster risk insurance as potential solutions.

Conclusion/s:
Sri Lanka's experience shows that effective climate finance in developing economies depends not only on the availability of capital, but also on institutional readiness, policy coordination, and innovative financing mechanisms. Among the available options, public-private partnerships and stronger incentives for green lending appear to be the most immediately feasible pathways for narrowing the climate finance gap.

Keywords: *climate finance, developing economies, Sri Lanka*

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EP 11

The Effect of Word-of-Mouth Communication on Brand Personality Formation: An Empirical Study of the Sri Lankan Cosmetic Industry

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Abstract

Background:
The Sri Lankan cosmetic industry has become increasingly competitive due to growing consumer interest in personal appearance and beauty products. As consumers frequently rely on recommendations before purchasing cosmetics, Word-of-Mouth (WOM) communication has emerged as an important determinant of brand personality formation.

Objective/s:
- To examine the impact of Word-of-Mouth communication on brand personality.
- To identify the effect of different Word-of-Mouth communication sources on brand personality.
- To determine the most significant influential source of Word-of-Mouth communication

Methods:
Data were collected through an online questionnaire from 150 female cosmetic consumers in the Colombo District using judgmental sampling. Brand personality was measured using established multidimensional brand personality attributes, while WOM was assessed across relatives, friends, experts, online reviews, and news/articles. Data were analysed using descriptive statistics, Pearson correlation, and multiple regression analysis in SPSS.

Results:
All WOM dimensions demonstrated significant positive relationships with brand personality. Pearson correlation analysis indicated significant associations for relatives ($r = 0.914$, $p < 0.001$), friends ($r = 0.852$, $p < 0.001$), experts ($r = 0.954$, $p < 0.001$), online reviews ($r = 0.820$, $p < 0.001$), and news/articles ($r = 0.784$, $p < 0.001$). Multiple regression further confirmed that expert WOM exerted the strongest influence on brand personality ($\beta = 0.877$, $p < 0.001$), followed by relatives ($\beta = 0.583$), friends ($\beta = 0.454$), news/articles ($\beta = 0.186$, $p = 0.008$), and online reviews ($\beta = 0.139$), indicating that all WOM sources significantly contributed to brand personality formation.

Conclusion/s:
The findings demonstrate that interpersonal and media-based WOM significantly shape brand personality in the Sri Lankan cosmetic industry, with expert recommendations exerting the strongest influence. These findings provide valuable insights for marketers seeking to strengthen brand positioning through credible WOM strategies. However, the use of judgmental sampling confined to female consumers in the Colombo District limits the generalisability of the findings, suggesting the need for broader future studies.

Keywords: *Brand Personality, Cosmetic Industry, Word-of-Mouth*

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EP 12

Factors Affecting Customer Satisfaction in the Footwear Industry with Reference to ABC Company

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Background:
Customer satisfaction is a critical determinant of organizational competitiveness and long-term business success in the footwear industry. Despite the growing importance of customer-centric marketing strategies, empirical evidence on the factors influencing customer satisfaction in the Sri Lankan footwear sector remains limited. Understanding the effects of corporate brand image, customer perceived value, product quality, and pricing is essential for developing effective strategies to enhance customer satisfaction.

Objective/s:
To examine the influence of corporate brand image, customer perceived value, product quality, and pricing on customer satisfaction in the Sri Lankan footwear industry, with special reference to ABC Company.

Methods:
A quantitative cross-sectional survey was conducted using a structured online questionnaire administered to customers of ABC Company. The online survey facilitated efficient data collection from a geographically dispersed customer base; however, it may have introduced selection bias by excluding individuals with limited internet access or digital literacy. Data was analysed using descriptive statistics, Pearson correlation analysis, and multiple regression analysis to examine the relationships between the study variables.

Results:
The findings revealed that all independent variables had statistically significant positive relationships with customer satisfaction ($p < 0.001$). Corporate brand image demonstrated the strongest positive correlation with customer satisfaction ($r = 0.807$), followed by customer perceived value ($r = 0.771$), product quality ($r = 0.752$), and pricing ($r = 0.676$). Multiple regression analysis indicated that the proposed model explained 73.6% of the variance in customer satisfaction ($R^2 = 0.736$), confirming the strong explanatory power of the selected predictors.

Conclusion/s:
The study concludes that corporate brand image, customer perceived value, product quality, and competitive pricing are significant determinants of customer satisfaction in the Sri Lankan footwear industry. Among these factors, corporate brand image emerged as the strongest predictor. The findings provide valuable managerial insights for strengthening customer satisfaction through strategic brand management, value creation, quality enhancement, and effective pricing practices, thereby contributing to sustained competitive advantage.

Keywords: Customer Satisfaction, Corporate Brand Image, Customer Perceived Value, Product Quality, Pricing.

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EP 13

Exploring the Role of Leadership in Fostering Innovation at Rocell

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Abstract

Introduction: Innovation is a key driver of competitiveness and sustainability in the manufacturing sector. Although Royal Ceramics Lanka PLC (Rocell) is recognized for design excellence, its recent decline in innovation performance highlights the need to examine organizational factors influencing innovation. While leadership is widely recognized as a key driver of employee creativity and innovation, limited empirical evidence exists on how specific leadership dimensions influence innovation within Sri Lanka's manufacturing sector. This study addresses this research gap.

Objectives: To investigate the influence of visionary leadership, empowerment and delegation, risk-taking support, and communication and collaboration on fostering innovation among employees at Rocell.

Methods: A quantitative case study approach was adopted. Data were collected through a structured questionnaire administered to employees selected using stratified purposive sampling from innovation-related departments, including research and development, product design, and project management, as these departments are directly involved in innovation activities. Of the 132 questionnaires distributed, 127 valid responses were analysed using descriptive statistics, reliability analysis, correlation analysis, and multiple regression analysis.

Results: All four leadership dimensions positively and significantly influenced innovation. Multiple regression analysis showed that leadership behaviours explained 54% of the variance in innovation outcomes ($R^2 = 0.540$; Adjusted $R^2 = 0.525$), indicating a strong explanatory model. Communication and collaboration ($\beta = 0.375$, $p < 0.001$) and risk-taking support ($\beta = 0.375$, $p < 0.001$) emerged as the strongest predictors of innovation, followed by empowerment and delegation ($\beta = 0.326$, $p < 0.001$) and visionary leadership ($\beta = 0.320$, $p < 0.001$).

Conclusions: The findings confirm that leadership practices play a significant role in fostering innovation within Sri Lanka's manufacturing sector. As communication and collaboration and risk-taking support demonstrated the strongest influence on innovation, managers should prioritize strengthening these leadership dimensions while promoting empowerment, delegation, and visionary leadership to enhance innovation performance and support sustainable organizational growth.

Keywords: *communication; innovation; leadership; manufacturing sector; risk-taking support*

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EP 14

Influence of Front-Desk Of5icer's Service Assurance on Customer Loyalty in Banking Industry (Case Study: Bank of Ceylon

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Background:
The banking industry is highly competitive, making customer loyalty essential for organizational success. Although previous studies have examined service assurance and service quality across hotel, airline and tourism industries in different countries, limited empirical evidence exists regarding Sri Lanka state-owned banking sector's influence of front-desk officers service assurance on customer loyalty. Therefore, Bank of Ceylon was selected because BOC is a largest commercial bank and it's branches spared across the country. This study investigates how front-desk officer's service assurance affects customer loyalty.

Objectives:
This study aims to investigate the influence of professionalism, consistency, reliability, and accountability on customer loyalty in the Sri Lankan banking industry.

Methods:
This study adopted a quantitative mono-method research design. Data were collected using a self-administrated-questionnaire through Google Form. The study involved 126,959, with 383 respondents selected using Raosoft online sample size calculator. Responses from BOC customers and employees in Eheliyagoda branch. Descriptive statistics summarized the data, correlation and regression analysis examined relationships between variables, and the Chi-square test determined significant associations. Reliability and validity were assessed using SPSS software.

Results:
The findings indicated all variables positively influence to enhance customer loyalty in banking industry. Professionalism had a significant positive relationship with customer loyalty ($r = 0.581$, $p < 0.001$). Reliability emerged as the strongest determinant of customer loyalty. The Chi-square analysis also confirmed significant associations between the independent variables and customer loyalty ($p < 0.05$). Overall, the results indicate that professionalism, service consistency, reliability, and responsibility significantly influence customer loyalty in the Sri Lankan banking industry.

Conclusion:
The findings demonstrate that front-desk officer's service assurance significantly enhances customer loyalty within the Sri Lankan banking industry. This study addresses an important research gap and provides practical implications for managers, policymakers, organizations to strengthen customer loyalty by improving front desk officer's professionalism, service consistency, reliability and responsibility.

Keywords: *Banking Industry*, *Customer Loyalty, Front-desk officers*, *Service Assurance*, *Sri Lanka Banking Industry*

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EP 15

The Role of social media in Building Customer Loyalty among SMEs in Trincomalee

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Abstract

Background: Small and Medium Enterprises (SMEs) in Trincomalee use social media to attract and retain customers. Yet evidence from metropolitan settings may not represent this tourism-dependent district, where businesses face limited digital infrastructure, marketing expertise, and financial resources. Local evidence is needed to identify engagement practices that produce loyalty benefits within a regional Sri Lankan environment rarely examined.

Objective/s: This study examined the direct influence of content quality, two-way communication, personalisation, and interactive features on customer loyalty among SME customers in Trincomalee. Customer loyalty was assessed through repeat purchases, trust and commitment, and brand advocacy.

Methods: A quantitative cross-sectional design was used. Through non-probability purposive sampling, 387 customers of Trincomalee SMEs who had interacted with those businesses through Facebook, Instagram, or WhatsApp completed a structured Likert-scale questionnaire. Data were analysed using the Statistical Package for the Social Sciences through descriptive statistics, reliability testing, correlation analysis, and multiple regression. The three loyalty outcomes were analysed separately rather than combined into one construct.

Results: All three regression models were significant, with probability values below 0.001. The predictors explained 89.5 per cent of repeat purchases, 87.2 per cent of trust and commitment, and 84.1 per cent of brand advocacy. Interactive features were the strongest predictor of repeat purchases, with a beta coefficient of 0.388, and brand advocacy, with a beta coefficient of 0.293. They also strongly predicted trust and commitment, with a beta coefficient of 0.352. Content quality and personalisation significantly predicted every outcome. Two-way communication predicted repeat purchases and advocacy, but not trust and commitment.

Conclusion/s: Social media engagement strengthens customer loyalty among SMEs in Trincomalee, although effects vary across loyalty dimensions. Resource-constrained SMEs should use low-cost platform features, including polls, stories, scheduled posts, personalised messages, prompt replies, and customer-generated content, to improve retention, trust, and advocacy without advanced technology or major advertising expenditure.

Keywords: *Brand advocacy, Customer loyalty, Personalisation, Small and medium enterprises, Social media engagement.*

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EP 16

Influence of Social Media Marketing Strategies on Consumer Purchase Intentions in the Luxury Ayurveda Industry in Kandy, Sri Lanka

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Abstract

Background: Social media has become a key platform for building consumer brand relationships, particularly within the beauty and wellness industry. However, the luxury Ayurveda sector differs from mainstream beauty markets by emphasizing cultural heritage, authenticity, and holistic wellness, making its digital marketing context distinct and underexplored. In Kandy, Sri Lanka, luxury Ayurveda brands increasingly rely on social media strategies to enhance visibility, engage consumers, and strengthen market presence. Despite this growing dependence, limited empirical evidence exists on how these strategies influence consumer purchase intentions, warranting investigation into this unique cultural and industry context.

Objective/s: This study examines the influence of social media marketing strategies on consumer purchase intentions in the luxury Ayurveda industry in Kandy, Sri Lanka. Specifically, it investigates the effects of content quality, consumer engagement, influencer collaborations, social media advertising, and platform consistency on consumers' purchase decision-making processes within this context.

Methods: Guided by a positivist philosophy and a deductive approach, the study employed a quantitative survey design. Measurement scales were adapted from validated instruments to ensure methodological rigor. Primary data were collected through structured questionnaires administered to social media-active consumers in Kandy's luxury Ayurveda sector, using simple random sampling. A total of 183 valid responses were analysed using descriptive statistics, reliability testing, correlation, and regression techniques, supplemented by secondary industry reports and academic sources. This methodological approach enabled systematic examination of social media strategies and their influence on consumer purchase intentions.

Results: Advertising and promotional activities ($\beta = 0.42$, $p < 0.01$), platform selection ($\beta = 0.36$, $p < 0.01$), and posting consistency ($\beta = 0.31$, $p < 0.05$) exerted the strongest positive influence on consumer purchase intentions. Engagement and influencer collaborations also showed significant effects, while content quality and creativity had weaker influence. This unexpected result suggests that consumers in the Ayurveda sector prioritize trust, consistency, and clarity of promotional communication over purely aesthetic elements, reflecting the cultural importance of authenticity in wellness markets.

Conclusion/s: Social media marketing functions not only as a promotional tool but as a determinant of consumer purchase intentions in Sri Lanka's luxury Ayurveda industry. Businesses in this sector should prioritize advertising clarity, consistent platform use, and budget allocation toward trust-building strategies, while balancing engagement and influencer collaborations. For firms with limited marketing budgets, focusing resources on consistency and promotional transparency may yield stronger consumer responses than investing heavily in creative aesthetics. The study contributes to literature on consumer Behaviour in emerging markets by showing how cultural and contextual factors shape responses to global digital trends. These findings offer both theoretical insights and practical guidance for marketers and brand managers seeking sustainable growth in competitive environments.

Keywords: *Advertising, Consumer purchase intention, Engagement, Social media marketing, Luxury Ayurveda Industry*

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EP 17

Factors Influencing Customer Satisfaction in Digital Banking Services: Evidence from ABC Bank in the Galle District

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Background: Digital transformation is rapidly reshaping the financial sector, making it imperative for banks to understand the drivers of customer satisfaction in a competitive landscape. While digital banking adoption is widespread, localized studies focusing on the specific behavioral dynamics of customers in regional districts like Galle are limited.

Objective/s: This study aims to examine the impact of convenience, security, affordability, and service quality on customer satisfaction among digital banking users at ABC Bank in the Galle District. It seeks to bridge the research gap by providing empirical evidence from a regional perspective, moving beyond established global trends to identify unique local determinants of satisfaction.

Methods: Adopting a quantitative approach, data was collected via a survey from a sample of 75 customers of ABC Bank within the Galle District. Analysis was performed to determine the relationship between the identified independent variables and the level of customer satisfaction.

Results: All four factors significantly and positively influence customer satisfaction. Service quality emerged as the strongest predictor ($\beta = 0.412$, $p < 0.001$), followed by security ($\beta = 0.298$, $p < 0.001$). Convenience ($\beta = 0.187$, $p < 0.05$) and affordability ($\beta = 0.156$, $p < 0.05$) also showed significant effects. The model explained 68.4% of the variance in customer satisfaction ($R^2 = 0.684$)

Conclusion/s: Enhancing robust security features and high service reliability should be prioritized by bank executives to drive user retention. A primary limitation is the localized, single-bank sample (N = 75), suggesting caution in broader regional generalization.

Keywords: *Affordability, Convenience, Customer Satisfaction, Security, Service Quality*

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EP 01

Hands-On Workshop Interventions for Digital Literacy in Sri Lankan Higher Education: A Case Study

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Abstract

Introduction: Digital skills gaps in undergraduate computing education persist across private higher education institutions (HEIs) in developing countries. Practitioner-led workshop interventions from South Asian private HEI settings remain underreported in the literature.

Objectives: This paper documents and evaluates two hands-on workshops in Linux systems administration and artificial intelligence (AI) literacy delivered at ESU, Kandy, Sri Lanka.

Methods: Two workshops were delivered to 212 Pearson HND students across all semesters. Linux Ground Zero (November 2025, n = 100) used a VM-based Ubuntu environment; AI Ground Zero (March 2026, n = 112) used Google Colab. Both incorporated competitive gamified quizzes with prizes and participation certificates, delivered free of charge. Feedback was collected from AI workshop participants via Google Form (N = 46; 41% response rate).

Results: Mean overall satisfaction was 4.67 out of 5.0. Content quality was rated Excellent or Good by 97.8% of respondents. Career and academic relevance was affirmed by 93.5%, with no negative responses. Practical exposure was rated Excellent or Good by 93.4%. Qualitative themes indicated strong engagement, demand for longer sessions, and interest in follow-on workshops in machine learning and cybersecurity.

Conclusions: Practitioner-led, tool-integrated workshops with gamification are viable and well-received for digital literacy development at private HEIs in Sri Lanka. The tool-environment selection principle -- local VMs when setup is the lesson, cloud notebooks when it is an obstacle -- offers a low-cost, replicable design heuristic for resource-constrained HEIs.

Keywords: *artificial intelligence, digital literacy, gamification, hands-on learning, Linux*

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Introduction

Need for graduates with marketable skills tied to production-level tool chains has increased in step with the proliferation of artificial intelligence solutions, cloud-enabled workflows, and open-source technologies into regional industries. Van Laar et al. characterise digital skills as consisting of "not only the technical skills needed to use digital tools, but also the context in which tools should be applied with purpose in various situations across the working world" [8]. Undergraduate programs frequently struggle to supply students with basic proficiencies expected by industry and research facilities, particularly private higher education institutions lacking specialist laboratories, licensable toolchains, and instructors with professional experience.

Recent literature has shown elevated interest in teaching artificial intelligence and machine learning concepts within undergraduate computing degrees [9, 11]. Workshop case studies originating from private higher education institutes in developing nations are comparatively rare in published form [11]. Existing studies on digital skills interventions in developing countries tend to focus on formal curricula reform or technology access rather than short-duration, practitioner-led workshops as a supplementary model. This study directly addresses that gap by documenting, evaluating, and deriving transferable design principles from two such workshops. Workshops can be deployed relatively inexpensively by institutions; they can be staffed by visiting industry and research professionals, cover time-sensitive topics before curricula updates, and reach hundreds of students while incurring reasonable overhead. Educational theories provide strong support for workshop-style active learning. According to Kolb's learning cycle theory, concrete experience is the first stage of learning [1]. Hands-on workshops satisfy this quadrant by providing students with tactile experience that activates further reflection and conceptual understanding. Bonwell and Eison's broad definition of active learning describes it as "anything that requires students to do something beyond passively listening to a lecture" [6]. Both the VM manipulation exercises from the Linux workshop and the coding exercises completed on Google Colab in the AI workshop fall under this umbrella. Lo et al. performed meta-analysis on active learning research and identified significant reductions in failure rates and improvements in grades for active learning in computing and engineering courses when compared to traditional lectures [2, 3]. Application of gamification in education, or the "use of game elements in non-game contexts" [4] has also been researched extensively. Increased student engagement and motivation are commonly observed; however, improvements to learning outcomes are mixed [5, 12].

We report two hands-on workshops offered at ESU, Kandy, Sri Lanka during November 2025 and March 2026. This paper contributes in three ways. First, we offer a documented workshop format led by industry practitioners for training students in two core digital skills. This format requires limited resources to replicate at another institution. Second, we detail our rationale for tool and environment selection to provide a guideline diagram for future practitioners building workshops under similar constraints. Finally, we share workshop feedback from students at a Sri Lankan private HEI. Students from these institutions comprise a significant portion of the technological workforce in developing countries but are underrepresented in educational technology research.

Our goals were to present the design of each workshop, assess student reactions to the AI workshop, and codify principles for workshop deployment at resource-constrained HEIs. The paper is structured as follows. First, we discuss the design of each workshop and provide implementation details. We then present quantitative and qualitative data collected from students who attended the AI workshop (N = 46). Last, we discuss recommendations for institutions who wish to offer similar workshops.

Methods

Study Design and Setting

This paper describes a project utilizing descriptive, intervention based methodology. The workshops were designed and conducted by author, who is a network/systems engineer experienced in systems administration, research network operations and AI training, with additional assistance from volunteer workshop crew helping with workshop logistics and hands-on instruction as needed. Workshops took place on the ESU, Kandy campus at no cost to attendees; there was no attendance fee nor were registration costs incurred. All utilized resources were open access: namely Ubuntu Linux and VirtualBox (Linux workshop), or Google Colab (AI workshop). Certificates of attendance were distributed to participants. The certificates provided credential-based inducement in addition to competitive quiz incentives. Attendance was voluntary; students from any year were permitted to attend. Students of all four semesters of the Pearson Higher National Diploma (HND) programme participated. Workshop content was developed to serve as a foundational, introductory intervention

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raising awareness and encouraging pursuit of self-directed continuing education in topic material; content was designed to be beginner-friendly regardless of participants' pre-existing knowledge. While the Linux Ground Zero workshop was limited to students enrolled in IT programmes who will require familiarity with Linux systems administration in their vocational training, enrollment in the AI Ground Zero workshop was opened to students of all STEM majors due to AI literacy's broadly cross-disciplinary nature. Table 1. summarises end-to-end design framework for workshops. Table 2 summarizes key implementation metrics between workshops.

Table 1. Workshop Intervention Design and Evaluation Framework

Workshop	1. Institutional Context	2. Tool Environment	3. Delivery	4. Engagement	5. Evaluation	6. Transferable Principle
Linux Ground Zero Nov 2025	Private HEI; IT undergraduates (n = 100)	Setup constitutes the lesson - local VM (Ubuntu) selected	Free; open-source tools; practitioner-led; volunteer crew	Competitive quiz; prizes (top 3); certificates (all 100)	Attendance: 100; Ubuntu install completion: 100%	Use local VM when setup is the lesson
AI Ground Zero Mar 2026	Private HEI; STEM undergraduates (n = 112)	Setup is an obstacle to the lesson - cloud notebook (Google Colab) selected	Free; open-access tools; practitioner-led; volunteer crew	Two quiz rounds; prizes (top 3); certificates (all 112)	N = 46 (41%); mean 4.67/5.0; 93.5% career relevance	Use cloud notebook when setup is an obstacle

Table 2. Comparative Overview of the Two Workshop Interventions

Component	Linux Ground Zero	AI Ground Zero
Year delivered	November 2025	March 2026
Participants (n) and target audience	*100 - IT undergraduates*	*112 - STEM undergraduates*
Learning environment	Local VM - Ubuntu on lab hardware	Google Colab – browser based Python notebooks
Tool selection rationale	Setup process is the learning objective	Frictionless access required for content-first delivery
Curriculum scope	11 modules: CLI, file systems, users, packages, networking, scripting, security	10 modules: ML paradigms, deep learning, CNNs, prompt engineering, AI tools
Gamification mechanism	Competitive multi-round quiz; top 3 receive material prizes; participation certificates issued to all	Two competitive quiz rounds; top 3 receive material prizes; participation certificates issued to all

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Component	Linux Ground Zero	AI Ground Zero
Evaluation instrument	Attendance record only	Structured Google Form (N = 46); 4 rated + 2 open-text questions

Workshop 1: Linux Ground Zero (November 2025)

Linux Ground Zero was delivered to 100 students who were IT undergraduates at any level of the Pearson HND programme. The intention was to give students enough awareness of Linux to take away and independently explore open source systems after the workshop had finished. Students provisioned their own virtual machine (VM) hosted on a lab workstation and performed a complete installation of Ubuntu. Students are expected to learn from the installation process as part of the workshop. Eleven topics were covered: Linux and Linux distributions; Bash, the Linux command line; Linux desktop introduction; files and directories; adding and managing users and groups; APT and DPkg package management; managing processes and services with systemd; Linux networking basics: IPs and networking tools; DNSutils and managing disks and swap; Introduction to bash scripting; firewall, updates and troubleshooting with UFW. Reference tables of commands were displayed as students were shown them used on the terminal. There was one quiz given at the end of the workshop. Everyone in attendance (n=100) completed the quiz and three students received prize copies of the learning material.

Workshop 2: AI Ground Zero (March 2026)

AI Ground Zero workshop took place on March 24th of 2026 and was attended by 112 undergraduate students from various STEM fields of study. It lasted around seven hours. We expanded our target audience from just students majoring in Information Technology because Artificial Intelligence literacy can benefit students in other fields of study. Machine learning, data analysis, and AI tools are quickly becoming useful skills to have in engineering, science, and technology programs as well. Coding activities were completed in Google Colab, which allowed students to write and execute Python code in their web browsers without having to download software onto their computers. Google Colab also runs on the cloud which provided students with similar computational capabilities regardless of the devices they used. Students learned about the following topics: What is AI? ; domains of AI; generative AI; transformer models, Generative Adversarial Networks (GANs), and diffusion models; commonly used generative AI tools; single agent vs. multi-agent systems in AI; NumPy, Pandas, Scikit-learn libraries [10], TensorFlow, PyTorch; types of machine learning; confusion matrices, precision, recall, and F1 score; an introduction to deep learning and neural networks; convolutional neural networks (CNNs); an introduction to computer vision; and prompt engineering with demonstrations. Learners applied what they learned by coding along with instructors to learn about linear regression; how to split data using a wine quality dataset; and how to classify Iris flowers with Scikit-learn [10]. Students used TensorFlow Playground to learn about neural networks. There were two quiz competitions that occurred, one in the middle of the workshop and one at the end. Each quiz was optional, but all 112 students participated in each quiz. We awarded 3 material prizes for each quiz; 1st place through 3rd place.

Feedback Instrument

Google Forms was administered to attendees of AI Ground Zero directly after the session concluded. The form included 4 questions with ratings and 2 questions with text entry. Question 1 Rated overall experience with options provided on a 5 point numeric scale ranging from 1 = Poor to 5 = Excellent. Questions 2 and 4 were answered using a 4 category ordinal scale with options Excellent, Good, Fair, Poor. Question 2 rated content of session and Question 4 rated the sessions practical application to using AI tools. Question 3 was responded to by selecting either Yes, Maybe, or No to indicate how much you felt you will benefit academically and career wise from attending the session. The final two questions were open-text entry for what you would like to see in the future and comments. Responses were gathered in real time on the day of the workshop within 2 hours after conclusion. 46 responses were received. One of these was determined to be likely entered as a joke due to the inconsistency of ratings (Overall experience was ranked 1/5, but content and practical experience were both marked as Excellent). This was kept in all data except where noted, but bullied due. If removed, the Mean Score for Question 1 increases from 4.67 to 4.76.

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Results

Participation

The Linux Ground Zero workshop was attended by 100 IT undergraduate students drawn from all semesters of the Pearson HND programme. All 100 participants completed the Ubuntu virtual machine installation and took part in the closing quiz. The AI Ground Zero workshop was attended by 112 STEM undergraduate students, also spanning all semesters, with 46 structured feedback responses received, representing a 41% response rate. All 112 participants took part in both quiz rounds. Participation certificates were issued to all 212 attendees across both workshops. Combined attendance totalled 212 participants.

Quantitative Feedback

Table 3 presents the quantitative feedback results for the AI Ground Zero workshop. On overall experience, 78.3% of respondents gave the maximum rating of 5 and 15.2% gave a rating of 4, yielding a mean of 4.67 out of 5.0. Content quality was rated Excellent by 65.2% and Good by 32.6% of respondents, with no Poor ratings recorded. Perceived career and academic relevance was affirmed by 93.5% of respondents, with the remaining 6.5% selecting Maybe; no respondent selected No. Practical exposure to AI tools was rated Excellent by 54.3% and Good by 39.1%, giving a combined positive rate of 93.4%.

Table 3. Feedback Results for AI Ground Zero Workshop (N = 46)

Question	Response	n	%
Q1: Overall experience (1–5 scale); Mean = 4.67	5 - Excellent	36	78.3
	4	7	15.2
	3	2	4.3
	1 (anomaly, see text)	1	2.2
Q2: Quality of content delivered	Excellent	30	65.2
	Good	15	32.6
	Fair	1	2.2
Q3: Beneficial for career and academic development	Yes	43	93.5
	Maybe	3	6.5
Q4: Practical exposure to AI tools	Excellent	25	54.3
	Good	18	39.1
	Fair	3	6.5

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Topics Requested for Future Sessions

Thirty-three of the 46 participants responded to the open question on preferred future topics. Machine learning and deep learning was the most frequently cited area, appearing across nine responses, indicating demand for greater depth rather than repetition of introductory content. Cybersecurity was the second most requested topic, cited in seven responses. Additional requests included practical Python and coding projects, web development, data science, cloud computing, and AI career pathways.

Qualitative Themes

Twenty- five participants submitted free- text comments. Four themes emerged. The most prevalent were positive reactions to the delivery. Participant 1 expressed that "the way they used examples, jokes, and activities made it even better looking forward to more workshops like this in the future." Participant 2 elaborated: "Session was very informative and easy to understand, learned useful basics about AI and ML". The second theme included requests for a longer workshop. Participant 3 explained: "really enjoyed the workshop and wish it was more like a 3- or 2-day workshop the content was valuable, but the time was limited." Absence of a formal Q& A was the third. One logistical complaint was that the workshop ended late. This negatively impacted students who had traveled far.

Discussion

The feedback data indicate that both workshops were well received and perceived as practically relevant. A mean satisfaction of 4.67 out of 5.0, with 93.5% affirming career relevance and no negative responses, is consistent with evidence that active learning formats are well received in technical disciplines [2, 3, 6]. The absence of any negative career-relevance response suggests students are acutely aware of the gap between their curricula and employer expectations, a pattern documented in the digital skills literature for developing country HEI contexts [8, 11].

The gap between Q2 (content quality: 65.2% Excellent) and Q4 (practical exposure: 54.3% Excellent) most likely reflects curriculum density relative to available time. Covering ten topic areas, live coding, and tool demonstrations in a single day necessarily compresses hands-on practice at each stage. The qualitative demand for a longer format directly corroborates this, consistent with the wider challenge of balancing breadth and depth in introductory AI curricula [9]. These findings directly inform the design of future sessions: the planned follow-on workshops in cybersecurity and applied machine learning will adopt a modular, two-day structure to provide greater hands-on depth per topic, addressing the most consistent participant request.

The central conceptual contribution of this paper is the tool environment selection principle illustrated in Table 2. In the Linux workshop, the VM-based installation process was the primary learning objective; placing students inside an unfamiliar OS from the outset was intentional, not overhead. Providing pre-configured images would have eliminated the most instructionally valuable part of the session. In the AI workshop, the reverse logic applied: requiring over 100 students to configure local Python environments on heterogeneous personal devices would have consumed most of the available time without contributing to the stated goals. Google Colab resolved this by providing uniform, GPU-capable environments accessible from any browser within minutes. The principle is simple: when environment configuration is itself the lesson, use a local VM; when it is an obstacle, use a cloud notebook. This tool-environment selection principle is the central transferable contribution of this study. It is directly applicable in settings where lab setup time is limited, student devices are heterogeneous, and specialist infrastructure is unavailable — conditions commonly encountered in private HEIs across developing-country settings. Practitioners designing similar interventions should evaluate upfront whether the tool setup process is instructionally valuable or a barrier, and select accordingly.

Gamification through competitive quiz rounds with material prizes served two functions: sustaining attention across a long single-day session and creating social incentives for engagement with the technical content. Multiple reviews of educational gamification have found that participation and motivational effects are generally positive, even when direct effects on learning outcomes are mixed [5, 7, 12]. Awarding prizes to the top three performers rather than a single winner was intended to distribute the motivational incentive across a broader portion of the audience, consistent with inclusive gamification design principles [4].

Although formal survey feedback was not collected for the Linux workshop, full task completion and full quiz participation by all 100 attendees provide operational evidence of engagement and feasibility that complements the survey-based evidence from the AI workshop.

The positive perceptions reported by participants raise the question of whether these translated into observable downstream outcomes. While no formally verified outcome data were collected, informal feedback from participants indicated direct utility beyond the session itself. Students reported applying Linux and AI skills in coursework assignments and academic modules, with anecdotal accounts describing improved confidence in related work. Formal assessment data are held by academic coordinators at ESU and will be sought in future iterations to verify academic impact.

Regarding transferability, the design elements that drove success — open-access tools, practitioner-led delivery, volunteer facilitation, and zero registration cost — are low-dependency and replicable at comparable private HEIs. The tool-environment selection principle applies regardless of institutional context; practitioners need only assess whether setup is part of the learning objective or a barrier to it.

Several limitations must be noted. Formal feedback exists only for the AI workshop; the Linux workshop has attendance and task completion data but no survey evaluation, preventing direct comparison. The absence of pre- and post-assessments is the primary scientific limitation: satisfaction data are proxies for learning, not evidence of it. Response bias is also plausible, as students with positive experiences may have been more likely to complete the survey. The single-institution setting constrains generalisability, and the 41% response rate means the sample may not fully represent all participants.

Conclusions

Workshops AI Ground Zero and Linux Ground Zero were hands-on digital literacy workshops with curricula designed and taught by practitioners. They were hosted at ESU, Kandy: Linux Ground Zero on 20-Nov-25 with 100 attending students from IT streams and AI Ground Zero on 20-Mar-26 with 112 attending students from STEM streams. Both workshops used competitive gamified quizzes with material prizes. The workshops were provided at no cost.

From AI Ground Zero, satisfaction survey responses were collected from 46 of 112 participants. The mean rating was 4.67/5.0 with 93.5% of respondents agreeing that the contents were relevant to their career and studies. This paper's three main contributions are: (i) a workshop model consisting of workshops taught by practitioners that can be reproduced with very light institutional overheads; (ii) a tool-&-environment-selection heuristic —if your lesson is about cloud notebook setup, use a cloud notebook. If your lesson is about pasting in code and hitting run, use a local VM.— to add to the set of concrete, portable design decisions useful for tool-selection in institutionally/resource-starved HEIs; and (iii) direct evidence of learner feedback for these interventions from a private Sri Lankan higher education context, which is relatively scant in educational technology and digital literacy literature. Our main take-home for practitioners reading this paper is to carefully consider whether setup is part of the lesson before defaulting to familiar tools or environments in which you or your students happen to be skilled.

We aim to expand upon this work in future through three efforts. Firstly, we will implement a pre-/post-assessment survey across both workshops to gather data on knowledge gained rather than only satisfaction. Secondly, we will retroactively apply a consistent structured feedback form to Linux Ground Zero to allow direct comparison to the AI Ground Zero survey responses. Thirdly, we will run two follow-up workshops requested most by attendees: a cybersecurity fundamentals workshop and an applied machine learning workshop (ie. students complete a cloud-native ML project) open to the same cohort of Pearson HND students. Both will directly apply lessons documented about tool/environment selection and zero-cost delivery in this paper. Where feasible, we will also attempt to follow up with attendees after six months to determine if they went on to learn more digital skills, take related courses, or felt more prepared to receive job offers. This longitudinal component would help provide proof of long-term impact that this paper cannot.

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References

1. Kolb DA. Experiential Learning: Experience as the Source of Learning and Development. Englewood Cliffs: Prentice-Hall; 1984.

2. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, et al. Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci USA. 2014;111(23):8410-5.

3. Prince M. Does active learning work? A review of the research. J Eng Educ. 2004;93(3):223-31.

4. Deterding S, Dixon D, Khaled R, Nacke L. From game design elements to gamefulness: defining 'gamification'. In: Proceedings of the 15th International Academic MindTrek Conference; 2011 Sep 28-30; Tampere, Finland. New York: ACM; 2011. p. 9-15.

5. Dichev C, Dicheva D. Gamifying education: what is known, what is believed and what remains uncertain: a critical review. Int J Educ Technol High Educ. 2017;14(1):9.

6. Bonwell CC, Eison JA. Active Learning: Creating Excitement in the Classroom. ASHE-ERIC Higher Education Report No. 1. Washington DC: George Washington University School of Education and Human Development; 1991.

7. Hamari J, Koivisto J, Sarsa H. Does gamification work? A literature review of empirical studies on gamification. In: Proceedings of the 47th Hawaii International Conference on System Sciences; 2014 Jan 6-9; Hawaii, USA. IEEE; 2014. p. 3025-34.

8. van Laar E, van Deursen AJAM, van Dijk JAGM, de Haan J. The relation between 21st-century skills and digital skills: a systematic literature review. Comput Human Behav. 2017;72:577-88.

9. Jordan MI, Mitchell TM. Machine learning: trends, perspectives, and prospects. Science. 2015;349(6245):255-60.

10. Pedregosa F, Varoquaux G, Gramfort A, Michel V, Thirion B, Grisel O, et al. Scikit-learn: machine learning in Python. J Mach Learn Res. 2011;12:2825-30.

11. Zawacki-Richter O, Marin VI, Bond M, Gouverneur F. Systematic review of research on artificial intelligence applications in higher education: where are the educators? Int J Educ Technol High Educ. 2019;16(1):39.

12. Seaborn K, Fels DI. Gamification in theory and action: a survey. Int J Hum Comput Stud. 2015;74:14-31.

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PP 02

Usage of Language Register in Translating Children's Literature: In Case of Sybil Wettasinghe's Selected Translation

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Abstract

Background: Language register is a fundamental aspect of translating children's literature, particularly in multilingual contexts where cultural appropriateness is closely implicated. Children's literature demands not only linguistic accuracy but also a high level of sensitivity to language tone and style, as well as emotional transference, with consideration for appropriateness to the target audience, requiring accessible engagement with the language targeting the young reading audience.

Objective/s: This study examines the role of language register in translating children's literature, with particular regard to Sybil Wettasinghe's selected translations and the translation procedures proposed by Peter Newmark. It investigates and evaluates the frequency of language registers in narration and dialogue, including the identification of dominant translation procedures applied across the selected texts.

Methods: A qualitative descriptive case study analysed 70 register instances from Kuḍa Horā and its English translation, The Umbrella Thief, and Mæṭi Gedara Ḷamayi with its English translation, Crystal and Clay. Instances were classified as frozen, formal, consultative, casual, or intimate. Eight representative source-target pairs were additionally examined for translation procedure. Descriptive Content analysis served as the principal research method, enabling the systematic identification and frequency measurement of language registers as classified by Martin Joos (1967), alongside the corresponding translation procedures drawn from Newmark.

Results: The casual register was the most frequent (50.0%), followed by the intimate register (37.%) and the consultative register (13. %); the frozen and formal registers were absent. In the eight representative examples, paraphrase occurred five times (62. %), while expansion and reduction, transference, and synonymy occurred once each. Casual language and paraphrase supported conversational readability, but some adaptations reduced culture-specific meaning.

Conclusion/s: The findings of the study contribute to academic knowledge, facilitating further exploration of the use of language register in Sri Lankan children's literature in relation to translation procedures and strategies. Further, it encourages translation scholars to evaluate the understudied areas of children's translation, including its language adaptability in translating children's literature.

Keywords: *Children's literature, language register, paraphrase, Sinhala-English translation, translation procedures*

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Introduction

The various fields, including fiction, fables, and non-fiction, have significantly influenced children's translation. Children's literature has a significant impact on the translation of literary works into many languages worldwide. According to Peter Newmark, translating is “A craft consisting in the attempt to replace a written message and/or a statement in one language by the same message and/or statement in another language (1988). Language is the fundamental mode of sharing and expressing emotions and thoughts. The language that has been used to render the meaning from one language to another in children's translation preserves the tone, register, and style of the intended language. The use of language register in translating children's literature is a considerable factor in handling diverse contexts and languages across the globe. According to American linguist and professor of German, Martin Joos (1967), there are five types of language registers: frozen, formal, consultative, casual, and intimate. In Sri Lanka, especially in the children's literature translation by Sybil Wettasinghe, the use of language register has been adjusted to preserve the cultural relevance and the adaptability of the Sri Lankan context for the target audience while maintaining the features of each register.

Henceforth, the main objective of conducting this study is to dispel the ambiguity and untranslatability when translating the language registers by using the selected translation procedures of Peter Newmark. These frameworks are especially suitable for children's literature because they answer complementary questions. Joos's model identifies the social relationship and degree of formality encoded in narration or dialogue, while Newmark's procedures show how a translator attempts to recreate that relationship across structurally and culturally different languages and the frameworks connect the function of a register used to preserve, simplify, or culturally adapt it. This is important for child readers, for whom dense syntax, unexplained cultural references, or an unsuitable level of formality may obstruct comprehension and emotional engagement.

Research on Sinhala-English literary translation has shown that register can create problems of equivalence and that translators sometimes employ omission, paraphrase, or other adjustments when source language semantic meanings do not transfer directly (3). International scholarship likewise describes children's translation as a field in which target-reader accessibility frequently competes with source-text fidelity (4-6). Studies in Turkish and other multilingual contexts show that culturally specific items are often handled through a negotiated combination of domestication and foreignisation rather than through one strategy alone (7). Readability research further indicates that syntactic choices shape the accessibility and ideological effect of children's texts (8).

Sybil Wettasinghe's stories offer a productive Sri Lankan case because dialogue, kinship terms, honorifics, humor, and oral-storytelling rhythms carry both interpersonal and cultural meaning. The present study therefore examines *Kuḍa Horā* and *Mæṭi Gedara Ļamayi*, together with their English versions *The Umbrella Thief* and *Crystal and Clay*. The objectives are to identify the frequency of Joos's register categories in selected narration and dialogue, identify the Newmark procedures illustrated by representative from source and target syntaxes, and critically interpret how register choices affect readability, cultural adaptation, and preservation of narrative voice.

Methods

This qualitative study examines the use of language register in translating children’s literature in the case of Sybil Wettasinghe’s selected translations, “Kuḍa horā” and “Mæṭi gedara ļamayi” with their translations, “The Umbrella Thief and " The Crystal Clay " by the same author. The selection of these works embodied variations in language, with special reference to language register. The application of Martin Joos’s register to the translations of the respective author has been conducted through the content analysis method. Martin Joos (1976) concept of language registers, including the types and selected translation strategies by Peter Newmark, is examined. The previously conducted studies and lecture notes were collected as the secondary data. The analysis of the collected data examined the use of selected translation strategies to observe how far the translator succeeded in translating the particular registers. The frequency of using the language register concerning Peter Newmark's selected translation strategies has been studied and referred to.

Results

The following tables present findings from selected passages of Sybil Wettasinghe's The Umbrella Thief and Crystal Clay, examining how the implied language registers in the Sinhala source text are rendered in the English target text, and which translation procedures were applied in each instance.

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Translation Procedures Applied

Paraphrase is the most frequently applied translation procedure, employed in five of the eight representative examples and accounting for 62.5% of the procedures used across the sample. Expansion and reduction, transference, and synonymy each appear once. The distribution indicates a consistent preference for communicative and meaning-oriented procedures over formally equivalent or literal approaches.

Table 1. Language Register and Translation Procedure Employability

Language Register	***Source Language***	***Target Language***	***Translation Procedure***
Casual	කැලේ කුඩ එකතු කළ කුඩ හොරා නම් අපේ හොඳ මිතුරෙක්මෙහෙම සතුටක් ගමේ මිනිස්සුන්ට දෙන්න මට උදව් කළා kælē kuḍa ekatu kaḷa kuḍa horā nam apē hoňda miturek mehema satuṭak gamē minissunṭa denna maṭa udav kaḷā	What a good thing the umbrella thief has done by collecting so many umbrellas thought kirimama	Paraphrase
Casual	කොල ඉහලීම විහිළුවක් කියා කිරිමාමා හිතුවා kola ihalīma vihiḷuvak kiyā kirimāmā hituvā	He thought of the umbrella and longed to have one	Expansion and Reduction
Intimate	මම ගිහිං එන්නම් පැටියෝ mama gihiṅ ennam pæṭiyō	Bye my little Jenny	Paraphrase
Intimate	ජෙනී මගේ දුව jenī magē duva	Hello my dear little Jenny	Paraphrase
Casual	මේක ඇතුලෙන් ගිහින් ගෙදරකට යන්න පුළුවන් ඇති යමුද අපි බලන්න? mēka ætulen gihin gedarakaṭa yanna puḷuvan æti yamuda api balanna?	Could there be a dwelling place down there?	Paraphrase
Intimate	මගේ පොඩිත්තිට මාලිගාවකට යන්න බෑ අපි දුප්පත් මිනිස්සු පුතේ magē poḍittiṭa māligāvakaṭa yanna bæ api duppat minissu putē	We are poor people little one how can we think of visiting palaces	Synonymy
Casual	ලොකු හාමු මට ගෙදර යන්න ඕන loku hāmu maṭa gedara yanna ōna	Loku hamu..I want to go home	Transference

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Consultative	දෙන්නා එක්ක හොඳට ඉගෙනගෙන ලොකු අය උනාම බැරි නෑ මාලිගා තනාගන්න dennā ekka hoňdaṭa igenagena loku aya unāma bæri næ̆ māligā tanāganna	By studying well at school and rising high in life is the only way into a palace	Paraphrase

Distribution of Language Register

The findings reveal that across the 70 instances coded from both texts, the casual register is the most frequently occurring, accounting for 50% of the total data. The intimate register accounts for 37% of the instances, while the consultative register accounts for 13%. The frozen and formal registers are entirely absent from both texts.

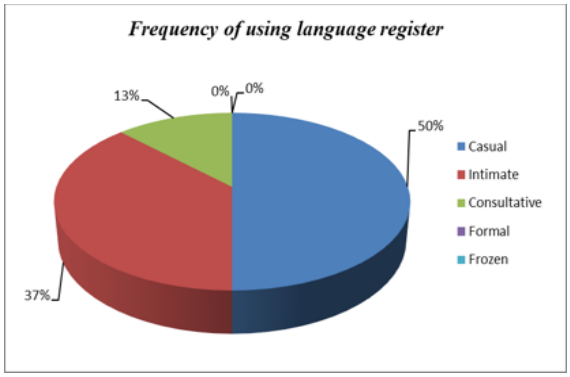

Figure 1-Frequency of using language register

Discussion

Distribution of Language Register in Children's Literature Translation

The predominance of the casual register (50%) across Wettasinghe's translated texts is not merely a statistical observation but reflects a principled translator's decision rooted in the cognitive and linguistic characteristics of the child reader. Children's literature operates within a communicative asymmetry in which the author or translator holds greater linguistic competence than the intended audience, necessitating deliberate simplification and tonal calibration of the target text (Tabbert, 2002). The casual register, characterised by informal syntactic structures, colloquial vocabulary, and a conversational narrative tone, is particularly effective in bridging this asymmetry, as it mirrors the register that child readers encounter in their daily interpersonal communication. By anchoring the translated text predominantly within the casual register, the translator ensures that young readers are not distanced from the narrative by unfamiliar linguistic formality, thereby sustaining their emotional engagement and comprehension throughout the reading.

This finding is consistent with Ubhayawardhana et al. (2022), who similarly found that casual and consultative registers were the most prevalent in the Sinhala-to-English translation of 'Madol Doova' with formal register elements in the source text systematically rendered through more accessible target-language equivalents. The convergence of these findings across two separate translation studies in the Sri Lankan context suggests a broader pattern in which translators of Sinhala children's and literary texts consistently prioritize register accessibility over register formality in the target language, a tendency that warrants further systematic investigation.

The Effectiveness of the Strategy Paraphrase as the Dominant Translation Procedure

The dominance of paraphrase as the primary translation procedure further reinforces the communicative approach observed in the register distribution. Rather than producing a semantically literal rendering of the Sinhala source text, paraphrase allows the translator to restructure meaning in ways that are syntactically natural and culturally intelligible within the English-language context. This is especially significant in the translation of children's literature, where convoluted or overly

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literal phrasing risks disrupting narrative flow and undermining the reading experience for a young audience. Newmark (1988) identified paraphrase as a procedure suited to contexts where semantic or communicative naturalness in the target language is the overriding concern, and the data here confirm that characterisation.

However, the reliance on paraphrase also carries an inherent risk of attenuating the author's distinctive narrative voice. Wettasinghe's original Sinhala texts are deeply embedded in Sri Lankan village life, and the idiomatic, culturally specific quality of her prose is a defining feature of her literary identity. Where paraphrase prioritises readability over fidelity to the source text's stylistic features, there is a potential for the translator's voice to gradually displace the author's, a tension characteristic of communicative translation more broadly (Newmark, 1988).

The Preservation of Register versus Cultural Adaptation

The data reveal several instances where the imperative to preserve source register comes into tension with the need for cultural adaptation. The intimate register passage translating " මම ගිහිං එන්නම් පැටියෝ" as "Bye, my little Jenny" is a clear example. While the intimate register is broadly maintained in the target text, the specific cultural and affective texture of the original Sinhala, where "පැටියෝ" carries a deeply familiar, nurturing connotation specific to the Sri Lankan family register, is domesticated through the use of the English colloquialism "Bye" and the introduction of a Western personal name. Similarly, the rendering of "දුව" (daughter) as "little one" in the synonymy example substitutes a culturally loaded kinship term with an affectionate but culturally neutral equivalent. These adaptations may enhance fluency and relatability for the English-speaking child reader, but they simultaneously reduce the cultural specificity of the source text.

The use of transference in retaining "Loku hamu" in the target text represents the opposite of translator's choice, one where cultural authenticity is preserved at the cost of immediate intelligibility. This procedural contrast within the same text illustrates the dynamic and context-dependent nature of the translator's decision-making process, and underscores the absence of a single dominant strategy for resolving the register-culture tension in children's literary translation.

The Comparison with Existing Research

The findings of this study are broadly consistent with research on children's literary translation in other multilingual contexts. Djamereng and Abdullah (2025) noted that register and language variation are shaped significantly by community and social context, reinforcing the centrality of register as a translatorial concern beyond the Sri Lankan setting. Tabbert (2002) similarly observed that translators for children systematically adapt texts to the norms and expectations of the target culture, a pattern confirmed by the domestication tendencies observed in this dataset. The consistency of these findings across cultural and linguistic contexts lends external validity to the present study's conclusions.

Conclusions

This study examined the usage of language register in the English translations of Sybil Wettasinghe's selected children's texts, applying Martin Joos's (1967) five-register framework alongside Peter Newmark's (1988) translation procedures as the analytical lens. The findings demonstrate that the casual register accounts for 50% of the total register usage across the selected passages, establishing it as the dominant mode of linguistic expression in the translated texts. This reflects a deliberate translation strategy to prioritise communicative accessibility for young readers, consistent with the cognitive and linguistic demands of the child audience.

Paraphrase emerged as the most frequently applied translation procedure (62.5%), enabling the translator to restructure source-language meaning in ways that are contextually natural and audience-appropriate in the target language. The near-total absence of frozen and formal registers from both texts confirms that the translator consistently oriented the target text toward the communicative needs of a young audience. Together, these findings affirm that the translator of Wettasinghe's selected works has been largely successful in fulfilling the dual function of children's literary translation: preserving the communicative essence of the source text while producing a target text that is linguistically appropriate, culturally accessible, and emotionally resonant.

However, this study is limited by its focus on only two texts by a single author-translator. The findings cannot be readily generalised to all Sinhala-English children's literary translations or to translators with different stylistic orientations. Future research should expand the corpus to include additional authors, different language pairs, and a wider range of translation procedures. Incorporating reader-response methodologies to assess how child audiences perceive and respond to register variation in translated texts would further enrich the field. At the level of practice, the findings have implications for

translator training programmes, particularly in equipping translators with tools for managing the register-culture tension in children's literary translation, and for children's publishers making decisions about the degree of domestication appropriate for target-culture readerships.

This study contributes to the limited body of scholarship on translation within Sri Lankan children's literature and encourages systematic exploration of language register across a broader range of texts, language pairs, and translation contexts.

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References

1. Joos M. The Five Clocks: A linguistic excursion into the five styles of English usage. New York: Harcourt, Brace & World; 1967. 108 p.
2. Newmark P. A TEXTBOOK OF TRANSLATION W *MRtt SHANGHAI FOREIGN LANGUAGE EDUCATION PRESS [Internet]. 1988. http://ilts.ir/Content/ilts.ir/Page/142/ContentImage/A%20Textbook%20of%20Translation%20by%20Peter%20Newmark%20(1).pdf
3. P. D. N. M. Ubhayawardhana, Imanshi Melanka Gunathilaka, Maduka Hansani. Transposition of Registers from Sinhalese into English: With Reference to „Madol Doova‟ by Martin Wickramasinghe and Its English Translation by Ashely Halpe. 2022 Jan 1;|Volume VI(Issue I):668–76. Available from: https://www.researchgate.net/publication/360187852_Transposition_of_Registers_from_Sinhalese_into_English_With_Reference_to_Madol_Doova_by_Martin_Wickramasinghe_and_Its_English_Translation_by_Ashely_Halpe
4. Tabbert R. Approaches to the translation of children's literature. Target International Journal of Translation Studies. 2002 Dec 31;14(2):303–51.
5. Oittinen R. Translating for Children. New York: Garland Publishing; 2000. 205 https://parhamti.com/wp-content/uploads/2023/07/Translating-for-Children.pdf
6. Djamereng J, Abdullah MAE. Register and Slang: Distinct Forms of Language Variation in Communities. IDEAS: Journal on English Language Teaching and Learning, Linguistics and Literature. 2025 Feb 24;12(2):3199–211.
7. HASTÜRKOĞLU, G. (2020). Translating culture in children's literature: A case study on the turkish translation of Letters from Father Christmas. *Dil Ve Dilbilimi Çalışmaları Dergisi*, *16*(2), 729–737. https://doi.org/10.17263/jlls.759280
8. Syntax, readability and ideology in Children's literature – meta. (2026). Érudit. https://id.erudit.org/iderudit/003879ar
9. Catford, J.C. (1965) A Linguistic Theory of Translation. Oxford University Press, London. - References - Scientific Research Publishing [Internet]. Scirp.org. 2022. https://www.scirp.org/reference/referencespapers?referenceid=3236203
10. Gao Y. Analysis of Eugene Nida's Translation Theory. International journal of education and humanities. 2023 Aug 16;10(1):203–6.
11. Para pean silta, Godefridus Bali Geroda, Widi Syahtia Pane. An Analysis Language Style Based on The Level of Formality According To Martin Joos Theory. Inquest Journal. 2023 Apr 30;1(02):163–74.

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Technology-Facilitated Gender-Based Violence in Sri Lanka: Evaluating the Adequacy of Existing Legal Frameworks

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Abstract

Background: Social media and digital technologies have become an integral part of modern society, but their widespread use has also contributed to the rise of Technology-Facilitated Gender-Based Violence (TFGBV) including online harassment, cyberstalking, cyberbullying, and image-based sexual abuse. Women and girls are disproportionately affected, experiencing significant psychological, social, and economic consequences. Despite the growing prevalence of TFGBV, concerns remain as to whether existing legal framework is adequately equipped to address these emerging forms of violence.

Objective/s: The main purpose of this research is to assess the adequacy of Sri Lanka's existing legal framework in addressing TFGBV, analyse the applicability and effectiveness of existing legal provisions, evaluating the adequacy of victim protection mechanisms and identifying gaps within the current legal framework and suggesting solutions.

Methods: This study adopts a doctrinal legal research methodology to evaluate the adequacy of Sri Lanka's legal framework in addressing TFGBV. The analysis is based on both primary and secondary sources. Primary sources include Sri Lankan legislation, case law, policy documents, and relevant international legal instruments, while secondary sources consist of academic literature, peer-reviewed journal articles, policy reports, and other scholarly publications.

Results: The findings reveal that although certain forms of TFGBV can be addressed through existing legal provisions in Sri Lanka, there is no dedicated legislation specifically designed to regulate and combat TFGBV. The current legal framework lacks comprehensive victim protection measures, effective enforcement mechanisms, and clear provisions to address emerging forms of digital abuse, highlighting the need for significant legal and institutional reforms.

Conclusion/s: Although the existing legal framework provides a foundation for addressing TFGBV in Sri Lanka, it remains inadequate to effectively respond to the evolving nature and increasing complexity of digital forms of abuse. The findings of this study indicate the need for comprehensive legal reforms, stronger enforcement mechanisms, enhanced victim protection measures, and a gender-sensitive approach to law and policy development. Addressing these gaps is essential to ensure effective prevention, accountability, and access to justice for victims of TFGBV.

Keywords: *Digital Abuse, Gender Equality, Online Harassment, Sri Lankan Legal Framework, Technology-Facilitated Gender-Based Violence*

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Introduction

Technological developments in information and communication systems have led to radical changes in the modern world. The internet, social media applications, mobile phones, laptops and other types of digital technologies have redefined how people interact with each other, acquire information, work and engage in socialization. Technology has created significant opportunities for economic prosperity, learning and social interaction. But apart from these positive impacts technology has given rise to various forms of exploitation and abuse.

In recent years TFGBV has become a crucial global concern. Technology-facilitated gender-based violence or TFGBV is "an act of violence perpetrated by one or more individuals that is committed, assisted, aggravated and amplified in part or fully by the use of information and communication technologies or digital media against a person on the basis of their gender". Such conduct may include various forms; cyberbullying, image based sexual abuse, cyberstalking, online harassment, online impersonation, defamation and the non-consensual distribution of intimate images. It is targeting women and girls through old and new technological devices such as phones, GPS tracking, laptops, drones and recording devices. TFGBV may lead to serious psychological, emotional, social and economic harm.

The comprehensive use of social media platforms has aggravated the prevalence of TFGBV. WhatsApp, TikTok, Facebook, Instagram and X have become widely used social media platforms for social engagement and communication. Despite this, these sites can also be platforms that allow users to become victims of harassment, humiliation, exploitation and threatening Behaviour. Since users can remain anonymous on these platforms, they will find it easier to harass others without fear of accountability.

TFGBV is distinguishable from traditional violence in various ways. The use of technology provides opportunities for the perpetrators to victimize their targets consistently irrespective of the location of both parties. Information can be disseminated within a short while to many people and stay on the internet for a long time. This can result in the infliction of serious harm that could persist beyond the harm inflicted through offline acts of violence. This could leave the victims experiencing fear, depression, anxiety and social isolation.

The problem of TFGBV is emerging as a pertinent topic in the Sri Lankan context, considering the increasing prevalence of digital technologies and social media sites. With the spread of internet connectivity, individuals have been able to participate in the digital world, but they have simultaneously become susceptible to online abuses. Victims include women, journalists, activists, politicians, students and other professionals. It can be argued that TFGBV demands appropriate measures from the law and policy side.

The law is essential in preventing people from violence and justice for those who have been victims of abuse. With the development of technologies, the need to update legal mechanisms emerges in order to deal with various new forms of crimes which did not exist at the time when many regulations were adopted. Therefore, it becomes important to consider whether current mechanisms are able to provide sufficient security against TFGBV.

Despite several laws enacted in Sri Lanka that can be used to address certain forms of cyber abuse, doubts still linger about whether the laws will sufficiently cater to TFGBV. The relevant sections in laws can be found in laws such as the Computer Crimes Act, No. 24 of 2007, the Online Safety Act, No. 9 of 2024, the Personal Data Protection Act, No 9 of 2022, The Penal Code Ordinance No, 11 of 1887 and Obscene Publications Ordinance, No.4 of 1927. Nevertheless none of these laws were intended to address all cases of TFGBV. Therefore, there might be legal loopholes, issues of effective implementation and even problems when protecting the victims hence lowering the law's ability to offer adequate protection. This leads to the issue of whether the legal framework in Sri Lanka is enough to protect women against TFGBV.

The main purpose of this research is to determine the adequacy of the existing legal regime in Sri Lanka to deal with TFGBV. Apart from that, it will try to explore what TFGBV entails, investigate how relevant the existing laws are, explore the

challenges involved in implementing and enforcing laws related to TFGBV, highlight any legal gaps in the existing legal regime and suggest improvements.

The present study is important since TFGBV is an emerging issue with far-reaching consequences on human rights, gender equality and access to justice. The results of this study will help to have a better insight into the legal issues arising out of TFGBV and contribute to policy makers, legislatures, legal professionals and academics in formulating appropriate legal responses to this problem. In addition, this study aims to make a contribution to current debates on the protection of women and girls from gender-based violence in cyberspace.

Moreover, this study becomes very significant at a time when there are ongoing advancements in digital technology that affect social relations. In light of the rise of various technologies including artificial intelligence, deepfakes and sophisticated means of communication that could be used to commit acts of online abuse, it is imperative that legal systems be flexible enough to accommodate these changes. Through analyzing the efficacy of current laws and pinpointing their shortcomings, this study aims to facilitate the formulation of a law to counter gender based abuse in technology-enabled settings.

Literature Review

Technology- Facilitated Gender-Based Violence (TFGBV) has been identified as a growing worldwide issue alongside the development of digital technologies and online communication platforms. Academic studies are increasingly highlighting the fact that despite the possibilities of communication provided by digital technology, these networks are also being used as arenas where TFGBV takes place. This chapter aims to provide a review of academic literature available on TFGBV, including the types of TFGBV and legal interventions adopted by different countries in response. Special focus is given to the appropriateness of legal frameworks in Sri Lanka.

Conceptualizing Technology-Facilitated Gender-Based Violence

The need for a clear definition is central to any legal or policy inquiry into TFGBV. UNFPA defines, TFGBV as acts of violence perpetrated by one or more individuals, committed, assisted, aggravated or amplified in part or fully through the use of information and communication technologies or digital media have been used entirely or partially to plan, execute, assist or amplify these acts against an individual because of their gender. This definition reflects the hybridity and dynamism of the TFGBV phenomenon as it encompasses both cyber-based and traditional forms of violence.

Powell and Henry (2017), among others present a more comprehensive conceptualization which classifies violence into three categories depending on whether it is technology-assisted or technology coerced. According to this approach, technology is seen as not merely providing a new medium for old- fashioned violence but as inherently changing its nature in the sense of allowing perpetration in an anonymous fashion on a much wider scale as well as making violent content persistent. Similarly, Citron (2014) considers online harassment a “civil rights violation” that mostly targets women in public spaces.

Henry and Powell (2018) also emphasize that TFGBV entails a range of Behaviours from image-based sexual assault, cyberstalking, non-consensual sharing of intimate images, doxxing, online impersonation and organized stalking. The significance of the concept of continuum is crucial when analyzing the legal aspects as it exposes the issue of addressing each offense separately in current laws rather than the systemic nature of the problem.

Gendered nature of TFGBV is well discussed in various academic works. According to Vitis and Gilmour (2017) such forms of gender-based violence exist because they represent tools for controlling women and preserving already established patriarchal power structures. In other words, they serve as ways to keep women in line in case they violate the traditional gender norms and become journalists, politicians, activists or even scholars. Hess (2014) mentions how the internet space replicates such gender hierarchies and makes women constantly victims of misogynistic attitudes. This can be seen as part of the broader issue discussed by Banet-Weiser and Miltner (2016)

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Forms and Manifestations of TFGBV

There are many types of TFGBV that have been documented in the literature, though some may overlap. One such type of TFGBV is the dissemination of non-consensual intimate images (NCII) which is also referred to as "revenge pornography". According to McGlynn and Rackley (2017) the phrase "revenge pornography" is problematic as it suggests that there is an excuse on part of the abuser and it underplays the immense mental

damage done to victims of the practice. The term "image-based sexual abuse as coined by McGlynn and Rackley is a much better descriptor.

Another type of Behaviour that has received much theoretical attention is cyberstalking. According to Bocig (2004) cyberstalking is described as a form of Behaviour characterized by threatening or harassing conduct using electronic means of communication that make the victim feel unsafe. Recent theories from Sheridan and Grant (2007) have pointed out how challenging it can be to legally charge someone with cyberstalking especially when it is a place where stalking laws demand physical proximity.

Online sexual harassment and sexual violence which includes unwanted sexual communications, threats of sexual violence and "pile-on" attacks, have also been subjects of considerable academic study. In her discussion of digital technologies' contribution to sustaining cultures of sexual harassment, Fileborn (2017) notes that " gendertrolling" or the use of threats of sexual violence as a way of shutting down women speaking out is a form of harassment with a particular gender context.

"Deepfakes" which are artificial media that are produces via artificial intelligence and superimpose one's image on non-consensual sexual material constitute an emerging and under-researched issue. Chesney and Citron (2019) point out the disparity in the effects of deepfakes and state that technology is largely used to create non-consensual pornography, resulting in significant damage to reputation, mental wellbeing and career opportunities. The authors suggest that there is an urgent need to legislate in light of the fast-changing field of AI-based abuse.

Psychological, Social and Economic Impacts on Victims

There is ample empirical evidence in the form of academic studies highlighting the multidimensional damage inflicted through TFGBV. According to the findings of the Pew Research Centre's Duggan (2017) survey on the subject matter an appreciable number of victims of online abuse of among women have reported high levels of emotional distress, self-censorship and withdrawal from online activities.

The mental impact including depression, anxiety, PTSD and suicidality is well established by numerous studies in clinical and sociological literature. For example, Bates (2017) performed qualitative study among victims of the NCII distribution and noted that victims invariably report their experiences to be similar to those of sexual assaults because of deep violations of the victim's dignity, bodily integrity and safety. Franks (2017) makes an analogous statement concerning the psychological impacts of image-based sexual abuse suggesting that such violations should be treated as primary rather than secondary to the physical one.

The social and economic implications of TFGBV are equally important. According to research conducted by the World Wide Web Foundation (2020), the repercussions for women facing cyberbullying can extend to their jobs, involving factors such as unemployment, reputational loss and disenfranchisement from economic opportunities provided through digital technology. This is even more pronounced among public women such as journalists, politicians and activists where TFGBV can be form of political censorship (UNESCO, 2021).

International Legal Frameworks and Comparative Legislative Responses

The International Human Rights Framework

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International law recognizes TFGBV through the framework of human rights law. CEDAW constitutes the main body of normative law in this regard. In particular, General Recommendation No. 35 of the convention explicitly addresses technology-facilitated violence against women as a form of gender based discrimination, calling on states to implement comprehensive measures to prevent it (UN Committee on CEDAW, 2017). Likewise, the Beijing platform for action and its reviews have incorporated the issue of digital violence into the gender equality agenda. UN Special Rapporteur on violence against women has on several occasions pointed out the deficiencies of national laws in dealing with TFGBV and advocated for the adoption of specialized laws that would criminalize such forms of gender-based violence (Simonovic, 2018). While regional instruments such as the Istanbul Convention adopted by the Council of Europe, they have been interpreted as covering technology facilitated forms of gender-based violence by some researches and human rights organizations (Thiara and Gill, 2012).

National Legislative Models

Comparative study of national legal responses towards TFGBV highlights different kinds of legislative efforts. For instance, the United Kingdom adopted Voyeurism (Offences) Act 2019, followed by the Online Safety Act 2023 which can be called one of the most thorough legislative instruments for addressing online harm worldwide. Under the terms of the Online Safety Act, online service providers are obligated to take considerable actions regarding prevention and elimination of harmful content, including TFGBV (UK Parliament, 2023). It should be noted that this act was welcomed by experts like Laidlaw (2023) for its ambitious regulation.

In this case, Australia has played an important role in the legislation process. The Enhancement of Online Safety Act 2015 and the Criminal Code Amendment (Sharing of Abusive Material) Act 2021 demonstrate a dual legislative and criminal approach in this regard. The powers of the eSafety Commissioner- a specialized regulator for this purpose- include the ability to force the removal of image-based sexual abuse material from online platforms and impose civil penalty orders on those not complying (Suzor et al., 2019). This approach has been assessed positively by such authors as Powell, Flynn and Hindes (2022).

The Anti-Photo and Video Voyeurism Act and the Safe Spaces Act were introduced in the Philippines in 2009 and 2019 respectively; both Acts are designed to prevent online sexual harassment in social spaces including social media. In Malaysia, there have been prosecutions in the case of cyber harassment under the Communication and Multimedia Act 1988 and the Penal Code; however, there have been concerns that the same laws have been applied in such a manner that would tend to make the victims of harassment suffer rather than the perpetrators (Fatimah,2020). The Information Technology Act of 2000, amended in 2008, criminalizes some forms of cyber harassment in India however, there have been implementation deficiencies of the law Kapur, (2019).

Although international scholarship on TFGBV has expanded, limited legal research has specifically examined the adequacy of Sri Lanka's legal framework in addressing TFGBV. This study contributes by identifying legal gaps in the existing framework and proposing reforms informed by international best practices.

Method

A doctrinal legal research method forms of main method of research in this project alongside comparative legal research. The doctrinal research method is defined as a study of "Black-letter law", the study of legal rules and principles and their interrelation in the specific body of law (Hutchinson and Duncan, 2012). In terms of the present research, this methodology is highly suitable since the question whether the existing laws of Sri Lanka provide enough measures against technology facilitated gender-based violence cannot be answered without a close examination of the statutes and judgements. In addition, doctrinal research will not be used separately from other methods. It will be used in combination with comparative legal research. Selected foreign jurisdictions will be analysed in order to find out which legislative solutions and judicial practice can serve as examples for the reform in Sri Lanka.

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Sources of Data Primary Legal sources

The principal sources of data for this research are primary legal materials including,

Statutes: The Computer Crimes Act No. 24 of 2007; The Online Safety Act No. 9 of 2004; The Personal Data Protection Act No. 9 of 2022; The Penal Code Ordinance No. 11 of 1887 (as amended) ; and The Obscene Publications Ordinance No.4 of 1927 (as amended).

Case law: Judicial decisions both reported and unreported made by courts in Sri Lanka which deal with the issues relating to cyber harassment, online abuse, defamation, obscenity and other similar topics to show how the statue was implemented in actual practice.

Subsidiary legislation and regulations: Gazette notifications, regulations and directives issued under the above statutes, including those establishing or empowering the Online Safety Commission

International and regional instruments: The Convention on the Elimination of All forms of Discrimination against Women (CEDAW) and General Recommendation No. 35; United Nations reports and resolutions; and instruments such as the Council of Europe's Istanbul Convention referenced for normative guidance.

Secondary Sources

Secondary sources are used to contextualize and critically interrogate the primary legal materials. These include,

Academic Publications and peer-reviewed journal articles in the fields of law, gender based studies, criminology and information technology.

Books and edited collections addressing technology-facilitated violence, online harassment and digital rights.

Policy papers, position statements and submissions made by civil society organizations and the Bar Association of Sri Lanka during the legislative process for the Online Safety Act.

Credible news media coverage and commentary, used cautiously and primarily to illustrate real- world instances of TFGBV and the operation (or non-operation) of legal remedies.

Reports published by government bodies including the Telecommunication Regulatory Commission of Sri Lanka (TRCSL) and by non-governmental international organizations such as Women and Medical Collective, the International Commission of Jurists (ICJ) Sri Lanka, UNESCO and the UNFPA.

Comparative Analysis

In order to discover reform possibilities that may be adopted in Sri Lanka, a comparative study is conducted on certain foreign jurisdictions. The foreign jurisdictions were chosen on the grounds of how mature and innovative their laws are in terms of their response of TFGBV as well as their applicability to common law jurisdictions similar to Sri Lankan law. These jurisdictions include the UK (Online Safety Act 2023 and Voyeurism (Offences) Act 2019), Australia (Enhancing Online Safety Act 2015/ 2021) and the eSafety Commissioner mode, the Philippines (Safe spaces Act 2019 and Anti Photo and Video Voyeurism Act 2009), Malaysia and India (Information Technology Act 2000). The comparative methodology adopted uses the functional approach where the emphasis is not on surface-level similarities of legal texts but rather on how the legal system of each country resolves the same socio-economic problem in its own way and that is how technology-enabled gender-based violence is prevented, criminalized and dealt with (Zweiger and Kotz,1998). The use of Functional comparison allows for the recognition of regulatory weaknesses of Sri Lankan laws and development of suitable recommendations, keeping in mind differences in legal culture and constitutional background between Sri Lanka and other countries.

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Methods of Legal Analysis

The study unfolds itself in four parts. Firstly, this study identifies the Behaviour constituting TFGBV from the literature review, and then the conduct mapped against existing laws of Sri Lanka to see what types of TFGBV are legally addressable under the present legal structure. Secondly, the study critically examines the effectiveness of the legal provisions in question, by examining various aspects such as definitions used by the law, scope of criminal and civil liability and the powers conferred upon regulatory and enforcement authorities. Thirdly, this study reviews the implementation and enforcement of these laws by relying on the secondary literature and reports of the court decisions and institutional reports to examine how the law is implemented in practice rather than just on paper. Fourthly, based on the comparative analysis, specific legislative or institutional reform is proposed for Sri Lankan context. In all these analysis, this study follows an evaluative framework based on the principles of international human rights laws- in particular, CEDAW General Recommendations No.35, which gives criteria to evaluate the adequacy of the domestic law regarding TFGBV.

Limitations

This research is based only on secondary sources without any primary data collected via interviews with victims, law enforcement personnel or policymakers. The study also does not include empirical perspectives from legal practitioners or judges which could provide valuable insights into the practical effectiveness of the existing legal framework. So this analysis depends on the correctness of the reported data. As the Online Safety Act is currently reviewed by Parliament, Some of the results presented here are based on legislation that is not finalized yet. The materials used for research mostly come from English Literature possibly missing some grassroots or vernacular-language data on TFGBV.

Results

Absence of a Statutory Definition of TFGBV

In each of five laws under review, there was no definition of the concept of “TFGBV” nor was this term mentioned or any other comprehensive term for it used. The laws contain provisions related to different aspects of TFGBV Behaviour; however there is no single definition of TFGBV or similar to those in Australia and UK or formulated by such international organizations as UNFPA. It could be stated that his approach shows TFGBV as a set of separate technical or public order issues rather than as a single gender-related phenomenon.

Fragmented and Overlapping Jurisdiction

Responsibility for tackling various dimensions of TFGBV is distributed among a number of agencies namely Sri Lanka Police (Computer Crime Investigation Division), Online Safety Commission which was recently set up and Data Protection Authority but the lack of coordination among them through proper statutory channels emerged from the analysis. The fragmented nature of these institution was seen to make it difficult for the victim to choose the proper forum to file a complaint.

Inadequate Coverage of Image-Based Sexual Abuse

None of the instruments reviewed had a distinct offence of the non-consensual sharing of intimate images based on consent (as opposed to obscenity unauthorized access to computer material and breach of confidentiality of personal information).This is a notable omission compared to other jurisdictions like the UK and Australia where image-based sexual assault has been recognized as a distinct statutory offence on the basis of lack of consent.

Limited Provision for Cyberstalking and Persistent Harassment

The study did not find any specific clause in the Sri Lankan laws deal with the problem of cyberstalking which is defined as the repeated acts that when accumulated together create an intimidating situation cause fear. Criminal intimidation and

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harassment laws need evidence of one threatening act in order to prove the crime. This requirement does not suit the nature of cyberstalking as described in the literature review.

Weak Victim Centreed Remedies and Civil Redress

A comparative study indicated that countries like Australia and UK had put in place separate administrative and civil laws such as quick removal of offensive content, civil penalty orders for the platforms and compensation measures for the victims which work separately and faster than criminal charges. On the other hand it was observed that the process of dealing with hate speech in Sri Lanka was highly dependent on the criminal law whereby content removal was done by the Commission with no separate civil provision for the victims.

Enforcement and Institutional Capacity Gaps

Analysis of some of the secondary sources examined such as those published by the Women and Media Collective (2021) and ICJ Sri Lanka (2022) reveals that implementation of the current applicable provisions is restricted by a lack of technical expertise amongst the investigative officials, weak digital forensic capacity, and inconsistent application of the laws by the police and prosecution departments. This was observed to have been further exacerbated by the lack of any specialized prosecutorial guidelines for TFGBV unlike other countries like the UK which have such guidelines.

Jurisdictional Limitations Over Transnational Platforms

None of the instruments reviewed have any effective means to ensure cooperation of the social media platforms residing abroad in relation to removal of the content, preserving the data and identifying the perpetrators.

Although the Online Safety Act provides the Commission with the power of directives in respect of online content, the effectiveness of such powers when it comes to platforms not having a physical presence in Sri Lanka is questionable and not analysed through any clear statute on mutual assistance or platform liability.

Discussion

The findings of this research demonstrate that despite a number of laws that can be used for dealing with TFGBV in Sri Lanka, the current legal system does not provide sufficient mechanisms for addressing this problem effectively. The Computer Crimes Act No.24 of 2007, The Online Safety Act No.9 of 2004, The Penal Code and The Personal Data Protection Act No.9 of 2022 are capable of providing some forms of protection. Nevertheless, none of these laws includes the definition of TFGBV. The future definition of TFGBV should in line with internationally recognized human rights principles, include technology-facilitated gender abuse, emphasize the absence of consent and cover key forms such as cyberstalking, image based sexual abuse and online harassment. These results confirm the previous research that has shown that many legal systems fail to address adequately the emerging forms of digital abuse. In particular, research has pointed out that online harassment, cyberstalking and other forms of technology-enabled abuse often lie beyond the scope of legal provisions. In the same manner, the study revealed that the legal framework of Sri Lanka has been constructed prior to the emergence of many of the current types of online abuse.

The further comparative analysis carried out in this research shows that there are several legislative approaches adopted in the United Kingdom, Australia, the Philippines, Malaysia and India which can serve as useful lessons for legal reforms in Sri Lanka. Nevertheless, these approaches cannot be implemented in full and only such legislative provisions that are consistent with the Sri Lankan constitutional system and institutional capabilities should be taken into account. In addition, legal reforms should take account of Sri Lanka's socio-cultural context, public awareness and institutional capacity to ensure their effective implementation. For instance, the introduction of such crimes as cyberstalking and the non-consensual distribution of intimate images, as recognized in the United Kingdom and Australia would address important gaps in the

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Sri Lankan legal framework because these forms of abuse are not expressly criminalized under existing legislation. Similarly, strengthening victim protection and reporting procedures as practiced in the Philippines as well as improving cyber-crime investigation techniques used in Malaysia and India could be incorporated within Sri Lanka's existing criminal justice system and institutional framework without requiring fundamental legal reforms. Another aspect uncovered by the results is that the issue of enforcement makes legal protection insufficient. While there might be cases which could be considered as punishable under existing legislation, enforcing authorities still encounter problems in tracing perpetrators, obtaining digital evidence and prosecuting crimes performed anonymously or across the border. It is a problem highlighted in international literature on technology-based offenses.

A significant issue that has come to light through research is the increasing danger posed by technology such as artificial intelligence and deepfakes. Such technologies have opened up new ways for TFGBV in the form of AI-generated intimate imagery, manipulation of videos, identity theft and sexual abuse of images which result in psychological, reputational and emotional trauma for victims. Currently, there are no laws in the Sri Lankan legal system which deal specifically with the issues of AI-generated abuse of deepfake contents. While existing laws may offer some protection in some cases, it is unclear whether they are adequate to address the evolving nature of such digital violence. Although technology-neutral laws provide some flexibility, specific legal provisions addressing

AI-generated abuse and deep-fakes should be considered to ensure effective protection. Thus, the introduction of new legislative provisions that will take into consideration the problem of AI-generated abuse as well as allow flexibility in the context of emerging technologies needs to be considered. Without proper legal protection, TFGBV victims may become the target of continuous abuse and be unwilling to report such crimes. In this context, enhancing Sri Lanka's approach towards TFGBV should entail both legislative changes as well as the implementation of practical strategies such as increased funding for digital forensic resources, specialized police training, stronger institutional coordination, enhanced cross-border cooperation with foreign authorities and online platforms, victim-centric reporting tools, awareness campaigns, legal aid services, counselling support, digital evidence preservation procedures, digital literacy programmes and educational initiatives. The implementation of legislative measures adopted from other jurisdictions should be carefully tailored to suit Sri Lanka's legal and institutional context, thereby enhancing the protection available to victims of TFGBV.

Conclusions

The study sought to determine whether the existing legal regime in Sri Lanka is sufficient enough to deal with TFGBV. The analysis of Computer Crimes Act, Online Safety Act, Personal Data Protection Act, Penal Code and Obscene Publications Ordinance reveals that the current legislation provides protection against TFGBV in an incidental way. This is because the aforementioned statutes were enacted for different purposes and were not specifically designed to address TFGBV. Moreover, there is no act that defines TFGBV or makes consent the cornerstone of TFGBV crimes. The lack of institutional capacity exacerbates these challenges such as lack of technical capability and absence of provisions for emerging threats such as deepfakes. Considering these gaps, there are several reforms that could be implemented. A legal definition of TFGBV should be introduced because at present there is no law that recognizes TFGBV as a unified concept. Alongside this, an independent crime related to the non-consensual distribution of intimate images should be defined, where lack of consent would be a distinguishing feature, instead of using the out of date obscenity test. Cyberstalking should be criminalized as continuous Behaviour, while the current legislation only recognizes a threatening act.

Furthermore, the Online Safety Act must be modified to ensure that gender-based online harms are considered as such through victim-focused processes, and not as standard prohibited content. To prevent delays that force victims to endure prolonged prosecution, quick civil redress must be provided in tandem with criminal proceedings. This requires improved coordination to be established between the Police, the Online Safety Commission, and the Data Protection Authority. Finally, implementing specialized training programs for law enforcement and prosecution personnel related to handling digital evidence and victim sensitivity in order to enhance enforcement efforts. The underlying legislation must be technology

neutral and applicable to AI-generated material and deepfakes; while effective measures should be taken to gain the cooperation of overseas social media platforms since a large percentage of TFGBV incidents are cross-border. Future research should incorporate empirical studies involving victims, legal practitioners, police officers, judges and policy makers to evaluate the practical implementation of existing laws and identify barriers to effective enforcement.

References

[1] UN Committee on CEDAW. General recommendation No.35 on gender-based violence against women, updating general recommendation No.19.CEDAW/GC/35.Geneva: United Nations; 2017.

[2] Powell A, Henry N. Sexual Violence in a Digital Age. New York: Palgrave Macmillan; 2017.

[3] Citron DK. Hate Crimes in Cyberspace. Cambridge (MA): Harvard University Press; 2014.

[4] Henry N, Powell A. Technology-facilitated sexual violence: A conceptual review of image-based sexual abuse and its legal features. International Journal for Crime, Justice and Social Democracy.2018; 7(1):61-77.

[5] Vitis L, Gilmour F. Dick pics, sexting and domestic violence: Negotiating gender norms and power structures in digital spaces. Feminist Media Studies. 2017; 17(4):687-702.

[6] Hess A. Why women aren't welcome on the internet. Pacific Standard. 2014; 7(1):36-45.

[7] Banet-Weiser S, Miltner KM. #MasculinitySoFragile: Culture, misogyny, and digital media. Feminist Media Studies. 2016; 16(1):171-174.

[8] McGlynn C, Rackley E. Image-based sexual abuse. Oxford Journal of Legal Studies. 2017; 37(3):534-561.

[9] Bocij P. Cyberstalking: Harassment in the Internet Age and How to Protect Your Family. Westport (CT): Praeger; 2004.

[10] Sheridan LP, Grant T. Is cyberstalking different? A comparison of offline and online stalking. Journal of Interpersonal Violence. 2007; 22(6):679-697.

[11] Fileborn B. Gendertrolling and the domestic terror of online sexual harassment. In: Cyber-Flashing and Digital Abuse. London: Palgrave Macmillan; 2017. p. 45-63.

[12] Chesney B, Citron D. Deepfakes and the new disinformation wave. Foreign Affairs. 2019; 98:147.

[13] Duggan M. Online Harassment 2017. Washington (DC): Pew Research Centre; 2017.

[14] Bates S. Revenge pornography and mental health: A qualitative analysis of the psychological impacts of non-consensual intimate image sharing. Feminist Criminology. 2017; 12(1):22-42.

[15] Franks MA. The law of the body: Virtual violations and primary harms. Michigan Law Review. 2017; 116(2):233-25.

[16] World Wide Web Foundation. Free to speak? Online harassment against women and girls on social media. Washington (DC): World Wide Web Foundation; 2020.

[17] UNESCO. The Chilling: Global trends in online violence against women journalists. Paris: United Nations Educational, Scientific and Cultural Organization; 2021.

[18] Simonovic D. Report of the Special Rapporteur on violence against women, its causes and consequences on online violence against women and girls from a human rights perspective. Human Rights Council (A/HRC/38/47). Geneva: United Nations; 2018.

[19] Thiara RK, Aujla W. Violence Against Women and Ethnicity: Common Challenges, International Perspectives. London: Jessica Kingsley Publishers; 2012.

[20] UK Parliament. Online Safety Act 2023. London: The Stationery Office; 2023.

[21] Laidlaw E. An ambitious regulation: Reviewing the UK Online Safety Act 2023. Communications Law. 2023; 28(4):189-202.

[22] Suzor N, Dragona J, Myers West S. Platform governance and the regulatory powers of the eSafety Commissioner. Media and Communication. 2019; 7(2):89-101.

[23] Powell A, Flynn A, Hindes J. Evaluating the administrative model: The eSafety Commissioner as a regulatory response to online harm. Law & Policy. 2022; 44(2):112-131.

[24] Fatimah S. Regulating cyber harassment in Malaysia: A double-edged sword for victims. Asian Journal of Criminology. 2020; 15(3):211-229.

[25] Kapur R. Implementation deficiencies of the Information Technology Act in India: The gendered impact. Journal of Indian Law and Society. 2019; 10(2):45-67.

[26] Hutchinson T, Duncan N. Defining what we do: Doctrinal legal research. Deakin Law Review. 2012; 17(1):83-119.

[27] Sri Lanka. Computer Crimes Act, No. 24 of 2007.

[28] Sri Lanka. Online Safety Act, No. 9 of 2004.

[29] Sri Lanka. Personal Data Protection Act, No. 9 of 2022.

[30] Sri Lanka. The Penal Code Ordinance, No. 11 of 1887.

[31] Sri Lanka. Obscene Publications Ordinance, No. 4 of 1927.

[32] Zweigert K, Kötz H. An Introduction to Comparative Law. 3rd ed. Oxford: Oxford University Press; 1998.

[33] Women and Media Collective. Mapping *Online* Violence Against Women in Sri Lanka: Institutional and Enforcement Gaps. Colombo: Women and Media Collective; 2021.

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EP 04

Mindful learning practices and student engagement in English language education

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Abstract

Background: Conventional approaches to English language pedagogy often emphasize repetive rote memorisation and high stakes assessments, which can frequently lead to learner burnout and emotional detachment. Mindful learning offers a transformative pedagogical alternative, focusing on present moment awareness, intentional focus, and cognitive flexibility within the classroom setting to improve the overall educational experiences.

Objective/s: This research aimed to investigate the specific impact of integrating mindfulness based practices on the multi-dimensional engagement levels cognitive, emotional, and behavioural of intermediate level students within an English language learning environment. The study sought to determine if these practices could effectively mitigate classroom anxiety and foster a more active learning posture.

Methods: The study employed a structured pre-test/post-test intervention conducted over a six-week period without a separate control group, involving a sample batch of intermediate level English learners ($N = 30$). Various mindfulness techniques, including focused breathing exercises and active listening tasks, were seamlessly incorporated into the standard curriculum. Data collection involved a mixed-method approach, utilizing systematic classroom observations and detailed participant feedback surveys to measure shifts in student attentiveness and participation levels.

Results: The findings demonstrated a statistically significant improvement in student focus and a marked reduction in performance-related speaking anxiety ($p < 0.05$). Participants displayed a greater willingness to participate in complex linguistic discussions and showed enhanced retention of grammatical structures. Qualitative feedback indicated that students felt more “mentally present” and motivated during lessons that included mindful transitions.

Conclusion/s: The findings suggest that embedding brief mindfulness exercises into routine lesson transitions is a highly effective, practical pedagogical tool that can easily be incorporated into standard teacher training programs. While it successfully boosts immediate student engagement and supports second-language acquisition, verifying long-term retention remains a limitation for future study.

Keywords: *Academic engagement, English pedagogy, Language acquisition, mindfulness, student motivation.*

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EP 05

Evaluating Sri Lanka's Cybercrime Laws: Addressing Online Financial Fraud and Protecting Digital Rights

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Background:

The rapid growth of digital technology, online banking systems, and social media platforms have transformed communication, commerce, and financial transactions in Sri Lanka. However, increased digital reliance has also contributed to cybercrime, particularly online financial fraud, hacking, identity theft, and social media scams. Emerging threats, including WhatsApp investment scams, fraudulent banking schemes, cryptocurrency fraud and online loan scams demonstrate the increasing sophistication of cybercrime affecting Sri Lankan users.

Objectives:

This study evaluates the effectiveness of Sri Lanka's existing legal and institutional framework in addressing online financial fraud and examines the protection of digital rights and privacy. It also identifies weaknesses within the current framework and explores reforms to strengthen cybersecurity and financial fraud prevention.

Methods:

The study adopts a doctrinal and comparative legal research methodology. It analyses the Computer Crimes Act No. 24 of 2007, the Electronic Transactions Act No. 19 of 2006, the Personal Data Protection Act No. 9 of 2022, relevant banking regulations, and the role of the Sri Lanka Computer Emergency Readiness Team (Sri Lanka CERT). Comparative analysis of selected legal and institutional mechanisms in Singapore and the United Kingdom identifies practices that may be adapted to Sri Lanka.

Results:

The findings indicate that Sri Lanka has established an important legislative foundation for combating cybercrime; however, effectiveness is limited by weaknesses in enforcement, technological expertise, institutional coordination, and public awareness. Comparative findings suggest that stronger public-private collaboration and coordinated mechanisms for reporting and responding to cyber incidents could improve the response to online financial fraud.

Conclusions:

Strengthening enforcement capacity and institutional coordination should be the most urgent reform priority. This should be supported by enhanced technological expertise, improved information-sharing between financial institutions and authorities, stronger cybersecurity practices, and increased public awareness. A coordinated and technologically responsive framework is essential to combat online financial fraud while protecting digital rights and privacy.

Keywords: *Cybercrime, Digital Rights, Online Financial Fraud, Privacy, Sri Lanka*

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EP 06

Digital Burnout Among Higher Education Lecturers in Technology-Driven Learning Environments

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Background:

Teaching, learning, and academic administration have all changed as a result of the quick adoption of digital technology in higher education. Although technology increases accessibility and flexibility, lecturers who rely too much on digital tools may experience digital fatigue. Emotional tiredness, decreased productivity, and stress brought on by extended exposure to technology-related demands are the hallmarks of digital burnout.

Objectives:

The purpose of this study is to determine the main organizational, technological, and individual elements that contribute to burnout in technology-driven learning settings as well as the frequency of digital burnout among lecturers in higher education.

Methods:

Higher education instructors from universities and other higher education institutions were given a structured online questionnaire as part of a quantitative research strategy. Information on workload, digital proficiency, work-life balance, technology usage patterns, and burnout symptoms was gathered. To find important correlations between variables, descriptive and inferential statistical studies were performed.

Results:

According to preliminary research, higher education lecturers in technology-driven learning environments have moderate to high levels of digital burnout due to increased online teaching workloads, ongoing demands for digital communication, technology-mediated administrative tasks, and weakened work-life boundary regulation. Furthermore, the findings show that burnout levels are strongly influenced by task management effectiveness, digital literacy proficiency, and perceived institutional support, with lower burnout symptoms being associated with greater organizational support.

Conclusions:

A new problem in higher education institutions going through digital transformation is digital fatigue. Organizational actions, such as workload optimization, professional development, and policies that support digital well-being, are necessary to address this problem. The results offer guidance to educational establishments looking to develop technology-enhanced learning environments that are both sustainable and encouraging.

Keywords: *Digital Burnout, Digital Well-being, Higher Education, Lecturers, Technology-Driven Learning.*

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EP 7

Sri Lankan Law and Cultural Perspectives on Assisted Suicide: A Comparative Analysis with UK and Indian Law

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Background: Assisted suicide remains a complex legal, ethical, and cultural issue, with different countries adopting approaches shaped by their legal traditions, religious beliefs, and societal values.

Objective/s: This study examines the legal and cultural perspectives on assisted suicide in Sri Lanka and compares them with the approaches adopted in the United Kingdom and India.

Methods: A qualitative comparative legal analysis was conducted using secondary sources, including legislation, judicial decisions, scholarly literature, and ethical perspectives. The study examined relevant legal frameworks, including the Sri Lankan Penal Code, the UK Suicide Act 1961, and Indian legal provisions and judicial developments concerning end-of-life decision-making.

Results: The findings indicate that Sri Lanka does not specifically regulate assisted suicide, and actions causing or facilitating death may be addressed under general homicide provisions. Buddhist principles of non-harm and the sanctity of life strongly influence cultural and moral perspectives. In the UK, assisting or encouraging suicide remains a criminal offence, although prosecutorial discretion reflects ongoing tensions between individual autonomy and the protection of vulnerable persons. In India, assisted suicide remains unlawful, while judicial recognition of the right to die with dignity and passive euthanasia demonstrates an evolving approach to end-of-life care. The comparison highlights the significant influence of culture, religion, autonomy, and compassion on legal responses.

Conclusion/s: The legal approaches of Sri Lanka, the UK, and India demonstrate that assisted suicide cannot be considered solely as a legal issue. Sri Lanka's approach is strongly influenced by Buddhist values, whereas the UK places greater emphasis on autonomy and India continues to balance traditional values with emerging concerns regarding dignity and compassionate end-of-life care. Future policy discussions should consider cultural values, ethical principles, individual rights, and the protection of vulnerable persons.

Keywords: *assisted suicide, comparative law, end-of-life care, law, Sri Lanka*

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EP 01

Dye Machine Cooling Water Reuse in the Fabric Dyeing and Printing Industry: A Case Study on Water Conservation Project in Sri Lanka

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Abstract

The fabric dyeing and printing industry is one of the largest consumers of freshwater in Sri Lanka, contributing significantly to industrial water pollution. Therefore, efficient water reuse practices are crucial for promoting sustainability and reducing environmental impact from these industries. In this case study, a significant volume of freshwater is utilized during key processes, including scouring, dyeing, printing, soaping, and finishing, which primarily use the water stored in the underground water sump in the facility. The analysis revealed that the dye machine cooling system could effectively implement water reuse. In this project, dye machine cooling water was reused. During the dye cycle, the water was used to cool the dye machines, and then a sample of used water was passed through a real-time monitoring system, which analysed pH, Total Dissolved Solids (TDS), Temperature, and Turbidity every 30 seconds. When all the parameters were within the specified limits, the water was directed back to the underground water sump for reuse; otherwise, it was diverted to the Effluent Treatment Plant (ETP). As a result of this initiative, about 6.43% of water was reused monthly, corresponding to an estimated annual saving of approximately 23,000 m^3. Furthermore, total wastewater generation was decreased by the same volume, thereby significantly lowering the environmental footprint of the facility and reducing costs associated with raw water consumption and wastewater treatment. Accordingly, the fabric dyeing and printing industry can successfully reuse dye machine cooling water, as this case study confirms.

Keywords: *Cooling Water, Dyeing, Reuse, Sump, Wastewater*

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Introduction

The demand for water resources is rising steadily, as they are indispensable to agricultural, industrial, and domestic sectors (1). Trends in water consumption in Sri Lanka indicate that there is an urgent need for the sustainable management of the country's water resources. In Sri Lanka, industrial activities account for approximately 6.42% of the total water usage (2). The textile and apparel industry is one of the major sectors in Sri Lanka, greatly contributing to industrial output; however, its traditional linear economy poses significant sustainability challenges due to high resource consumption and environmental pollution (3) (4). The textile industry accounts for a substantial share of water usage in its operations (3). A large amount of water is used in most manufacturing steps of the textile industry, with bleaching, dyeing, and finishing processes typically consuming more than half of the total water requirement. This industry generates a substantial volume of wastewater that must be treated before industrial discharge (5); (6). Producing 1 kg of textile requires approximately 100 L to 200 L of freshwater, although this value may vary depending on the dyeing process and the type of textile material (6). Therefore, efficient water management strategies and effective water treatment methods are needed to ensure sustainable water usage.

Good housekeeping practices, the use of automatic shut-off valves, flow control valves, low liquor ratio systems, and water reuse techniques are some of the effective methods to conserve water in the textile industry (7). The advanced treatment methods, such as ion exchange and membrane filtration, present economic challenges due to their high capital and maintenance costs (8). Among the identified Best Available Techniques (BAT), cooling water reuse was prioritized because of its high feasibility, low implementation complexity, and immediate potential for water savings.

Water reuse practices reduce the wastewater load to the treatment system by using the same water in more than one process. Water reuse can involve both process water and water recovered from auxiliary operations, such as bleach baths, final rinse water from dyeing (used for preparing new dye baths), washing processes, and cooling water from dyeing machines (9). Cooling water that remains uncontaminated by fabrics or process chemicals can be collected for direct reuse. This includes cooling water from condensers, water-cooled bearings, heat exchangers, cooling rolls, yarn dryers, pressure dyeing machines, and air compressors (6). Although cooling water reuse has been widely discussed in industries in other countries, documented case studies with quantified industrial-scale performance data are not available for Sri Lanka. The present study demonstrates a full-scale implementation of a real-time monitored cooling water reuse system integrated with automated water quality assessment. The aim of this study was to investigate the potential for water reuse in dye machine cooling systems within a fabric dyeing and printing company that heavily depends on water for its production processes.

Method

General Information and Production processes of the Company

The company is a fabric dyeing and printing facility located in, Sri Lanka, with a primary focus on producing dyed and printed fabrics. The estimated monthly production capacity is approximately 202,068 kg. Although the specific production procedure may vary depending on fabric type, required color, and customer specifications, a general process flow can be described as shown in Figure 1.

Raw materials, including greige fabric, greige yarn, and dyes/chemicals, are first received at the warehouse. Greige fabrics are directed to the greige preparation section, where greige fabrics are arranged for easy feeding into dyeing machines. This procedure ensures efficient material handling and uniform dye penetration during subsequent processing. Then greige fabrics are directed to the dyeing department.

The dyeing department consists of both fabric and yarn dyeing units. Fabrics and yarns are treated with specified dye classes and auxiliary chemicals according to process recipes. In fabric dyeing, the dyeing process primarily consists of three main stages: scouring, dyeing, and soaping. These stages, which collectively consume a significant volume of water, are carried out within dyeing machines. During these operations, the temperature of the dye bath should vary depending on the specific process requirements. When a reduction in the dye bath temperature is necessary, a cooling water system is employed to enhance the cooling rate and maintain the desired thermal conditions.

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Dyed fabrics are subsequently subjected to the finishing process to achieve the desired texture, appearance, and performance characteristics. During finishing, the tubular fabric is cut open by the slitter machine, which converts it into a flat form. The fabric is then transferred to the relax dryer, where it is dried under relaxed conditions to restore its natural width and softness. After drying, it is processed through the compactor to minimize shrinkage, enhance dimensional stability, and improve the overall fabric appearance and handle. Once the finishing process is complete, the fabrics are carefully inspected, and approved materials are stored in the finished goods warehouse. If the fabrics are intended for printing, they are transferred to the printing department, where printing is carried out according to the specified designs and color patterns. After printing, the fabrics are handed over to the finishing department for final finishing. Finally, the completed fabrics are inspected once again and stored in the finished goods warehouse.

The greige yarns are first subjected to soft winding to ensure uniformity and are then processed through yarn dyeing. Dyed yarns are sent to the knitting department, where they are used in both circular and flat knitting operations. In circular knitting, dyed yarns produce yarn-dyed fabrics, which are handed over to the dyeing department for washing and then directed to the finishing department, where the remaining steps proceed as mentioned above. Additionally, greige fabric can be knitted directly from greige yarns in circular knitting. In the flat knitting section, dyed yarns are used to produce specific products such as colored cuffs and other knitted components. After knitting, these items are handed over to the rib finishing section, where they undergo finishing processes to achieve the required appearance, texture, and quality. Once finishing is complete, the products are inspected, packed, and transferred to the finished goods warehouse.

There were also supporting utility systems, including chillers, boilers, the Effluent Treatment Plant (ETP), a softener room, and compressors.

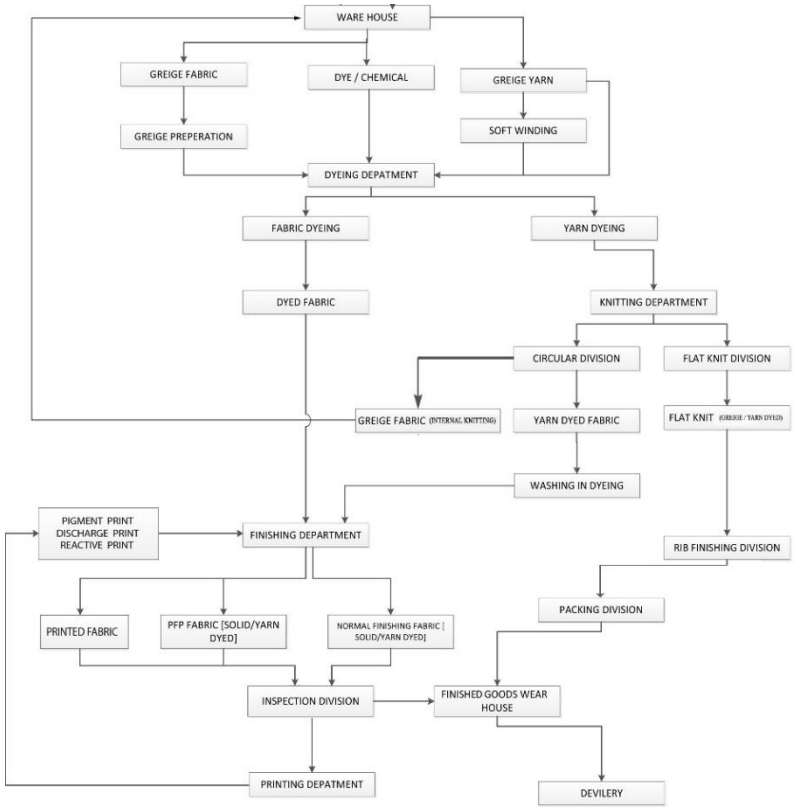

Figure 1: Total process flow chart of the facility

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Data Collection and Evaluation of Water Use

A walk-through audit was conducted with company officials to collect detailed information on the inputs and outputs of the main processes, after which the total process flow diagram was developed (10). It is essential to obtain data on the total water consumption across all installations within the facility. Accordingly, information regarding the quantities of fresh water used and wastewater generated during the year 2024 (from January to October) was gathered (11). For the purpose of data collection, information sources such as process-based record sheets and water bills were analysed. However, production in the textile industry fluctuates not only throughout the year but even within a single day due to seasonal trends and fashion demands. Consequently, it is challenging to standardize and correlate the emissions from various processes within the mill. The recommended approach is a "systematic analysis of the specific processes." Therefore, the most water-intensive processes were identified, and the impact of Best Available Techniques (BAT) on water consumption for these processes was evaluated (12). Then, the most suitable techniques were implemented. Among those implementations, the reuse of cooling water from the dyeing machine discussed in this case study.

The system boundary for this study includes the dye machine cooling circuit from water withdrawal from the underground sump, circulation through the cooling system, real-time quality monitoring, and subsequent diversion either for reuse in the sump or discharge to the Effluent Treatment Plant (ETP). The system does not include textile wet processing operations. The monitoring system measure pH, temperature, TDS, and turbidity at approximately 30-second intervals. Water quality thresholds for reuse were established based on operational requirements of the dyeing process. These thresholds were selected to ensure that reused water would not adversely affect process stability, equipment performance, or product quality. When any parameter exceeded the defined limits, water was automatically diverted to the Effluent Treatment Plant for treatment. Water consumption was measured using water meters, and the recorded data were reviewed monthly to identify anomalies or system interruptions.

Baseline conditions were defined based on operational practices prior to system implementation, during which all dye machine cooling water was discharged directly to the Effluent Treatment Plant without reuse. The previous water consumption and wastewater discharge records were used to characterize baseline performance. Post-implementation performance was evaluated using monitored data collected after a 15-day system stabilization period. Water reuse percentage was calculated by comparing measured reuse volumes against total water usage during the monitoring period.

This study has several assumptions and limitations. The monitoring period covered three months of operation following system stabilization and may not fully capture long-term seasonal variations in production or water demand. The analysis assumes stable sensor performance between calibration checks.

Results

Water use evaluation

The selected facility has a total production capacity of 202,068 kg per month. The monthly water consumption, wastewater generation, and total production were recorded and analysed over 2024 (Between January and October) (Table 1) to get an idea about the water consumption trend in the facility (13).

Table 1: Monthly water consumption and the production data of the facility in 2024 (January to October)

Month	Water consumption (m^3)	Wastewater discharged (m^3)	Total Weight of Production (kg)
January	34,343	30908.7	187,397
February	31,807	28626.3	161,600
March	39,274	35346.6	227,382
April	30,937	27843.3	184,899
May	41,306	37175.4	280,005

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June	37,960	34164.0	258,486
July	33,409	30068.1	251,762
August	32,276	29048.4	229,709
September	26,032	23428.8	148,034
October	26,133	23519.7	190,001

The monthly water consumption varied with the production quantity. Therefore, a systematic analysis of the specific processes was carried out, and wet processes were identified. The process flowchart of the facility is presented in Figure 1. Among the main operations, three are wet processes, including dyeing, printing, and finishing (14). In addition, supporting units such as the boiler house and compressors also contribute to water consumption, but in smaller amounts (13). Water was also used for cleaning, washing, and other domestic purposes.

It was observed that the cooling water from the dye machines was directly discharged into the ETP. Additionally, no submeters were installed to monitor water consumption for each process step individually. To minimize water consumption, it is essential to adopt more efficient water utilization methods. Therefore, Best Available Techniques (BAT) were suggested to be implemented in the facility (1).

Discussion

Sustainable practices to reduce the water consumption

Based on the overall findings and observations made during the site visit, several processes and practices requiring improvement were identified to reduce water consumption and minimize wastewater generation.

The following sustainable measures were recognized and proposed for implementation.

1. Reuse cooling water from dye machines (14)
2. Implementation of an ultrafiltration and reverse osmosis system to enable effluent recycling (15)
3. Reuse final rinse water from the dyeing process for use in dye bath preparation (16)
4. Reuse stenter cooling water (17)
5. Training and awareness programs for employees (16)
6. Rooftop rainwater harvesting system (18)

Among the sustainable measures listed above, items 1 and 5 were implemented at the end of the 2024 as the most suitable and feasible option following a detailed evaluation conducted. However, this study focuses on the reuse of dye machine cooling water.

Installation of cooling water reuse system

Raw water is supplied from the National Water Supply and subsequently treated in the softener room to achieve the required water quality standards for production purposes. The softened water is then directed to the underground water sump for storage. Process water requirements are fulfilled through the supply from this sump.

In the previous system, the dye machine cooling water, after serving its cooling function, was discharged directly to the Effluent Treatment Plant (ETP). Following the implementation of the improved system, the dye machine cooling water can now be reused, thereby enhancing water conservation and minimizing wastewater generation.

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The line diagram of the implemented dye cooling water reuse system is shown in Figure 3. The water required for the cooling of the dye machine is supplied from the underground water sump. After cooling the dyeing machines, a sample of the used cooling water is automatically analysed by a real-time monitoring system. The system continuously measures key quality parameters, including pH, Temperature, Total Dissolved Solids (TDS), and Turbidity. If all measured parameters fall within the predefined acceptable limits, an automated signal is transmitted to open valve 1, enabling the water to be redirected to the underground water sump for reuse in the process. Conversely, if any parameter exceeds the permissible limit, a signal is sent to open valve 2, directing the water to the ETP for treatment. The sample analysis unit performs monitoring at approximately 30-second intervals, ensuring real-time assessment and reliable control of the cooling water reuse process. The system is equipped with a water meter to measure the amount of dye machine cooling water being reused.

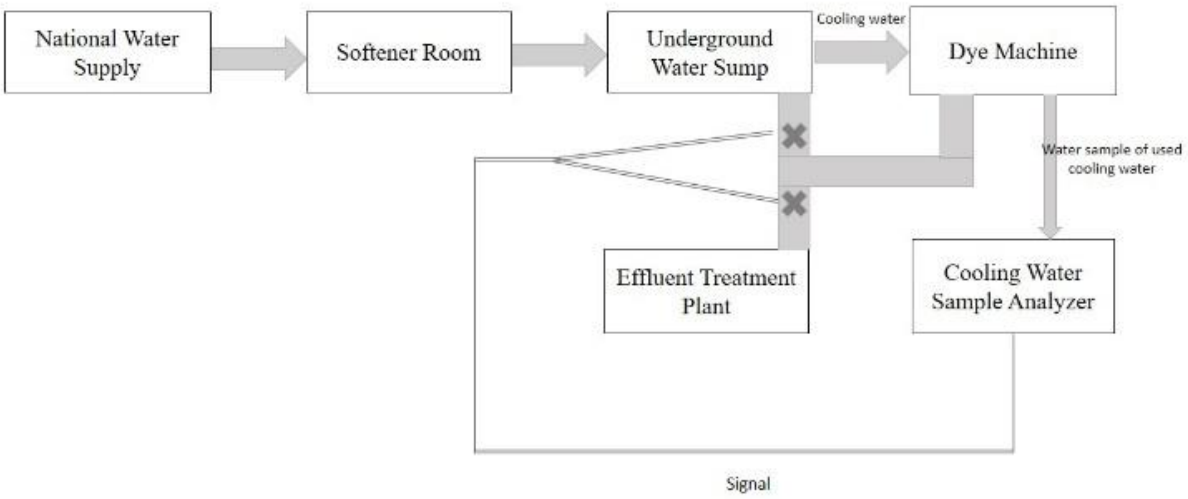

Figure 2: Dye machine cooling water reuse system

Analysis of the water saving from cooling water reuse system

After a 15-day stabilization period, data were analysed over three months following the implementation. Table 2 presents the total freshwater consumption, wastewater generation, and percentage of reused water over the three-month period.

Table 2: Total freshwater usage, wastewater generation, reused water and percentage of reused water

Month	**Total fresh water usage (m^3)**	**Wastewater (m^3)**	**Reused water (m^3)**	**Percentage of reused water %**
January	28560	25691	1921	6.96
February	35383	31844	1803	5.36
March	30573	27490	2059	6.97

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During this period, the proportion of recycled water varied between approximately 5.36% and 6.97%, with an average monthly reuse rate of 6.43%. Based on the analysed data, an estimated 23,000 m³ of water was conserved annually. These results indicate that a substantial fraction of the wastewater was reused through the reuse of dye machine cooling water. Before system implementation, all cooling water from the dye machines was discharged directly to the Effluent Treatment Plant (ETP) as wastewater. Following the adoption of the reuse system, water with a defined quality (pH, temperature, TDS, and turbidity) was redirected for reuse, leading to a notable reduction in both wastewater generation and freshwater consumption.

Earlier research has demonstrated that cooling water reuse can reduce freshwater consumption when the stream remains relatively uncontaminated and suitable for direct recirculation with minimal treatment. previous studies have also investigated cooling water reuse, including reuse in wet-cooled power plants (19) and the reuse of cooling water blowdown streams (1). However, reported reuse efficiencies vary widely depending on plant configuration, cooling demand, and monitoring strategies. The literature does not report specific analyses focusing solely on dye machine cooling water reuse in the textile industry. In comparison with studies that rely on periodic sampling or treatment-based recycling, the present system demonstrates the operational feasibility of continuous real-time monitoring combined with automated diversion control. This approach enables safe reuse under dynamic production conditions.

The proportion of reused water varied between monitoring periods, reflecting fluctuations in production schedules, cooling demand, and operating temperatures of dyeing processes. Variability may also result from changes in process chemistry, heat load, and equipment operation, which influence cooling water quality and reuse eligibility. Such operational variability is typical in textile manufacturing, where batch processing and product change overs frequently alter water and energy requirements.

Overall, the implementation of the reuse system enhanced water-use efficiency by decreasing dependence on freshwater sources and reducing the hydraulic load on the ETP, thereby contributing to more sustainable production operations.

Conclusions

This study demonstrated that reusing dye machine cooling water in a fabric dyeing and printing facility is a practical approach to industrial water conservation. The real-time monitoring system, which measured pH, temperature, total dissolved solids, and turbidity, ensured the quality of recycled water before reuse. The proportion of recycled water ranged between 5.36% and 6.97%, with an average monthly reuse rate of 6.43%. Data analysis indicated that approximately 23,000 m³ of water was saved annually, leading to reduced freshwater consumption and wastewater generation.

Before implementation, cooling water from dyeing machines was entirely discharged to the effluent treatment plant. The new system recovered this clean water, minimizing freshwater intake and reducing the hydraulic load on the ETP while also lowering production costs.

Overall, the findings highlight that simple and efficient water reuse systems can significantly enhance sustainability in textile manufacturing and serve as a model for similar facilities in Sri Lanka and other developing countries.

References

1. Alkaya E, Demirer GN. Water recycling and reuse in soft drink/beverage industry: A case study for sustainable industrial water management in Turkey. "Resources, Conserv Recycl. 2015;

2. Rajakaruna RMASD, Najim MM., Sewwandi BGN. Future of Water Consumption in Sri Lanka : A comparison with a water-scarce and a water-rich country. In: Open University Research Sessions. 2023.

3. Cate M. Optimization of Dyeing and Finishing Processes in Textile Industry for Reduced Environmental Impact. 2025;

4. Silva M De, Withanaarachchi A. Essential Factors for the Advancement of the Yarn Manufacturing Sector in Sri

Lanka : Implications of the Socio-Economic Environment. SLIIT Bus Rev. 2023;03(02):25–54.

5. Thombre N, Patil P, Yadav A, Patwardhan A. A short review on water management and reuse in textile industry – a sustainable approach. Discov Water. 2025;

6. Yin H, Qiu P, Qian Y, Kong Z, Zheng X, Tang Z, et al. Textile Wastewater Treatment for Water Reuse. Processes. 2019;7(34).

7. Shaikh MA. Water conservation in textile industry. Pakistan Text J. 2009;58(11):48–51.

8. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater treatment. Environ Chem Lett. 2019;17(1):145–55.

9. Alam F Bin, Hossain MA. Conservation of Water Resource in Textile and Apparel Industries. J Polym Text Eng. 2018;5(5):11–4.

10. Ozturk E, Koseoglu H, Karaboyacı M, Yigit NO, Yetis U, Kitis M. Minimization of Water and Chemical Use in a Cotton/Polyester Fabric Dyeing Textile Mill. J Clean Prod. 2016;

11. Roth J, Zerger B, De Geeter D, Gomez Benavides J, Roudier S. Best Available Techniques (BAT) Reference Document for the Textiles Industry. 2023.

12. Hoque S, Shahid I, Parvez AAP, Hossain J, Sheen SM. Knitted Denim Fabrics : Fabrication Process and Fibrous Influence on Several Properties of the Fabric. Journel Res. 2022;9(6):286–300.

13. Noor H, Shaikh IA. Implementation and evaluation of sustainable measures for water conservation in denim producing mills of Pakistan. Discov Sustain. 2025;6.

14. Haque S, Nahar N, Sayem S. Industrial Water Management and Sustainability : Development of SIWP Tool for Textile Industries of Bangladesh Industrial water management and sustainability : Development of SIWP tool for textile industries of Bangladesh. Water Resour Ind. 2021;25:100145.

15. Nandy T, Manekar P, Dhodapkar R, Pophali G, Devotta S. Water conservation through implementation of ultrafiltration and reverse osmosis system with recourse to recycling of effluent in textile industry – A case study. Resour Conserv Recycl. 2007;51:64–77.

16. Mikucioniene D, Mínguez-García D, Repon R, Milašius R, Priniotakis G, Chronis I, et al. UNDERSTANDING AND ADDRESSING THE WATER FOOTPRINT IN THE TEXTILE SECTOR : A REVIEW. Autex Res J. 2024;24(1).

17. Alkaya E, Demirer GN. Sustainable textile production : a case study from a woven fabric manufacturing mill in Turkey. Clean Prod. 2013;1(9).

18. Madara DS, Namango SS, Katana H. Potential of Roof Rain Water Harvesting at an industrial setup. J Environ Earth Sci. 2016;6(7):110–7.

19. Biedunkova O, Kuznietsov P, Korbutiak V. Environment Evaluation of return cooling water reuse in the wet cooled power plant to minimise the impact of water intake and drainage. Sustain Chem Environ. 2024;7:100151.

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EP 02

Assessing the Relationship Between AI-based Pest Detection Systems and Pest Damage Control in Paddy Farming: A Correlation Study Among Paddy Farmers in Ampara District, Sri Lanka

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Abstract

AI-based Pest Detection Systems support effective pest monitoring, reduce crop damage, and improve agricultural productivity in paddy farming. This study examines the relationship between Sensor Technologies, Decision Support Systems (DSS), and Scalability and Adaptability on pest damage control in paddy farming in the Ampara District of Sri Lanka. A quantitative research design was applied using structured questionnaires to collect data from paddy farmers in selected farming areas. Statistical analysis methods were used to identify the connection between AI-based Pest Detection Systems and pest damage control. The findings show that AI-based Pest Detection Systems support early pest identification, reduce crop losses, lower unnecessary pesticide use, and improve agricultural productivity. Sensor technologies enable real-time field monitoring, while Decision Support Systems provide appropriate pest-control recommendations. Scalability and Adaptability: AI-based Pest Detection Systems enhance monitoring performance across diverse environmental conditions. The study highlights technology knowledge, training support, and system availability as important factors for successful AI adoption in agriculture. The results provide useful information for agricultural institutions, policymakers, and farming communities to support sustainable and technology-based agricultural development in Sri Lanka. Index Terms: AI-based Pest Detection, Smart Agriculture, paddy farming, sustainable agriculture, Precision Farming.

Keywords - *Scalability and Adaptability, Artificial Intelligence (AI), Decision Support Systems, paddy farming, Sensor Technologies*

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Introduction

paddy farming is one of the most important agricultural activities in Sri Lanka, especially in the Ampara District. Pest attacks continue to create serious problems in paddy farming and reduce crop production every year. Traditional pest monitoring methods mainly depend on manual field inspections and visual observation. These methods are time-consuming, require greater labour, and often fail to detect pest attacks at an early stage. Late pest detection increases crop damage, raises pesticide expenses, and negatively affects soil quality and environmental sustainability. Recent developments in AI-based Pest Detection Systems provide advanced solutions for improving pest monitoring and supporting sustainable agriculture. AI-based Pest Detection Systems such as machine learning, computer vision, drones, and Sensor Technologies improve pest identification accuracy, support real-time monitoring, and reduce unnecessary pesticide application, leading to better crop protection and improved agricultural productivity(1,2).

Global research studies explain that AI-based pest management systems improve farming efficiency through early pest detection and predictive analysis. AI-based Pest Detection Systems analyse field images, weather conditions, humidity levels, and soil data to identify possible pest outbreaks before serious crop damage occurs. Modern technologies, including Internet of Things (IoT) Sensor Technologies and drone monitoring systems, help paddy farmers manage large farming areas more efficiently while reducing labour requirements and operational costs(3–5).

Deep learning models such as Convolutional Neural Networks (CNN) further improve pest recognition accuracy by analysing pest shapes, colours, and crop damage patterns automatically(6).

Despite these technological improvements, the adoption of AI-based Pest Detection Systems in Sri Lanka remains limited, especially among paddy farmers in the Ampara District. Limited technical knowledge, lack of awareness, high technology costs, and low access to modern farming tools reduce the practical use of AI-based Pest Detection Systems in local farming environments. Most paddy farmers still rely on traditional pest-control methods, which often lead to delayed pest management and increased crop losses. Existing international studies mainly focus on developed countries and large commercial farms, while limited research explains the practical relationship of AI-based pest detection among smallholder paddy farmers in local Sri Lankan farming conditions (7–9).

Limited empirical evidence exists on AI-based pest detection among smallholder paddy farmers in the Ampara District of Sri Lanka. Previous studies mainly focus on developed countries and large commercial farms. Research findings provide practical evidence from local farming communities and add valuable knowledge related to AI adoption, pest management, and sustainable agriculture in Sri Lanka.

Several well-known AI adoption theories provide the theoretical foundation for the research. The Technology Acceptance Model (TAM) explains AI adoption through perceived usefulness and perceived ease of use. The Diffusion of Innovation (DOI) Theory explains the spread of new agricultural technologies based on relative advantage, compatibility, and observability. The Technology–Organization–Environment (TOE) Framework explains how technological readiness, organizational support, and environmental conditions influence AI adoption. Precision Agriculture Theory supports the use of AI, Sensor Technologies, drones, and data-driven technologies to improve pest monitoring, reduce pesticide use, and increase agricultural productivity. Combined theoretical perspectives provide a strong foundation for understanding AI adoption in paddy farming in the Ampara District.

This research, therefore, examines the relationship between AI-based Pest Detection Systems and pest damage control in paddy fields among paddy farmers in the Ampara District. The study mainly focuses on sensor technologies, Decision Support Systems, and Scalability and Adaptability features in AI-based Pest Detection Systems. A quantitative research approach was selected for the study, and structured questionnaires were used for primary data collection among paddy farmers. Statistical analysis methods were applied to identify the relationship between AI-based Pest Detection Systems and pest damage control in paddy farming.

The study is limited to paddy farmers in the Ampara District and mainly depends on questionnaire-based responses collected during the research period. Although the research scope is limited to one geographical area, the findings provide important practical evidence about the contribution of AI-based Pest Detection Systems toward improving pest management,

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increasing crop productivity, reducing pesticide use, and supporting environmentally sustainable agriculture in Sri Lanka (10,11).

Methods

This study used a quantitative research design under the positivist research philosophy, focusing on numerical data collection and statistical analysis to measure the relationship between AI-based Pest Detection Systems and pest damage control in paddy farming in the Ampara District. A deductive research approach was selected because the study examined existing theories and hypotheses related to sensor technologies, Decision Support Systems, Scalability and Adaptability, and pest damage control in paddy farming. The research used a cross-sectional questionnaire survey. Statistical results indicate significant associations between Sensor Technologies, Decision Support Systems, Scalability and Adaptability, and pest damage control in paddy farming. Statistical findings do not confirm direct cause-and-effect relationships. The results indicate statistically significant associations among the study variables.

The study population included paddy farmers from the Sammanthurai and Kalmunai Divisional Secretariat areas in the Ampara District. Probability sampling was selected to provide equal selection opportunities for every farmer in the target population. Cluster sampling was first applied to divide paddy farmers into groups based on geographical areas. After group formation, simple random sampling was used inside each group to select respondents fairly and reduce selection bias. The total farmer population for the study included nearly 8,800 paddy farmers. Based on the Krejci and Morgan Sample Size Table, a sample of 699 respondents was selected for the research, including 364 paddy farmers from Sammanthurai and 335 paddy farmers from Kalmunai. A structured questionnaire was distributed to the selected paddy farmers for data collection.

A total of 167 completed questionnaires were collected and used for statistical analysis because only these responses were fully completed and suitable for analysis. The remaining questionnaires were not included due to incomplete or missing responses. The final response rate was 23.9% (167 out of 699). Only fully completed questionnaires were included for statistical analysis to ensure data quality.

Primary data collection was completed using a structured questionnaire distributed among paddy farmers through direct field collection and online methods. The questionnaire collected information related to sensor technologies, Decision Support Systems, scalability and adaptability features, and pest damage control in paddy farming. A five-point Likert scale was used to measure responses and maintain consistency in data collection. This method supported the collection of direct, reliable, and field-based information related to AI-based pest detection practices in local farming environments.

Data analysis was completed using statistical analysis methods to evaluate the relationship between independent and dependent variables. Descriptive statistics were used to summarise demographic information and research responses. Reliability testing was completed using Cronbach's Alpha values to measure internal consistency. Validity analysis was also conducted to confirm the accuracy and suitability of the collected data. Pearson correlation analysis measured the relationship between AI-based Pest Detection Systems and Pest Damage Control, while regression analysis identified the relationship of sensor technologies, Decision Support Systems, scalability, and adaptability on paddy field pest management. Ethical considerations were maintained throughout the research process, including informed consent, confidentiality, anonymity, and voluntary participation during data collection activities.

Results

Table 1: Summary of Statistical Analysis

Analysis Area	Key Findings
Reliability and Validity	Cronbach's Alpha values confirmed strong reliability for all variables. Sensor Technologies showed excellent reliability (0.746), Decision Support Systems showed strong reliability (0.644), Scalability and Adaptability showed good reliability (0.663), and pest damage control showed acceptable reliability (0.825). KMO values were above 0.5, and Bartlett's

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	Test was significant ($p = 0.000$). The results confirmed that the data were reliable and suitable for further analysis.
Descriptive Statistics	Descriptive analysis showed moderate response levels across the study variables. Sensor Technologies recorded a mean value of 1.92, Decision Support Systems recorded 2.14, and Scalability and Adaptability recorded 2.17. The results indicate a moderate level of acceptance and use of AI-based Pest Detection Systems among paddy farmers.
Correlation Analysis	Pearson correlation analysis identified significant positive relationships between all independent variables and pest damage control in paddy farming. Sensor Technologies showed the strongest relationship ($r = 0.524$, $p = 0.000$), followed by Decision Support Systems ($r = 0.790$, $p = 0.000$) and Scalability and Adaptability ($r = 0.777$, $p = 0.000$).
Regression Analysis	Multiple regression analysis produced a statistically significant model ($F = 135.518$, $p < 0.001$). The model explained 72.0% of the variation in pest damage control in paddy farming ($R^2 = 0.720$), indicating a good model fit. Decision Support Systems showed the strongest standardized regression coefficient ($\beta = 0.434$, $B = 0.353$, 95% CI = 0.252–0.454, $p < 0.001$). Scalability and Adaptability showed the second strongest standardized regression coefficient ($\beta = 0.410$, $B = 0.336$, 95% CI = 0.237–0.435, $p < 0.001$). Sensor Technologies also showed a statistically significant positive relationship with pest damage control in paddy farming ($\beta = 0.111$, $B = 0.092$, 95% CI = 0.012–0.171, $p = 0.024$). All independent variables showed significant positive relationships with pest damage control in paddy farming. Variance Inflation Factor (VIF) values remained below the recommended level, indicating no multicollinearity problem. Regression assumptions were checked using normality and residual analysis, confirming that the model was suitable for multiple regression analysis. Effect size results indicated a strong relationship between the independent variables and pest damage control in paddy farming.

The demographic analysis shows that 167 paddy farmers participated in the study. The respondents represent paddy farmers from the selected study area. The demographic information includes gender, age group, education level, and years of farming experience. These details help explain the respondents' backgrounds and support the interpretation of the study results.

In terms of gender, most respondents are male, with 117 respondents (70.1%), while 50 respondents (29.9%) are female. The results indicate that male participation in farming activities is higher than female participation.

The age distribution shows that respondents are spread across different age groups. The 18–30 and 31–40 age groups each have 32 respondents (19.2%). The 41–50 age group has the highest number with 59 respondents (35.3%), while the 51 and

above group has 44 respondents (26.3%). This shows that most paddy farmers are middle-aged, with strong participation from older groups as well.

The farming experience data shows that most respondents have more years of experience. The 1–5 years group includes 23 respondents (13.8%), the 6–10 years group has 16 respondents (9.6%), the 11–15 years group has 59 respondents (35.3%), and the more than 16 years group has 69 respondents (41.3%). These findings indicate that the majority of respondents possess considerable farming experience, enhancing the credibility of their responses.

The education level results show that most respondents have low education levels. Primary education has the highest number with 69 respondents (41.3%), followed by no formal education with 67 respondents (40.1%). Secondary education has 20 respondents (12%), and higher education has only 11 respondents (6.6%). The findings indicate that most paddy farmers have only a basic level of education.

Overall, the demographic results indicate that the respondents were predominantly male, middle-aged, and highly experienced paddy farmers. Most respondents have basic education and long farming experience; this helps to provide practical and reliable insights for the study.

The reliability analysis shows that all variables are consistent and suitable for analysis. Sensor Technologies has Cronbach's Alpha 0.746, Decision Support Systems has 0.644, Scalability and Adaptability have 0.663, and pest damage control in paddy farming has 0.825. All values are acceptable, indicating that the collected data are reliable.

The validity analysis shows that all variables are suitable for further study. KMO values are Sensor Technologies 0.630, Decision Support Systems 0.638, Scalability and Adaptability 0.657, and pest damage control 0.828. All values are above 0.5. Bartlett's Test for all variables is 0.000, showing strong relationships between variables.

Descriptive statistics show moderate response levels. Sensor Technologies has a mean of 1.92, Decision Support Systems has 2.14, and Scalability and Adaptability have 2.17, showing moderate usage and perception levels. Responses related to pest damage control showed variation across the measurement items.

Correlation analysis shows strong positive relationships. Sensor Technologies has $r = 0.524$, Decision Support Systems has $r = 0.790$, and Scalability and Adaptability has $r = 0.777$ with pest damage control variables. All results are significant at 0.000, showing strong relationships between AI-based Pest Detection Systems and pest damage control.

Regression analysis shows a strong model fit. The R value is 0.849, and the R Square is 0.720, showing that 72% of pest damage control variation is explained by the independent variables. The Adjusted R Square is 0.715, and the Standard Error is 0.468, showing good accuracy. ANOVA result is significant at 0.000, confirming the model is valid. Overall, the results indicate significant positive associations between AI-based Pest Detection Systems and pest damage control in paddy farming.

Discussion

To determine the relationship of Sensor Technologies on pest damage control in paddy farming.

The correlation analysis identified a positive relationship between Sensor Technologies and pest damage control in paddy farming, with a correlation value of $r = 0.524$ and a significance value of $p = 0.000$. Real-time monitoring systems, IoT Sensor Technologies, and AI-based Pest Detection Systems supported early pest detection by continuously analysing temperature, humidity, soil moisture, and pest activity. The findings indicate that improved sensor technologies enhance pest monitoring accuracy, enabling earlier pest detection and reducing crop damage in paddy farming.

Regression analysis further confirmed that Sensor Technologies showed a significant positive relationship with pest damage control, with a regression coefficient value of $B = 0.092$. The regression analysis indicated that Sensor Technologies

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explained 27.4% of the variance in pest damage control ($R^2 = 0.274$). The statistical results showed that real-time sensor monitoring improved pest prediction, supported timely intervention, and reduced dependence on manual field inspections. The findings confirmed that sensor-based technologies played an important role in improving crop protection and agricultural productivity in paddy farming.

To determine the relationship of Decision Support Systems on pest damage control in paddy farming

The correlation analysis showed a strong positive relationship between Decision Support Systems and pest damage control in paddy farming. The correlation value was $r = 0.790$ with a significance value of $p = 0.000$. The results showed that Decision Support Systems helped paddy farmers improve their decisions in pest control and crop protection by using weather data, soil information, satellite images, and sensor inputs to guide actions.

The regression analysis showed a positive relationship between Decision Support Systems and pest damage control, with a regression coefficient value of $B = 0.353$. The regression analysis indicated that Decision Support Systems explained 62.4% of the variance in pest damage control ($R^2 = 0.624$). This means Decision Support Systems played an important role in improving pest management, reducing unnecessary pesticide use, and supporting better and more sustainable agriculture in paddy farming, especially in the Ampara District.

To determine the relationship of Scalability and Adaptability on pest damage control in paddy farming.

The correlation analysis identified a positive relationship between Scalability and Adaptability and pest damage control in paddy farming. The correlation value was $r = 0.777$ with a significance value of $p = 0.000$. The findings suggest that scalable and adaptive AI-based Pest Detection Systems improve pest monitoring efficiency and enhance pest control under varying environmental conditions, such as weather changes, pest behaviour, and field variations.

The regression analysis showed a positive relationship between Scalability and Adaptability and pest damage control, with a regression coefficient value of $B = 0.336$. The regression analysis indicated that Scalability and Adaptability explained 60.4% of the variance in pest damage control ($R^2 = 0.604$). These findings indicate a positive relationship between Scalability and Adaptability and pest damage control, suggesting that improvements in scalable AI-based Pest Detection Systems lead to better pest management outcomes. The results confirmed that adaptive and cloud-based AI-based Pest Detection Systems improved prediction accuracy, reduced crop damage, and supported sustainable long-term agricultural productivity in paddy farming.

Research findings provide valuable guidance for agricultural development in Sri Lanka. Farmer training and extension services can improve knowledge, awareness, and practical use of AI-based Pest Detection Systems. Affordable technologies and government subsidies can increase AI adoption among smallholder paddy farmers. Strong digital infrastructure and public–private partnerships can further support technology access, research collaboration, and sustainable paddy farming.

Research findings show similarities with studies conducted in India, China, and Vietnam. AI-based Pest Detection Systems in those countries improve early pest detection, reduce pesticide use, and increase agricultural productivity. Similar benefits appear among paddy farmers in the Ampara District. Limited financial resources, technology costs, and technical knowledge remain common challenges across developing agricultural regions. These similarities strengthen the international relevance of the present study.

Conclusion

The study identified significant positive associations between AI-based Pest Detection Systems and pest damage control in paddy farming among paddy farmers in the Ampara District of Sri Lanka. This study provides empirical evidence supporting the adoption of AI-based pest detection technologies among smallholder paddy farmers in Sri Lanka and offers practical insights for policymakers, agricultural institutions, and future digital agriculture initiatives.

This study contributes to the existing literature by providing empirical evidence on AI adoption among smallholder paddy farmers in the Ampara District, where limited research has previously been conducted. The research provides a valuable foundation for future studies and supports evidence-based decision-making for the adoption of AI technologies in agriculture.

The study was limited to selected farming areas in the Ampara District and was based on a cross-sectional questionnaire survey. Therefore, the results indicate statistically significant associations rather than direct causal relationships.

Future research should include larger sample sizes, multiple agricultural regions, longitudinal research designs, drone-assisted pest detection, computer vision-based pest identification, economic cost–benefit analysis, and integration with climate-smart agriculture to strengthen the evidence for AI adoption in sustainable paddy farming.

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References

1. Guo W, Fu Q, Li X. Research Progress of Convolutional Neural Network Model Based on Crop Disease Detection and Recognition. Journal of Chinese Agricultural Mechanization. 2022;43(10):157.

2. Wang Y, Zhang Y, Yang C, Meng Q, Shang J. Advances in New Nondestructive Detection and Identification Techniques of Crop Diseases Based on Deep Learning. Journal of Zhejiang Agricultural Sciences. 2019;31(4):669–76.

3. Lu J, Sun L, Huang W. Research Progress in Monitoring and Forecasting of Crop Pests and Diseases by Remote Sensing. Remote Sensing Technology and Application (Remote Sens Technol Appl). 2019;34:21–32.

4. Abbasi R, Martinez P, Ahmad R. The Digitization of Agricultural Industry: A Systematic Literature Review on Agriculture 4.0. Smart Agricultural Technology. 2022;2:100042.

5. Lima M, de Almeida Leandro M, Valero C, Coronel L, Bazzo C. Automatic Detection and Monitoring of Insect Pests: A Review. Agriculture. 2020;10(5):161.

6. Jiang S, Min W, Wang S. Overview and Prospect of Image Recognition Technology for Intelligent Interaction. Computer Research and Development. 2016;53(1):113–22.

7. Hashem T, Hasoneh A. Smart Business as a Booster for Better E-Marketing Results: Moderating Influence of Technological Vigilance. In. Institute of Research Engineers and Doctors (ISERD); 2021. p. 29–34.

8. Misra N, Dixit Y, Al-Mallahi A, Bhullar M, Rohit U, Alex M. IoT, Big Data, and Artificial Intelligence in Agriculture and Food Industry. IEEE Internet of Things Journal. 2020;9(9):6305–24.

9. Tian H, Wang T, Liu Y, Qiao X, Li Y. Computer Vision Technology in Agricultural Automation: A Review. Elsevier (on behalf of China Agricultural University and KeAi). 2020;7(1):1–19.

10. Selvaraj M, Vergara A, Ruiz H, Safari N, Elayabalan S, Ocimati W, et al. AI-Powered Banana Diseases and Pest Detection. Plant Methods. 2019;15(1):92.

11. Prabha K. Disease Sniffing Robots to Apps Fixing Plant Diseases: Applications of Artificial Intelligence in Plant Pathology A Mini Review. Indian Phytopathology. 2021;74(1):13–20.

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EP 03

Vacuum Chamber-Based Method for the Safe Removal of Toner Powder from Used Toner Cartridges: A Sustainable Approach to E-Waste Management in Sri Lanka

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Abstract

The increasing use of photocopiers and printers in Sri Lanka has led to major e-waste management challenges due to inadequate toner cartridge recycling facilities. Most waste toner cartridges are discarded as municipal solid waste, with only a small fraction used for energy recovery via incineration. Improper management of toner cartridges leads to air and groundwater contamination, while occupational exposure to toner particles causes respiratory and genotoxic effects. This study aims to develop a cost-effective and efficient method for the safe removal of toner powder from used cartridges using a vacuum chamber. The chamber is a 1.5 m length, 0.6 m width, and 0.6 m height box constructed from low-density polyethylene and a metal frame, which is equipped with an exhaust fan to create negative pressure. The cartridge can be inserted into the box from the opening on the left side, and the operator can dismantle the cartridge by inserting only his/her hand into the chamber from the front opening, thereby preventing exposure to dust. On average, 3–4 cartridges were dismantled per hour. This approach facilitates the safe extraction of toner dust while minimizing occupational exposure and environmental impacts. Recycling opportunities can be identified through dismantling, which enables a reduction in waste volume and promotes the recycling of components instead of direct disposal. The extracted toner dust has potential applications in cement-based production. Additionally, recovered metals and plastic components can be directed to recycling processes. Overall, the proposed vacuum chamber method offers a low-cost, scalable solution for toner cartridge waste management in Sri Lanka.

Keywords: *Photocopiers, Printers, Recycling, Sri Lanka, Toner Cartridge*

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Introduction

Toner cartridges are components in photocopiers and printing devices. Discarded toner cartridges consist of about 8% residual toner powder, 35% plastic, 40% steel, 5% magnetic materials, and 12% aluminium (1). Toner powder is mainly composed of 85%-95% polyester (finely grounded plastic material), which can vary depending on manufacturer and model. It also contains carbon black or other colour pigments (yellow, cyan, and magenta) and polypropylene wax (2).

The main problem of toner cartridge waste is the challenge of its effective management, since it contains hazardous components (3). While toner powder generally poses no risk when enclosed within intact cartridges, refilling and recycling processes can lead to their release, potentially causing significant environmental and health effects (4). Further, unused and waste toner are disposed of in landfills; its fine particle size (8–10 µm) allows it to easily contaminate air and groundwater. The World Health Organization has classified toner waste as a Group 2B carcinogen, indicating its potential to pose health risks. Toner dust can lead to significant respiratory health issues among workers engaged in the recycling process. Toner particles have been shown to cause ROS-induced oxidative stress on A549 lung cells and may exhibit genotoxic effects with repeated exposure. Heavy metals in toner powder can accumulate in the environment and in human populations living near recycling workshops. The cadmium present in printer toners is known to cause damage to the kidneys and bones (5).

In Sri Lanka, printers and photocopying machines are widely used in offices, educational institutions, government organizations, and bookshops for routine documentation, administrative work, and academic purposes. During the 2006–2007 period in Sri Lanka, the market demand was approximately 130,000 printers per annum with various types and models. Within this sector, about 5% of used printers were being imported. The sector recorded an annual growth rate of around 5–7% during this period (4).

Several review articles on e-waste management in Sri Lanka have identified toner powder from printer cartridges as an emerging environmental concern and have proposed various management strategies (4). Furthermore, a local agent practising Extended Producer Responsibility (EPR) has been reported to collect their used cartridges and re-export them to the parent company, primarily for brand protection purposes (6). However, to the best of our knowledge, Sri Lanka still lacks a well-established mechanism for toner cartridge recycling. As a result, most cartridges are not properly disposed of, and there is a significant gap in research addressing this issue. It is critical to develop practical solutions for the safe dismantling, recovery, recycling, and reuse of toner cartridges in Sri Lanka, particularly approaches that minimize occupational exposure during toner powder handling. This study focuses on developing a sustainable and efficient method for dismantling toner cartridges using a vacuum chamber to safely remove toner powder, while also proposing solutions for managing the resulting dismantled waste components to support improved e-waste management in Sri Lanka.

Method

Preparation of the Vacuum Chamber

Low-density polyethylene (LDPE) and a metal frame were used as the material for the chamber preparation. The chamber has a 1.5 m length, 0.6 m width, and 0.6 m height. There is an exhaust fan on the top of the chamber and one opening from the left side of the box in order to input the cartridge. It has another small opening from the front side. Using this opening operator can insert his/her hand into the chamber for the dismantling process. The exhaust fan is connected to a tube that opens into a toner dust collection box. Figure 1 represents the schematic diagram of the vacuum chamber. The integrated exhaust fan, with a rated power of 1200–1800 W, was used as the extraction system for the cartridge dismantling chamber. The exhaust system was designed to provide an airflow rate of approximately 40 L/s (0.04 m^3/s), thereby generating negative pressure within the chamber. The extraction line consisted of a 50 mm diameter duct connected to a cyclone pre-separator and a HEPA H13 filtration unit to minimize toner particle release. The selected airflow provided approximately 267 air changes per hour within the 0.54 m^3 enclosed chamber.

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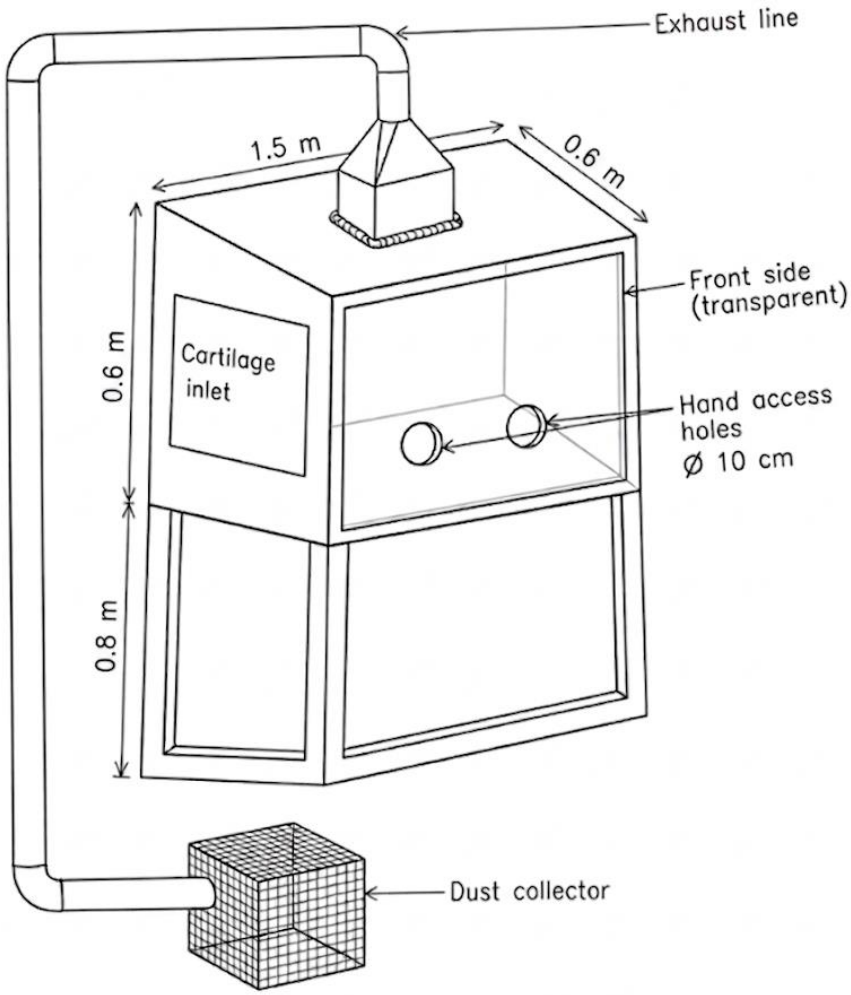

Figure 1: Vacuum Chamber

Toner Powder Removing

First, the exhaust fan was switched on, and the window at the left side of the vacuum chamber was opened. Then, the used printer cartridge was inserted into the chamber, and that window was then closed. After that, toner dust was removed under vacuum conditions using the front opening, and all components were carefully brushed to ensure complete removal of the toner powder. The collected toner dust was then gathered separately. Finally, the remaining parts of the toner cartridge were dismantled, sorted, and stored appropriately before being sent to recyclers.

Results

A schematic diagram of the setup is presented in Figure 01. First, the exhaust fan should be switched on, and the used cartridge can then be inserted through the left-side opening, and the operator can use the front opening for the dismantling process. The toner powder is removed under vacuum conditions and collected separately. During the preliminary operation, approximately 3–4 toner cartridges could be dismantled per hour, demonstrating the practical feasibility of the developed chamber.

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Discussion

Toner cartridges are integral components used in photocopiers and printing devices (7). Printers have an average lifespan of 1–8 years, whereas photocopy machines typically last between 5 and 10 years (8)(6). A recent study conducted by the Ministry of Environment and Natural Resources in collaboration with the Central Environmental Authority reported that major electronic devices, including printers, personal computers, televisions, and batteries, were estimated to have annual growth rates ranging between 4% and 10% (9). Table 1 indicates a significant increase in the use of photocopy machines in Sri Lanka over the past two decades (6).

Table 1: Usage of Photocopy Machines in Sri Lanka from 2008 to 2015

	2008	2009	2010	2011	2012	2013	2014	2015
Sum of net units (nos.)	17,372	133,867	146,274	166,194	170,028	139,445	150,841	165,917
Sum of net mass(kg)	171,275	1,074,835	1,321,872	1,749,705	1,502,970	1,837,318	1,745,852	2,018,322

Sri Lanka lacks a proper waste management system for toner cartridges; however, a small proportion of discarded cartridges is incinerated for energy recovery together with other hazardous or non-hazardous wastes. The combustion of toner materials involves highly exothermic reactions. The heterogeneous composition of toner powder makes this disposal method unreliable, as the types of pollutants generated during combustion are difficult to predict. In addition, the fine particle size of toner allows it to become entrained in flue gases (10). Also, it has been reported that a company implementing Extended Producer Responsibility (EPR) collects their used cartridges and exports them back to its parent company, mainly to ensure brand protection (6).

This study examines the feasibility of removing toner powder using a vacuum chamber while addressing the associated risk of dust explosions and suggesting recycling opportunities for the resulting waste categories. Collected toner powder can be utilized for various applications, such as the removal of heavy metals from aqueous solutions (11), use as an adsorbent for defluorination of water (7), and incorporation into cement-based construction materials. Subsequently, other materials such as plastics, metals, and non-metallic components can be recovered and recycled.

From an occupational safety perspective, the enclosed vacuum chamber design provides a physical barrier between the operator and released toner particles during cartridge dismantling. Although the system reduces direct exposure by maintaining a controlled working environment, appropriate personal protective equipment (PPE), including respiratory protection, gloves, and protective clothing, should be used during operation as an additional safety measure (12).

Compared with other reported toner cartridge recycling approaches, which mainly focus on large-scale automated material recovery systems, the proposed vacuum chamber method represents a simpler approach aimed at safe toner powder removal during cartridge dismantling. Although industrial recycling facilities can achieve efficient material recovery, they generally require specialized equipment, established collection networks, and higher infrastructure investment (5). In contrast, the proposed system offers a low-cost and locally adaptable solution suitable for small- and medium-scale e-waste management operations.

For practical implementation, the proposed method could be integrated with existing e-waste management networks through collaborations among printer manufacturers, recycling companies, government agencies, and other stakeholders. Partnerships with manufacturers under Extended Producer Responsibility (EPR) programmes could support the collection and proper management of used toner cartridges, while recycling companies could utilize the recovered toner powder, plastics, and metals through appropriate recycling pathways (13). Government agencies can facilitate policy support, awareness programmes, and integration of such approaches into national e-waste management strategies. These collaborations would improve the feasibility and long-term sustainability of implementing the proposed vacuum chamber-based system in Sri Lanka.

The implementation of a vacuum chamber-based toner cartridge dismantling method offers several environmental benefits by improving the recovery and management of toner cartridge waste throughout its life cycle. By enabling the controlled separation of toner powder, plastics, metals, and other components, the proposed approach can reduce the quantity of toner cartridges disposed of through municipal solid waste streams and minimize potential environmental contamination associated with improper disposal. Furthermore, the proposed method supports circular economy principles by promoting resource recovery, waste minimization, and value retention of discarded materials (14).

The present study represents an initial effort to develop and demonstrate a prototype vacuum chamber system for safer toner cartridge dismantling. The developed approach provides a practical means of reducing direct exposure to toner particles during manual dismantling; however, the current evaluation was limited to prototype-scale operation under controlled conditions. Future research should validate the system performance through quantitative measurements of filtration efficiency and airborne particle reduction. Further improvements should focus on automation, and evaluation of toner recovery efficiency across different cartridge types and models. Life-cycle assessment (LCA) and techno-economic analysis are also recommended to determine the environmental and economic performance of the system and support its potential integration into larger-scale e-waste recycling facilities in Sri Lanka.

Overall, the proposed vacuum chamber method demonstrates a practical, low-cost, and safer approach for toner cartridge dismantling, with significant potential to improve e-waste management practices in Sri Lanka while supporting environmental protection and resource recovery.

Conclusions

This study demonstrated that the use of a vacuum chamber is an effective and practical method for the safe removal of toner powder from used toner cartridges. The technique minimizes the release of fine toner particles into the environment, thereby reducing potential risks to both human health and surrounding ecosystems. The findings also highlight that significant material recovery is possible through this approach. Separated toner powder can be reused in value-added applications, while other components such as plastics and metals can be recycled, contributing to waste reduction and resource recovery. This supports the transition toward a more sustainable and circular approach to e-waste management. In the context of Sri Lanka, where formal systems for toner cartridge recycling are still limited, this method offers a low-cost and adaptable solution suitable for small- to medium-scale implementation. Overall, the proposed approach provides a promising pathway for improving toner cartridge waste management while enhancing environmental protection and occupational safety.

References

1. Melnjak I, Vučinić AA, Radetić L, Grčić I. WASTE TONER POWDER IN CONCRETE INDUSTRY : AN APPROACH TOWARDS CIRCULAR ECONOMY. Environ Eng Manag J. 2019;18(9):1897–906.

2. Moron W. The explosion suppression effects of added limestone dust on minimizing the risk of dust explosions in the printer cartridge recycling installation. J Loss Prev Process Ind. 2026;100.

3. Barrios SU, Martínez MF, Giner IM, Verdejo R, Manchado MAL, Santana MH. New recyclable and self-healing elastomer composites using waste from toner cartridges. Compos Sci Technol. 2023;244.

4. Samarakoon MB. A Review of Electrical and Electronic Waste Management in Sri Lanka. In: International Conference on Chemical, Civil and Environmental Engineering. Singapore; 2014.

5. Parthasarathy M. Challenges and Emerging Trends in Toner Waste Recycling : A Review. Recycling. 2021;6.

6. Ranasinghe WW, Athapattu BCL. Challenges in E-waste management in Sri Lanka. Handbook of Electronic Waste Management. INC; 2020. 283–322 p.

7. Choudhary D, Kaithwas S, Kamlesh, Sharma RK, Mishra A, Singhai S, et al. Recycling of waste toner derived from exhausted printer cartridges as adsorbent for defluoridation of water. Environ Technol Innov [Internet]. 2024;34:103572. Available from: https://doi.org/10.1016/j.eti.2024.103572

8. Edirisinghe MAPH, Ranasinghe HGS, Sandeepani MLV, Wickamanayake S, Dilrukshi STND, Yasas TDL, et al. e-waste Management in Sri Lanka. Gunarathne ADN, editor. 2015.

9. Mallawarachchi H, Karunasena G. Electronic and electrical waste management in Sri Lanka : Suggestions for national policy enhancements. Resour Conserv Recycl. 2012;68:44–53.

10. Yordanova D, Angelova S, Dombalov I. Utilisation Options for Waste Toner Powder. Int Sci J. 2014;140–4.

11. Fernández B, Ayala J, Valle E del, Martínez-Blanco D, Castañón AM, Menéndez-Aguado JM. Recycling of Waste Toner Powder as Adsorbent to Remove Aqueous Heavy Metals. Materials (Basel). 2022;1–24.

12. Personal Protective Equipment. 2023.

13. Kiddee P, Naidu R, Wong MH. Electronic waste management approaches : An overview. Waste Manag. 2013;33:1237–50.

14. Shahib MI, Dsouza CG, Vijayakumar RP. A review on end-of-life waste toner powder : recovery , utilization and upcycling. Waste Manag. 2025;204:114911.

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EP 04

Dye Machine Cooling Water Reuse in the Fabric Dyeing and Printing Industry: A Case Study on Water Conservation Project in Sri Lanka

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Abstract

The fabric dyeing and printing industry is one of the largest consumers of freshwater in Sri Lanka, contributing significantly to industrial water pollution. Therefore, efficient water reuse practices are crucial for promoting sustainability and reducing environmental impact from these industries. In this case study, a significant volume of freshwater is utilized during key processes, including scouring, dyeing, printing, soaping, and finishing, which primarily use the water stored in the underground water sump in the facility. The analysis revealed that the dye machine cooling system could effectively implement water reuse. In this project, dye machine cooling water was reused. During the dye cycle, the water was used to cool the dye machines, and then a sample of used water was passed through a real-time monitoring system, which analyzed pH, Total Dissolved Solids (TDS), Temperature, and Turbidity every 30 seconds. When all the parameters were within the specified limits, the water was directed back to the underground water sump for reuse; otherwise, it was diverted to the Effluent Treatment Plant (ETP). As a result of this initiative, about 6.43% of water was reused monthly, corresponding to an estimated annual saving of approximately 23,000 m^3. Furthermore, total wastewater generation was decreased by the same volume, thereby significantly lowering the environmental footprint of the facility and reducing costs associated with raw water consumption and wastewater treatment. Accordingly, the fabric dyeing and printing industry can successfully reuse dye machine cooling water, as this case study confirms.

Keywords: *Cooling Water, Dyeing, Reuse, Sump, Wastewater*

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Introduction

The demand for water resources is rising steadily, as they are indispensable to agricultural, industrial, and domestic sectors (1). Trends in water consumption in Sri Lanka indicate that there is an urgent need for the sustainable management of the country's water resources. In Sri Lanka, industrial activities account for approximately 6.42% of the total water usage (2). The textile and apparel industry is one of the major sectors in Sri Lanka, greatly contributing to industrial output; however, its traditional linear economy poses significant sustainability challenges due to high resource consumption and environmental pollution (3) (4). The textile industry accounts for a substantial share of water usage in its operations (3). A large amount of water is used in most manufacturing steps of the textile industry, with bleaching, dyeing, and finishing processes typically consuming more than half of the total water requirement. This industry generates a substantial volume of wastewater that must be treated before industrial discharge (5); (6). Producing 1 kg of textile requires approximately 100 L to 200 L of freshwater, although this value may vary depending on the dyeing process and the type of textile material (6). Therefore, efficient water management strategies and effective water treatment methods are needed to ensure sustainable water usage.

Good housekeeping practices, the use of automatic shut-off valves, flow control valves, low liquor ratio systems, and water reuse techniques are some of the effective methods to conserve water in the textile industry (7). The advanced treatment methods, such as ion exchange and membrane filtration, present economic challenges due to their high capital and maintenance costs (8). Among the identified Best Available Techniques (BAT), cooling water reuse was prioritized because of its high feasibility, low implementation complexity, and immediate potential for water savings.

Water reuse practices reduce the wastewater load to the treatment system by using the same water in more than one process. Water reuse can involve both process water and water recovered from auxiliary operations, such as bleach baths, final rinse water from dyeing (used for preparing new dye baths), washing processes, and cooling water from dyeing machines (9). Cooling water that remains uncontaminated by fabrics or process chemicals can be collected for direct reuse. This includes cooling water from condensers, water-cooled bearings, heat exchangers, cooling rolls, yarn dryers, pressure dyeing machines, and air compressors (6). Although cooling water reuse has been widely discussed in industries in other countries, documented case studies with quantified industrial-scale performance data are not available for Sri Lanka. The present study demonstrates a full-scale implementation of a real-time monitored cooling water reuse system integrated with automated water quality assessment. The aim of this study was to investigate the potential for water reuse in dye machine cooling systems within a fabric dyeing and printing company that heavily depends on water for its production processes.

2. Method

2.1. General Information and Production processes of the Company

The company is a fabric dyeing and printing facility located in, Sri Lanka, with a primary focus on producing dyed and printed fabrics. The estimated monthly production capacity is approximately 202,068 kg. Although the specific production procedure may vary depending on fabric type, required color, and customer specifications, a general process flow can be described as shown in Figure 1.

Raw materials, including greige fabric, greige yarn, and dyes/chemicals, are first received at the warehouse. Greige fabrics are directed to the greige preparation section, where greige fabrics are arranged for easy feeding into dyeing machines. This procedure ensures efficient material handling and uniform dye penetration during subsequent processing. Then greige fabrics are directed to the dyeing department.

The dyeing department consists of both fabric and yarn dyeing units. Fabrics and yarns are treated with specified dye classes and auxiliary chemicals according to process recipes. In fabric dyeing, the dyeing process primarily consists of three main stages: scouring, dyeing, and soaping. These stages, which collectively consume a significant volume of water, are carried out within dyeing machines. During these operations, the temperature of the dye bath should vary depending on the specific process requirements. When a reduction in the dye bath temperature is necessary, a cooling water system is employed to enhance the cooling rate and maintain the desired thermal conditions.

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Dyed fabrics are subsequently subjected to the finishing process to achieve the desired texture, appearance, and performance characteristics. During finishing, the tubular fabric is cut open by the slitter machine, which converts it into a flat form. The fabric is then transferred to the relax dryer, where it is dried under relaxed conditions to restore its natural width and softness. After drying, it is processed through the compactor to minimize shrinkage, enhance dimensional stability, and improve the overall fabric appearance and handle. Once the finishing process is complete, the fabrics are carefully inspected, and approved materials are stored in the finished goods warehouse. If the fabrics are intended for printing, they are transferred to the printing department, where printing is carried out according to the specified designs and color patterns. After printing, the fabrics are handed over to the finishing department for final finishing. Finally, the completed fabrics are inspected once again and stored in the finished goods warehouse.

The greige yarns are first subjected to soft winding to ensure uniformity and are then processed through yarn dyeing. Dyed yarns are sent to the knitting department, where they are used in both circular and flat knitting operations. In circular knitting, dyed yarns produce yarn-dyed fabrics, which are handed over to the dyeing department for washing and then directed to the finishing department, where the remaining steps proceed as mentioned above. Additionally, greige fabric can be knitted directly from greige yarns in circular knitting. In the flat knitting section, dyed yarns are used to produce specific products such as colored cuffs and other knitted components. After knitting, these items are handed over to the rib finishing section, where they undergo finishing processes to achieve the required appearance, texture, and quality. Once finishing is complete, the products are inspected, packed, and transferred to the finished goods warehouse.

There were also supporting utility systems, including chillers, boilers, the Effluent Treatment Plant (ETP), a softener room, and compressors.

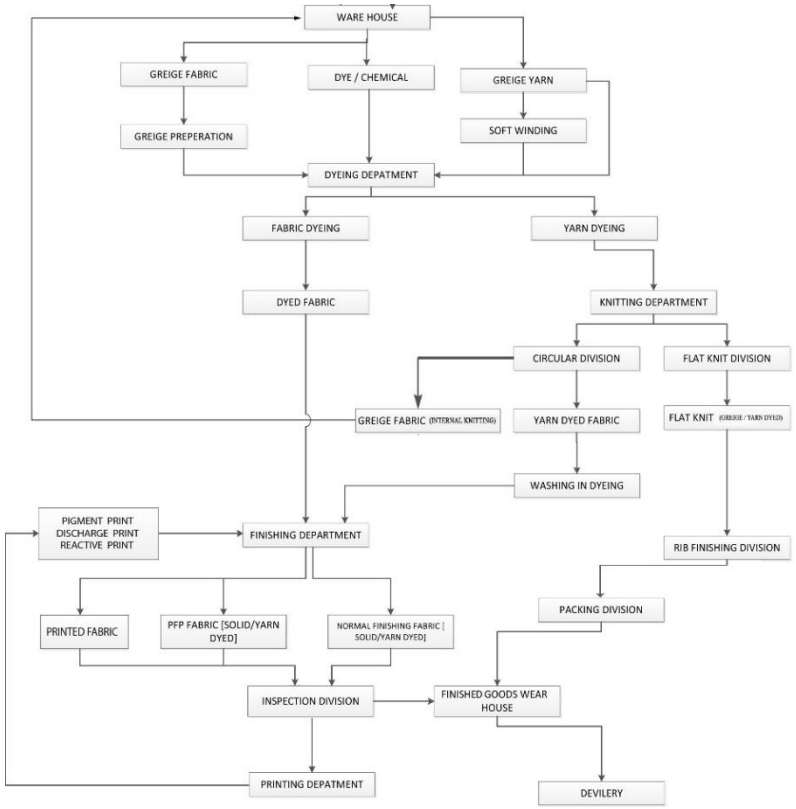

Figure 33: Total process flow chart of the facility

2.2. Data Collection and Evaluation of Water Use

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A walk-through audit was conducted with company officials to collect detailed information on the inputs and outputs of the main processes, after which the total process flow diagram was developed (10). It is essential to obtain data on the total water consumption across all installations within the facility. Accordingly, information regarding the quantities of fresh water used and wastewater generated during the year 2024 (from January to October) was gathered (11). For the purpose of data collection, information sources such as process-based record sheets and water bills were analyzed. However, production in the textile industry fluctuates not only throughout the year but even within a single day due to seasonal trends and fashion demands. Consequently, it is challenging to standardize and correlate the emissions from various processes within the mill. The recommended approach is a "systematic analysis of the specific processes." Therefore, the most water-intensive processes were identified, and the impact of Best Available Techniques (BAT) on water consumption for these processes was evaluated (12). Then, the most suitable techniques were implemented. Among those implementations, the reuse of cooling water from the dyeing machine discussed in this case study.

The system boundary for this study includes the dye machine cooling circuit from water withdrawal from the underground sump, circulation through the cooling system, real-time quality monitoring, and subsequent diversion either for reuse in the sump or discharge to the Effluent Treatment Plant (ETP). The system does not include textile wet processing operations. The monitoring system measure pH, temperature, TDS, and turbidity at approximately 30-second intervals. Water quality thresholds for reuse were established based on operational requirements of the dyeing process. These thresholds were selected to ensure that reused water would not adversely affect process stability, equipment performance, or product quality. When any parameter exceeded the defined limits, water was automatically diverted to the Effluent Treatment Plant for treatment. Water consumption was measured using water meters, and the recorded data were reviewed monthly to identify anomalies or system interruptions.

Baseline conditions were defined based on operational practices prior to system implementation, during which all dye machine cooling water was discharged directly to the Effluent Treatment Plant without reuse. The previous water consumption and wastewater discharge records were used to characterize baseline performance. Post-implementation performance was evaluated using monitored data collected after a 15-day system stabilization period. Water reuse percentage was calculated by comparing measured reuse volumes against total water usage during the monitoring period.

This study has several assumptions and limitations. The monitoring period covered three months of operation following system stabilization and may not fully capture long-term seasonal variations in production or water demand. The analysis assumes stable sensor performance between calibration checks.

3. Results

3.1. Water use evaluation

The selected facility has a total production capacity of 202,068 kg per month. The monthly water consumption, wastewater generation, and total production were recorded and analyzed over 2024 (Between January and October) (Table 1) to get an idea about the water consumption trend in the facility (13).

Table 23: Monthly water consumption and the production data of the facility in 2024 (January to October)

Month	Water consumption (m^3)	Wastewater discharged (m^3)	Total Weight of Production (kg)
January	34,343	30908.7	187,397
February	31,807	28626.3	161,600
March	39,274	35346.6	227,382
April	30,937	27843.3	184,899
May	41,306	37175.4	280,005
June	37,960	34164.0	258,486
July	33,409	30068.1	251,762
August	32,276	29048.4	229,709

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September	26,032	23428.8	148,034
October	26,133	23519.7	190,001

The monthly water consumption varied with the production quantity. Therefore, a systematic analysis of the specific processes was carried out, and wet processes were identified. The process flowchart of the facility is presented in Figure 1. Among the main operations, three are wet processes, including dyeing, printing, and finishing (14). In addition, supporting units such as the boiler house and compressors also contribute to water consumption, but in smaller amounts (13). Water was also used for cleaning, washing, and other domestic purposes.

It was observed that the cooling water from the dye machines was directly discharged into the ETP. Additionally, no submeters were installed to monitor water consumption for each process step individually. To minimize water consumption, it is essential to adopt more efficient water utilization methods. Therefore, Best Available Techniques (BAT) were suggested to be implemented in the facility (1).

4. Discussion

4.1. Sustainable practices to reduce the water consumption

Based on the overall findings and observations made during the site visit, several processes and practices requiring improvement were identified to reduce water consumption and minimize wastewater generation.

The following sustainable measures were recognized and proposed for implementation.

1. Reuse cooling water from dye machines (14)
2. Implementation of an ultrafiltration and reverse osmosis system to enable effluent recycling (15)
3. Reuse final rinse water from the dyeing process for use in dye bath preparation (16)
4. Reuse stenter cooling water (17)
5. Training and awareness programs for employees (16)
6. Rooftop rainwater harvesting system (18)

Among the sustainable measures listed above, items 1 and 5 were implemented at the end of the 2024 as the most suitable and feasible option following a detailed evaluation conducted. However, this study focuses on the reuse of dye machine cooling water.

4.2. Installation of cooling water reuse system

Raw water is supplied from the National Water Supply and subsequently treated in the softener room to achieve the required water quality standards for production purposes. The softened water is then directed to the underground water sump for storage. Process water requirements are fulfilled through the supply from this sump.

In the previous system, the dye machine cooling water, after serving its cooling function, was discharged directly to the Effluent Treatment Plant (ETP). Following the implementation of the improved system, the dye machine cooling water can now be reused, thereby enhancing water conservation and minimizing wastewater generation.

The line diagram of the implemented dye cooling water reuse system is shown in Figure 3. The water required for the cooling of the dye machine is supplied from the underground water sump. After cooling the dyeing machines, a sample of

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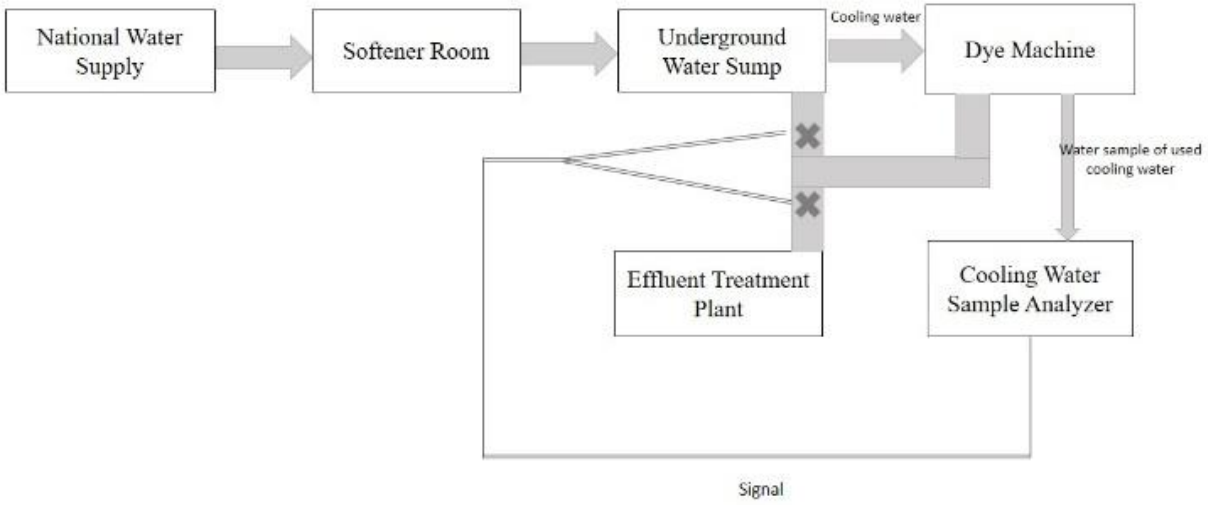
the used cooling water is automatically analyzed by a real-time monitoring system. The system continuously measures key quality parameters, including pH, Temperature, Total Dissolved Solids (TDS), and Turbidity. If all measured parameters fall within the predefined acceptable limits, an automated signal is transmitted to open valve 1, enabling the water to be redirected to the underground water sump for reuse in the process. Conversely, if any parameter exceeds the permissible limit, a signal is sent to open valve 2, directing the water to the ETP for treatment. The sample analysis unit performs monitoring at approximately 30-second intervals, ensuring real-time assessment and reliable control of the cooling water reuse process. The system is equipped with a water meter to measure the amount of dye machine cooling water being reused.

Figure 34: Dye machine cooling water reuse system

4.3. Analysis of the water saving from cooling water reuse system



After a 15-day stabilization period, data were analyzed over three months following the implementation. Table 2 presents the total freshwater consumption, wastewater generation, and percentage of reused water over the three-month period.

Table 24: Total fresh water usage, wastewater generation, reused water and percentage of reused water

Month	Total fresh water usage (m^3)	Wastewater (m^3)	Reused water (m^3)	Percentage of reused water %
January	28560	25691	1921	6.96
February	35383	31844	1803	5.36
March	30573	27490	2059	6.97

During this period, the proportion of recycled water varied between approximately 5.36% and 6.97%, with an average monthly reuse rate of 6.43%. Based on the analyzed data, an estimated 23,000 m^3 of water was conserved annually. These results indicate that a substantial fraction of the wastewater was reused through the reuse of dye machine cooling water.

Before system implementation, all cooling water from the dye machines was discharged directly to the Effluent Treatment Plant (ETP) as wastewater. Following the adoption of the reuse system, water with a defined quality (pH, temperature, TDS, and turbidity) was redirected for reuse, leading to a notable reduction in both wastewater generation and freshwater consumption.

Earlier research has demonstrated that cooling water reuse can reduce freshwater consumption when the stream remains relatively uncontaminated and suitable for direct recirculation with minimal treatment. previous studies have also investigated cooling water reuse, including reuse in wet-cooled power plants (19) and the reuse of cooling water blowdown streams (1). However, reported reuse efficiencies vary widely depending on plant configuration, cooling demand, and monitoring strategies. The literature does not report specific analyses focusing solely on dye machine cooling water reuse in the textile industry. In comparison with studies that rely on periodic sampling or treatment-based recycling, the present system demonstrates the operational feasibility of continuous real-time monitoring combined with automated diversion control. This approach enables safe reuse under dynamic production conditions.

The proportion of reused water varied between monitoring periods, reflecting fluctuations in production schedules, cooling demand, and operating temperatures of dyeing processes. Variability may also result from changes in process chemistry, heat load, and equipment operation, which influence cooling water quality and reuse eligibility. Such operational variability is typical in textile manufacturing, where batch processing and product change overs frequently alter water and energy requirements.

Overall, the implementation of the reuse system enhanced water-use efficiency by decreasing dependence on freshwater sources and reducing the hydraulic load on the ETP, thereby contributing to more sustainable production operations.

5. Conclusions

This study demonstrated that reusing dye machine cooling water in a fabric dyeing and printing facility is a practical approach to industrial water conservation. The real-time monitoring system, which measured pH, temperature, total dissolved solids, and turbidity, ensured the quality of recycled water before reuse. The proportion of recycled water ranged between 5.36% and 6.97%, with an average monthly reuse rate of 6.43%. Data analysis indicated that approximately 23,000 m^3 of water was saved annually, leading to reduced freshwater consumption and wastewater generation.

Before implementation, cooling water from dyeing machines was entirely discharged to the effluent treatment plant. The new system recovered this clean water, minimizing freshwater intake and reducing the hydraulic load on the ETP while also lowering production costs.

Overall, the findings highlight that simple and efficient water reuse systems can significantly enhance sustainability in textile manufacturing and serve as a model for similar facilities in Sri Lanka and other developing countries.

6. References

1. Alkaya E, Demirer GN. Water recycling and reuse in soft drink/beverage industry: A case study for sustainable industrial water management in Turkey. "Resources, Conserv Recycl. 2015;

2. Rajakaruna RMASD, Najim MM., Sewwandi BGN. Future of Water Consumption in Sri Lanka : A comparison with a water-scarce and a water-rich country. In: Open University Research Sessions. 2023.

3. Cate M. Optimization of Dyeing and Finishing Processes in Textile Industry for Reduced Environmental Impact. 2025;

4. Silva M De, Withanaarachchi A. Essential Factors for the Advancement of the Yarn Manufacturing Sector in Sri Lanka : Implications of the Socio-Economic Environment. SLIIT Bus Rev. 2023;03(02):25–54.

5. Thombre N, Patil P, Yadav A, Patwardhan A. A short review on water management and reuse in textile industry – a sustainable approach. Discov Water. 2025;

6. Yin H, Qiu P, Qian Y, Kong Z, Zheng X, Tang Z, et al. Textile Wastewater Treatment for Water Reuse. Processes. 2019;7(34).

7. Shaikh MA. Water conservation in textile industry. Pakistan Text J. 2009;58(11):48–51.

8. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater treatment. Environ Chem Lett. 2019;17(1):145–55.

9. Alam F Bin, Hossain MA. Conservation of Water Resource in Textile and Apparel Industries. J Polym Text Eng. 2018;5(5):11–4.

10. Ozturk E, Koseoglu H, Karaboyacı M, Yigit NO, Yetis U, Kitis M. Minimization of Water and Chemical Use in a Cotton/Polyester Fabric Dyeing Textile Mill. J Clean Prod. 2016;

11. Roth J, Zerger B, De Geeter D, Gomez Benavides J, Roudier S. Best Available Techniques (BAT) Reference Document for the Textiles Industry. 2023.

12. Hoque S, Shahid I, Parvez AAP, Hossain J, Sheen SM. Knitted Denim Fabrics : Fabrication Process and Fibrous Influence on Several Properties of the Fabric. Journel Res. 2022;9(6):286–300.

13. Noor H, Shaikh IA. Implementation and evaluation of sustainable measures for water conservation in denim producing mills of Pakistan. Discov Sustain. 2025;6.

14. Haque S, Nahar N, Sayem S. Industrial Water Management and Sustainability : Development of SIWP Tool for Textile Industries of Bangladesh Industrial water management and sustainability : Development of SIWP tool for textile industries of Bangladesh. Water Resour Ind. 2021;25:100145.

15. Nandy T, Manekar P, Dhodapkar R, Pophali G, Devotta S. Water conservation through implementation of ultrafiltration and reverse osmosis system with recourse to recycling of effluent in textile industry – A case study. Resour Conserv Recycl. 2007;51:64–77.

16. Mikucioniene D, Mínguez-García D, Repon R, Milašius R, Priniotakis G, Chronis I, et al. UNDERSTANDING AND ADDRESSING THE WATER FOOTPRINT IN THE TEXTILE SECTOR : A REVIEW. Autex Res J. 2024;24(1).

17. Alkaya E, Demirer GN. Sustainable textile production : a case study from a woven fabric manufacturing mill in Turkey. Clean Prod. 2013;1(9).

18. Madara DS, Namango SS, Katana H. Potential of Roof Rain Water Harvesting at an industrial setup. J Environ Earth Sci. 2016;6(7):110–7.

19. Biedunkova O, Kuznietsov P, Korbutiak V. Environment Evaluation of return cooling water reuse in the wet cooled power plant to minimise the impact of water intake and drainage. Sustain Chem Environ. 2024;7:100151.

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EP 04

Bridging the Cybersecurity Awareness–Behaviour Gap Among Sri Lankan Internet Users: A Behavioural Risk Analysis

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Background: Despite the expansion of cybersecurity awareness initiatives in Sri Lanka, limited empirical evidence exists on whether cybersecurity knowledge is translated into secure online Behaviour among internet users. Therefore, this study examines the awareness–Behaviour gap among Sri Lankan internet users using a Behavioural risk analysis approach.

Objective/s: To investigate the association between cybersecurity awareness and cybersecurity Behaviour among Sri Lankan internet users and assess the awareness–Behaviour gap as an indicator of Behavioural cybersecurity risk.

Methods: A quantitative cross-sectional survey was conducted among 200 active internet users in Sri Lanka. Participants were recruited through convenience and snowball sampling using online platforms, university networks, workplaces, and community contacts. A structured questionnaire comprising validated five-point Likert-scale items measured cybersecurity awareness and Behaviour. The Behavioural risk analysis framework evaluated both the association between awareness and Behaviour and the discrepancy between their scores. Data were analysed using IBM SPSS Statistics through descriptive statistics, Pearson correlation, and gap analysis.

Results: Respondents demonstrated a moderate level of cybersecurity awareness (mean = 3.84/5.00), while cybersecurity Behaviour was comparatively lower (mean = 3.41/5.00). The awareness–Behaviour gap of 0.43 indicates that cybersecurity knowledge is not consistently translated into secure online practices. Pearson correlation analysis revealed a statistically significant moderate positive association between cybersecurity awareness and Behaviour ($r = 0.52$, $p < 0.01$), indicating that respondents with higher awareness generally reported safer cybersecurity Behaviours. However, the moderate strength of the relationship suggests that awareness alone may not ensure consistently secure practices.

Conclusion/s: Cybersecurity awareness is significantly associated with safer online Behaviour, but knowledge alone is insufficient to ensure consistent cybersecurity practices. Behaviour-focused interventions, such as scenario-based cybersecurity training and simulated phishing exercises, together with enhanced digital literacy programmes, are recommended to strengthen cybersecurity resilience among Sri Lankan internet users.

Keywords: *Behavioural cybersecurity, Cybersecurity awareness, Cybersecurity Behaviour, Cybersecurity risk, Sri Lanka*

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EP 05

Analysis of the Suitability of Harvested Rainwater as a Drinking Water Source

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Background: Water scarcity and increasing demand for safe drinking water have become significant challenges in many parts of Sri Lanka. Rainwater harvesting (RWH) has emerged as a potential alternative water source, particularly in areas with adequate rainfall such as the Nawalapitiya Divisional Secretariat Division in Kandy District.

Objective/s: To evaluate the suitability of harvested rainwater as a drinking water source, assess rainwater quality against WHO and SLS standards, identify an affordable domestic storage system, and propose appropriate purification methods for safe use.

Methods: Field observations, system design analysis, and laboratory testing were conducted using rainwater samples collected from five household RWH systems in Nawalapitiya. Samples were collected during a single sampling period. Physical, chemical, and microbiological parameters including pH, turbidity, conductivity, hardness, nitrate, iron, and coliform/E. coli were analysed and compared with WHO and SLS drinking water standards.

Results: Most physicochemical parameters were within acceptable drinking water limits. pH values ranged from 6.4–6.8, while turbidity remained below 1 NTU. Conductivity, hardness, nitrate, and iron concentrations were generally compliant with standards. Microbiological analysis confirmed the absence of E. coli and total coliforms in all samples. Slight acidity and low mineral content were observed, indicating the need for minimal post-treatment. The evaluated domestic system, comprising a 28 m² roof catchment area and a 750 L storage tank, was adequate to meet basic household water demand.

Conclusion/s: Harvested rainwater in the study area is generally suitable for drinking when supported by appropriate system design and basic treatment. Chlorination is recommended as a simple, low-cost, and effective household disinfection method. The findings demonstrate the importance of both water quality assessment and system design in ensuring safe domestic use. However, the limited sample size of five household systems may affect wider applicability. Future studies should consider larger sample sizes and seasonal variations in water quality.

Keywords: *domestic water supply, drinking water quality, rainwater harvesting, Sri Lanka, water treatment*

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EP 01

Next-Generation Stem Cell Therapies: Bridging the Gap in Cardiac Regeneration for Ischemic Heart Disease: A Narrative Review

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Abstract

Background: Myocardial infarction (MI)-induced heart failure (HF) is a major global health concern since it increases mortality and morbidity rates. The existing treatment approach mostly involves symptom management, thus necessitating the use of stem cell-based regeneration approaches. Some of the common types of stem cells used include mesenchymal (MSC) and induced pluripotent stem cells(iPSC), which have the potential of regenerating heart muscle tissue through angiogenesis, inflammation, and heart regeneration. However, the long-term success of stem cell treatments in heart repair is still limited due to challenges like poor cell survival, low ability to settle in the heart, low retention rates, and risks of causing irregular heartbeats.

Objective: This narrative review aims to evaluate the therapeutic potential of stem cell–based strategies, including MSCs and iPSCs, in cardiac regeneration following myocardial infarction, with particular attention to novel delivery methods that may enhance cell survival and reduce arrhythmogenic risks.

Methods: Results from preclinical animal research and clinical trials pertaining to stem cell treatment for ischemic heart disease were used in a narrative evaluation of published material. In addition to new technologies like CRISPR/Cas9-mediated genetic alteration and exosome-based treatments intended to enhance cell survival, engraftment, and therapeutic efficiency, the review looked at a number of regeneration strategies employing MSCs, iPSCs, and cardiac progenitor cells (CPCs).

Results: The left ventricular ejection fraction (LVEF) has improved somewhat in clinical trials, showed modest LVEF improvement with limited long-term engraftment. Potential arrhythmogenicity is one safety risk that emphasizes the necessity of standard operating procedures for efficient patient care.

Conclusion: Regenerative techniques are becoming more prevalent in stem cell therapy for ischemic heart disease. Low cell survival and retention that affects long-term recovery are the main obstacles. Future developments could include exosome technology, gene-enhanced stem cells, and bioengineering.

Keywords: *ischemic heart disease(IHD), heart failure(HF), stemcell thearpy, CRISPR technology*

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Introduction

Ischemic Heart Disease (IHD) remains the leading cause of mortality and disability worldwide, creating a substantial to the myocardium. Complete occlusion of a major coronary artery can lead to acute myocardial infarction (MI), causing the loss of up to one billion cardiomyocytes within minutes through ischemic necrosis and apoptosis. Due to the limited regenerative capacity of adult human cardiomyocytes, with an estimated turnover rate of less than 1% per year, damaged myocardium cannot be naturally replaced. Instead, the injured tissue undergoes a healing process characterized by inflammatory cell infiltration, degradation of the extracellular matrix, proliferation of cardiac fibroblasts, and formation of a dense collagenous scar. Although this fibrotic scar preserves ventricular wall integrity and prevents cardiac rupture, it lacks contractile function and contributes to pathological ventricular remodelling, including ventricular dilation, wall thinning, hypertrophy of adjacent myocardium, and interstitial fibrosis. Over time, these changes culminate in congestive heart failure (CHF).

While advances in reperfusion therapies, including thrombolysis and primary percutaneous coronary intervention, have significantly improved survival following MI, they have also increased the number of patients living with chronic heart failure. Conventional pharmacological therapies such as beta-blockers, angiotensin receptor-neprilysin inhibitors (ARNIs), angiotensin-converting enzyme inhibitors (ACEIs), and mineralocorticoid receptor antagonists (MRAs) are effective in slowing disease progression but cannot replace lost cardiomyocytes. Heart transplantation remains the only definitive treatment for end-stage heart failure; however, its widespread application is limited by donor shortages, high costs, and the requirement for lifelong immunosuppression.

These limitations have stimulated the development of cardiac regenerative medicine, with stem cell therapy emerging as a promising strategy for myocardial repair. Initial approaches focused on the direct replacement of damaged cardiomyocytes through transplantation of stem and progenitor cells. Although preclinical studies demonstrated encouraging results, clinical outcomes have remained inconsistent. Current evidence suggests that the benefits of many stem cell therapies arise primarily through paracrine mechanisms rather than direct differentiation into functional cardiomyocytes. Stem cells release growth factors, cytokines, extracellular vesicles, and exosomes that promote angiogenesis, reduce inflammation, inhibit apoptosis, and support endogenous repair. Nevertheless, challenges such as poor cell retention, low engraftment rates, and age-related cellular senescence continue to limit therapeutic efficacy. Recent research has therefore focused on advanced bioengineering approaches, direct cellular reprogramming, and cell-free regenerative therapies to overcome these barriers. This review aims to evaluate recent advances in stem cell-based cardiac regeneration and explore emerging strategies that may improve clinical translation for the treatment of ischemic heart disease. Although many review articles have described single stem cell-based therapies for ischemic heart disease, only a limited number offer a direct comparison of mesenchymal stem cells, induced pluripotent stem cells and cardiac progenitor cells while also critically addressing translation obstacles that hinder the clinical success of these approaches. This review consolidates existing evidence on the established and emerging regenerative strategies such as cell-based therapies, exosome-based therapies, direct cardiac reprogramming, biomaterial-enabled delivery strategies and tissue engineering. Additionally, it evaluates regulatory, manufacturing, ethical and clinical impediments that must be addressed to achieve effective clinical utilization of regenerative medicine in ischemic heart disease.

While significant progress has been made in the research of stem cells, translation of regenerative treatments for the treatment of ischemic heart disease continues to be hampered by variable effects, low cell engraftment rates and safety, regulatory, and manufacturing barriers. Hence, this review attempts to thoroughly compare, critically and objectively evaluate the pros and cons and the present state of readiness in the clinics of currently available stem cell-based treatments, in order to compare it against new generation regenerative cell therapy options.

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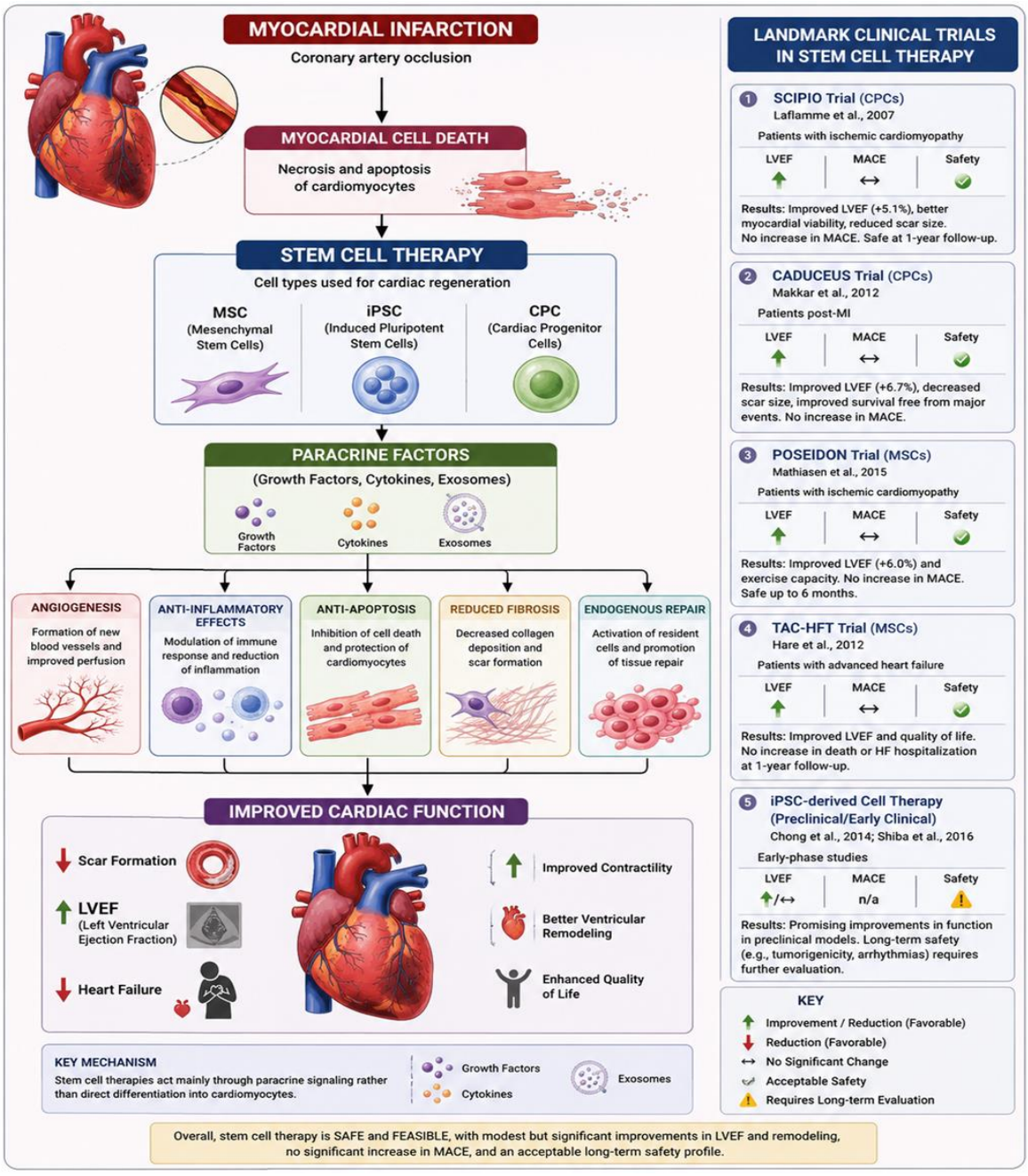

Figure 1. Mechanisms of Stem Cell Therapy in Ischemic Heart Disease

Methods

Literature review: Peer-reviewed biomedical systematic reviews, meta-analyses and clinical trial reports published between 2015 and 2024 were searched in the online databases PubMed and Google Scholar for terms including *"ischemic heart disease", "myocardial infarction", "cardiac regeneration"* and *"diverse stem cells"* in conjunction with the Boolean operators to specify studies of interest for *stem cell therapies in IHD and MI*. Only articles published in the English language, systematic reviews, meta-analyses, preclinical studies, and clinical trial reports on the stem cell-based therapies for cardiac repair were included. Excluded were conference abstracts, editorials, non-peer-reviewed studies published prior to 2015 unless landmark studies were present. Literature was appraised and contrasted based on biological characteristics,

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therapeutic effect, safety profile, and translational *capacity of MSCs, induced iPSCs, CPCs, and other regenerative* approaches, while also the existing problems were summarized as the inconsistencies in preclinical and clinical trials, poor cell survival, insufficient engraftment, premature ageing (senescence), fabrication obstacles, and the regulatory and ethical issues were highlighted.

Results

Evidence from two decades of clinical research demonstrates that stem cell transplantation is generally safe and feasible; however, therapeutic efficacy varies considerably depending on the cell type used. Skeletal myoblasts showed limited clinical benefit and were associated with significant arrhythmogenic complications due to poor electrical integration within host myocardium. Bone marrow mononuclear cells demonstrated only modest improvements in cardiac function and left ventricular ejection fraction (LVEF) during long-term follow-up. MSCs produced more consistent benefits, including reductions in infarct size, attenuation of adverse ventricular remodelling, and moderate improvements in LVEF. These effects appear to be mediated primarily through paracrine signalling rather than direct cardiomyocyte differentiation.

More advanced regenerative strategies involving embryonic stem cells (ESCs) and iPSCs have demonstrated the capacity to generate functional cardiomyocytes and engineered cardiac tissues.

Table 1. Comparison of major stem cell therapies for ischemic heart diseases

Feature	Mesenchymal Stem Cells (MSCs)	Induced Pluripotent Stem Cells (iPSCs)	Cardiac Progenitor Cells (CPCs)
Cell source	Bone marrow, adipose tissue, umbilical cord	Reprogrammed adult somatic cells	Resident cardiac tissue
Differentiation potential	Multipotent	Pluripotent	Cardiac-specific multipotent
Primary mechanism	Paracrine signaling, immunomodulation, angiogenesis	Direct cardiomyocyte replacement and regeneration	Cardiac tissue regeneration and endogenous repair
Cardiac regeneration potential	Moderate	Very high	High
Immunogenicity	Low	Very low (autologous)	Low–moderate
Major advantages	Excellent safety, anti-inflammatory, pro-angiogenic, most clinical experience	Unlimited expansion, personalized therapy, strongest regenerative capacity	Better cardiac specificity and myocardial integration
Major limitations	Poor long-term engraftment, limited cardiomyocyte differentiation	Tumorigenicity, arrhythmia risk, expensive production, quality control	Low cell yield, invasive harvesting, inconsistent outcomes
Clinical readiness	Phase I–III clinical trials (most advanced)	Mostly preclinical/early clinical trials	Early clinical trials

MSCs have the strongest clinical evidence as shown in Table 1 due to their well-established safety, immune modulatory functions, and numerous clinical investigations. iPSCs have the largest regenerative potential as they are pluripotent, yet currently restricted by the issues of tumorgenicity, genomic instability, challenging production and prohibitively expensive

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processes. CPCs are more specific to the cardiac system and integrate into the tissue more readily than MSCs, but their clinical usage is constrained by scarcity of cells and highly invasive procurement methods.

However, challenges related to tumorigenicity, immune compatibility, ethical concerns, and large-scale manufacturing continue to hinder clinical implementation. Direct cardiac reprogramming has also shown promise in experimental models by converting resident cardiac fibroblasts into induced cardiomyocytes, although further research is required before clinical application becomes feasible.

Several barriers to successful clinical translation were consistently identified. Poor survival and engraftment of transplanted cells within the hostile inflammatory environment of the infarcted myocardium remain major limitations. In addition, stem cell senescence in elderly patients reduces regenerative capacity, while variations in trial design, cell dosage, timing of administration, and delivery methods complicate comparisons between studies. Emerging solutions include injectable hydrogels, engineered scaffolds, decellularized matrices, and three-dimensional bio printed tissues, all of which aim to improve cell retention, survival, and therapeutic efficacy.

Discussion

The accumulated evidence indicates a significant paradigm shift in cardiac regenerative medicine. Rather than functioning through direct myocardial replacement, many stem cell therapies exert their effects through paracrine mechanisms that promote angiogenesis, suppress inflammation, reduce apoptosis, and limit adverse remodelling. Stem cells therefore act as biological mediators that stimulate endogenous repair processes rather than directly forming new myocardium.

Addressing the limitations of current therapies will require overcoming challenges related to stem cell senescence, poor cell retention, and inconsistent clinical outcomes. Bioengineered delivery systems such as injectable hydrogels offer promising solutions by enhancing cell survival and prolonging therapeutic activity within the damaged myocardium. Furthermore, emerging technologies including cellular reprogramming, exosome-based therapies, and gene-editing approaches have the potential to overcome many of the biological barriers that currently restrict regenerative success. Integration of regenerative therapies with lifestyle modification, exercise, and metabolic optimization may further improve clinical outcomes and support long-term cardiac repair. Ethical considerations remain an integral component of the clinical development of regenerative medicine. While adult MSCs and iPSCs have addressed much of the ethical concern surrounding ESCs, significant concerns persist related to informed consent, patient expectation, equitable patient access, long-term follow-up, safety and monitoring, as well as preventing unscrupulous providers of non-regulated commercial stem cell therapy. International regulations recommend that regulatory frameworks emphasize ethical review, GMP, timely clinical disclosure and long-term follow-up of treated patients for a safe and responsible clinical translation of these innovative treatments.

Future Perspectives

Future therapeutic approaches for ischemic heart disease are likely to transition from the current reliance on simple stem cell transplantation to more targeted, personalized and biomimetic regenerative treatments. AI and precision medicine will also play increasingly important roles in optimizing treatment timing, stratifying patients according to response predictions (using genomic and imaging information) and in predicting individual treatment outcomes with gene, imaging and patient clinical data. The stem cell-derived exosome, as a cell-free therapy, has garnered substantial interest and can induce angiogenesis, modulate inflammation, mitigate fibrosis, and trigger endogenous cardiac repair, whilst circumventing numerous safety issues associated with direct stem cell transplantation.

In tandem, 3D bioprinting technology has allowed the fabrication of biomimetic cardiac tissue-engineered products and heart patches, which are capable of promoting cell survival, integration and functional restoration post-myocardial infarction.

Additionally, CRISPR/Cas9 gene-editing technology holds great potential to enhance the safety of stem cells and improve their regenerative potential by rectifying genetic errors that promote disease development and reducing the likelihood of tumorigenesis. Patient-specific iPSCs in the context of gene editing, integrated into the personalized stem cell therapy, may also alleviate the limitations of cell immunogenicity and interpatient variability seen with donor stem cells. Though different in terms of development status, these innovations will, with extensive research efforts from multidisciplinary teams, standardization of manufacture, establishment of regulatory pathways and the commencement of further clinical trials, inevitably lead to the clinical implementation of regenerative approaches for ischemic heart disease.

Conclusion

The application of regenerative medicine in treating ischemic myocardium as a follow-up to ischemic heart disease and myocardial infarction has opened up new avenues. Literature studies indicate that stem cells like MSCs have excellent clinical relevance because of their safety profile and immunomodulatory functions. iPSCs possess excellent regenerative capacity, potential tumorigenicity and complex manufacturing may impede their clinical translation.

CPCs are also a cardiac-specific option, but shortage of cells and varied outcomes are concerning factors.

However, the focus has now shifted towards augmenting the innate repair system rather than cell transplantation only. Challenges are being encountered at each step: poor cell retention, cellular senescence, lack of a standardized production process and increased costs. Exosome therapy, direct cardiac reprogramming and 3D bioprinting technology may overcome these limitations in future. The future of regenerative medicine will be built up with the integration of research from various fields, standardization and approval of products, cost-effective manufacturing and large-scale trials with longer follow-up.

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References

1. Madonna R, Van Laake LW, Botker HE, Davidson SM, De Caterina R, Engel FB, Eschenhagen T, Fernandez-Aviles F, Hausenloy DJ, Hulot JS, Lecour S. ESC working group on cellular biology of the heart: tissue engineering and cell-based therapies for cardiac repair in ischemic heart disease and heart failure. Cardiovascular Research. 2019 Mar 1;115(3):488-500.
2. Menasché P. Cardiac cell therapy trials: chronic myocardial infarction and congestive heart failure. Journal of cardiovascular translational research. 2008 Sep;1(3):201-6.
3. Vagnozzi RJ, Maillet M, Sargent MA, Khalil H, Johansen AK, Schwanekamp JA, York AJ, Huang V, Nahrendorf M, Sadayappan S, Molkentin JD. An acute immune response underlies the benefit of cardiac stem cell therapy. Nature. 2020 Jan 16;577(7790):405-9.
4. Campostrini G, Windt LM, Van Meer BJ, Bellin M, Mummery CL. Cardiac tissues from stem cells: new routes to maturation and cardiac regeneration. Circulation Research. 2021 Mar 19;128(6):775-801.
5. Zhang H, Shen Y, Kim IM, Liu Y, Cai J, Berman AE, Nilsson KR, Weintraub NL, Tang Y. Electrical stimulation increases the secretion of cardioprotective extracellular vesicles from cardiac mesenchymal stem cells. Cells. 2023 Mar 11;12(6):875.
6. Heidenreich PA, Bozkurt B, Aguilar D, Allen LA, Byun JJ, Colvin MM, Deswal A, Drazner MH, Dunlay SM, Evers LR, Fang JC. 2022 AHA/ACC/HFSA guideline for the management of heart failure: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Journal of the American College of Cardiology. 2022 May 3;79(17):e263-421.
7. Virani SS, Newby LK, Arnold SV, Bittner V, Brewer LC, Demeter SH, Dixon DL, Fearon WF, Hess B, Johnson HM, Kazi DS. 2023 AHA/ACC/ACCP/ASPC/NLA/PCNA guideline for the management of patients with chronic coronary disease: a report of the American Heart Association/American College of Cardiology Joint Committee on Clinical Practice Guidelines. Circulation. 2023 Aug 29;148(9):e9-119.
8. Takahashi K, Yamanaka S. Induction of pluripotent stem cells from mouse embryonic and adult fibroblast cultures by defined factors. cell. 2006 Aug 25;126(4):663-76.
9. Thomson JA, Itskovitz-Eldor J, Shapiro SS, Waknitz MA, Swiergiel JJ, Marshall VS, Jones JM. Embryonic stem cell lines derived from human blastocysts. science. 1998 Nov 6;282(5391):1145-7.
10. Murry CE, Keller G. Differentiation of embryonic stem cells to clinically relevant populations: lessons from embryonic development. Cell. 2008 Feb 22;132(4):661-80.
11. Chong JJ, Yang X, Don CW, Minami E, Liu YW, Weyers JJ, Mahoney WM, Van Biber B, Cook SM, Palpant NJ, Gantz JA. Human embryonic-stem-cell-derived cardiomyocytes regenerate non-human primate hearts. Nature. 2014 Jun 12;510(7504):273-7.
12. Qian C, Decker EA, Xiao H, McClements DJ. Nanoemulsion delivery systems: Influence of carrier oil on β-carotene bioaccessibility. Food Chemistry. 2012 Dec 1;135(3):1440-7.

13. Oskouei BN, Lamirault G, Joseph C, Treuer AV, Landa S, Da Silva J, Hatzistergos K, Dauer M, Balkan W, McNiece I, Hare JM. Increased potency of cardiac stem cells compared with bone marrow mesenchymal stem cells in cardiac repair. Stem cells translational medicine. 2012 Feb 1;1(2):116-24.
14. Behfar A, Crespo-Diaz R, Terzic A, Gersh BJ. Cell therapy for cardiac repair—lessons from clinical trials. Nature Reviews Cardiology. 2014 Apr;11(4):232-46.
15. Cheever NA, Rosen LD, Carrier LM, Chavez A. Out of sight is not out of mind: The impact of restricting wireless mobile device use on anxiety levels among low, moderate and high users. Computers in Human Behaviour. 2014 Aug 1;37:290-7.
16. Yamanaka S. Pluripotent stem cell-based cell therapy—promise and challenges. Cell stem cell. 2020 Oct 1;27(4):523-31.
17. Elsaka O. Exosome-based Therapeutics in Cardiovascular Disease: Comprehensive Analysis of Current Developments and Future Directions. Journal of Indian College of Cardiology. 2025 Oct 1;15(4):124-31.
18. Guo Y, Pu WT. Cardiomyocyte maturation: new phase in development. Circulation research. 2020 Apr 10;126(8):1086-106.
19. Cui X, Guo J, Yuan P, Dai Y, Du P, Yu F, Sun Z, Zhang J, Cheng K, Tang J. Bioderived nanoparticles for cardiac repair. ACS nano. 2024 Aug 26;18(36):24622-49.
20. Heidenreich PA, Bozkurt B, Aguilar D, Allen LA, Byun JJ, Colvin MM, Deswal A, Drazner MH, Dunlay SM, Evers LR, Fang JC. 2022 AHA/ACC/HFSA guideline for the management of heart failure: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Journal of the American College of Cardiology. 2022 May 3;79(17):e263-421.
21. Eschenhagen T, Bolli R, Braun T, Field LJ, Fleischmann BK, Frisén J, Giacca M, Hare JM, Houser S, Lee RT, Marbán E. Cardiomyocyte regeneration: a consensus statement. Circulation. 2017 Aug 15;136(7):680-6.
22. Passier R, van Laake LW, Mummery CL. Stem-cell-based therapy and lessons from the heart. Nature. 2008 May 15;453(7193):322-9.
23. Sadek H, Olson EN. Toward the goal of human heart regeneration. Cell stem cell. 2020 Jan 2;26(1):7-16..
24. Tzahor E, Poss KD. Cardiac regeneration strategies: staying young at heart. Science. 2017 Jun 9;356(6342):1035-9.
25. Kamao H, Mandai M, Okamoto S, Sakai N, Suga A, Sugita S, Kiryu J, Takahashi M. Characterization of human induced pluripotent stem cell-derived retinal pigment epithelium cell sheets aiming for clinical application. Stem cell reports. 2014 Feb 11;2(2):205-18
26. Addis RC, Epstein JA. Induced regeneration—the progress and promise of direct reprogramming for heart repair. Nature medicine. 2013 Jul;19(7):829-36.
27. Chong JJ, Yang X, Don CW, Minami E, Liu YW, Weyers JJ, Mahoney WM, Van Biber B, Cook SM, Palpant NJ, Gantz JA. Human embryonic-stem-cell-derived cardiomyocytes regenerate non-human primate hearts. Nature. 2014 Jun 12;510(7504):273-7.
28. Gerbin KA, Murry CE. The winding road to regenerating the human heart. Cardiovascular Pathology. 2015 May 1;24(3):133-40.
29. Van Berlo JH, Molkentin JD. An emerging consensus on cardiac regeneration. Nature medicine. 2014 Dec;20(12):1386-93.
30. Rink JC. Stem cell systems and regeneration in planaria. Development genes and evolution. 2013 Mar;223(1):67-84.
31. Liu Y, Bai Z, Li Q, Zhao Y, Li J. Healing and regeneration of the freshwater pearl mussel Hyriopsis cumingii Lea after donating mantle saibos. Aquaculture. 2013 May 10;392:34-43.
32. Behfar A, Crespo-Diaz R, Terzic A, Gersh BJ. Cell therapy for cardiac repair—lessons from clinical trials. Nature Reviews Cardiology. 2014 Apr;11(4):232-46.
33. Rosen MR, Myerburg RJ, Francis DP, Cole GD, Marbán E. Translating stem cell research to cardiac disease therapies: pitfalls and prospects for improvement. Journal of the American College of Cardiology. 2014 Sep 2;64(9):922-37.
34. Telukuntla KS, Suncion VY, Schulman IH, Hare JM. The advancing field of cell-based therapy: insights and lessons from clinical trials. Journal of the American Heart Association. 2013 Oct 10;2(5):e000338
35. He JQ, Ma Y, Lee Y, Thomson JA, Kamp TJ. Human embryonic stem cells develop into multiple types of cardiac myocytes: action potential characterization. Circulation research. 2003 Jul 11;93(1):32-9.

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EP 02

Smart wearable devices for precision medical & personalized healthcare: A Narrative Review

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Abstract

Background: Wearable technology and mobile health (mHealth) system are transubstantiating ultramodern healthcare, enabling real- time, nonstop monitoring for habitual complaint operation, recuperation, and preventative care while advancements in flexible sensors, IoT- enabled devices such as smartwatches, fitness trackers, wearable ECG monitors, and biosensor patches-each differing in sensing capability, connectivity, and clinical application and wireless communication have enhanced device functionality, significant challenges regarding long-term usability, data privacy, and clinical validation persist.

Objective/s: The study looked at the advantages, user acceptance, data security, and implementation issues of wearable technology and mHealth apps in relation to healthcare delivery.

Methods: A literature study was undertaken using research published in the past five months from sources such as PubMed, Scopus, and IEEE Xplore. The evaluation reviewed [30] studies in areas like cardiovascular monitoring, neurological problems, and senior care. Studies were picked using preset inclusion and exclusion criteria approaches. The analysis focused on device accuracy, usability, user engagement, and cloud-based healthcare integration.

Results: Based on the review articles depends on their ease of use and capacity to measure physiological parameters, biochemical profiling, and physical activities, smartwatches, fitness bands, biosensors, and remote monitoring equipment have proven effective in telemedicine. On the other hand, there are differences in clinical use, accuracy, energy consumption, and usability.

Conclusion/s: Personalized healthcare is enhanced by wearable and mHealth devices. Reliability, privacy, accessibility, ethical issues, and user-cantered design should all be covered in future studies.

Keywords: *mHealth, Personalized healthcare, Precision medicine, Remote monitoring, Wearable technology*

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Introduction

Smart wearable devices are advanced electronic technologies designed to be worn on the human body for continuous monitoring, data collection, and communication. First introduced in the 1960s by Edward O. Thorp, wearable technology has rapidly evolved with advancements on the internet, intelligent hardware, wireless communication, and big data. Today, wearable devices are widely used in healthcare, education, fitness, social networking, and military applications. Common examples include smart watches, fitness bands, smart glasses, smart clothing, and implantable medical devices.

In the healthcare sector wearable devices are really important for keeping track of things like heart rate and blood pressure. They can also check how fast you are breathing, your body temperature, blood oxygen level and even your electrocardiogram signals all in time.

These devices have a lot of parts like sensors and microelectronics that work together with wireless technologies such as Bluetooth, Radio Frequency Identification and the Internet of Things. This helps them send information to your smartphone, computer or healthcare provider so they can check on you from afar.

Wearable devices are effective because they do not invade your body you can carry them around easily. They are smart. They can really help with healthcare by preventing problems predicting what might happen giving care and letting you take part in your own healthcare with wearable devices. Wearable devices are making a difference, in the healthcare sector with wearable devices.

Role of the function

This study explores developments in wearable technologies and mobile health applications for precision medicine and personalized healthcare. The study used a narrative literature review approach. A comprehensive literature search was done using three electronic databases: PubMed, Scopus and IEEE Xplore. The search looked for peer-reviewed articles published in English between 2020 and 2025. This was done to ensure real the review included the recent advances in wearable healthcare technologies.

The search used a combination of keywords including technology, smart wearable devices, mHealth, Internet of Things, biosensors, remote patient monitoring, telemedicine, digital health, precision medicine and personalized healthcare. These keywords were used to find studies. Duplicate records were removed before looking at the titles and abstracts to see if they were relevant to the review objectives.

Then full-text articles that met the screening criteria were explore in detail. The study included healthcare devices, biosensors, Internet of Things enabled healthcare systems or mHealth applications that reported outcomes related to device performance, clinical effectiveness, usability, user acceptance or healthcare delivery. Studies that were not in English, editorials, conference abstracts without papers, duplicate records or not related to healthcare applications were excluded.

After applying these criteria 30 relevant studies were selected for the review. Data from these studies were. Compared based on wearable device type sensing technology healthcare application, clinical performance, usability, data security, cloud integration and implementation challenges. The findings from the selected studies were put together to identify trends, research gaps, limitations and future directions for the development and adoption of wearable technologies in personalized healthcare. Wearable technologies are essential for healthcare. The study of technologies is necessary, for precision medicine.

Challenges

One of the major challenges is improving the clinical accuracy and real-time monitoring capabilities of wearable devices. Another challenge is developing secure systems for storing and transmitting sensitive patient information.

Researchers also face difficulties in designing affordable, user-friendly, and energy-efficient wearable technologies suitable for diverse populations. In addition, there is limited evidence-based research on the effectiveness of wearable devices in medical education, patient care, and long-term healthcare monitoring in real-world settings.

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Methods

Type narrative

Wearable technology is cool. People have been working on it since the 1960s. Now we have biosensors and wearable chemo sensors that can help us with our health. We also have health applications and Internet of Things-enabled healthcare systems. These things can help us monitor patients from away and give them the right medicine at the right time.

The studies I explores talk about how sensors and wireless communication and cloud computing and Internet of Things technologies can help us keep an eye on our health in time. They also talk about how we can use devices like smartwatches and motion trackers and biosensors and chemo sensors to check things like our heart rate and blood pressure and body temperature. We can even use these devices to help people who're sick or hurt.

I found these studies by looking at PubMed and Scopus and IEEE Xplore. I only explore studies that were written in English and published between 2020 and 2025. I used keywords like technologies and wearable biosensors and Internet of Things and mobile health and remote patient monitoring. I got rid of any studies that were not about healthcare. That were just editorials.

I ended up with 30 studies that were effective. I explore the types of wearable devices and the technology they use and how they can help us with our health. I also explore best how easy they're to use and how safe they are.

Wearable healthcare technologies are really important, for precision medicine. They can help us prevent diseases and diagnose them early. They can also help us take care of people who're sick or hurt. We still need to do more research and make these technologies better.

Results

Wearable healthcare technologies play an important role in continuous health monitoring, remote patient management, and personalized healthcare. Their performance depends on the sensing technology, device design, intended healthcare application, and level of clinical validation. Medical-grade devices such as wearable ECG patches and continuous glucose monitoring systems generally provide higher diagnostic accuracy because they use clinically validated sensors and algorithms. For example, ECG-based devices directly measure cardiac electrical activity and are more accurate for cardiac monitoring than photoplethysmography (PPG)-based smartwatches, while continuous glucose monitors provide reliable long-term glucose measurements through interstitial fluid monitoring.

Consumer wearable devices, including smartwatches and fitness bands, remain valuable for lifestyle monitoring, disease prevention, and routine health screening because they are affordable, easy to use, and widely accepted. These devices monitor physiological parameters such as heart rate, blood pressure, blood glucose, temperature, respiration, oxygen saturation, sleep patterns, and physical activity. However, their accuracy may decrease during vigorous physical activity, poor sensor-to-skin contact, or irregular cardiac rhythms, and many biosensor-based technologies still require additional clinical validation.

Wearable technologies integrated with the Internet of Things (IoT), cloud computing, artificial intelligence, and mobile health platforms enable continuous collection and transmission of physiological data. This allows healthcare providers to remotely monitor patients, detect disease progression at an early stage, make timely clinical decisions, and develop personalized treatment plans. These capabilities improve chronic disease management, reduce unnecessary hospital visits, enhance patient engagement, and support preventive healthcare, particularly for patients with cardiovascular disease, diabetes, and other long-term conditions.

Despite these advantages, several challenges continue to limit widespread clinical adoption. Important concerns include measurement accuracy, usability, cybersecurity, data privacy, interoperability between wearable devices and healthcare information systems, high implementation costs, and the absence of standardized validation protocols. In addition, many emerging wearable technologies require large-scale clinical studies to establish long-term safety, reliability, and effectiveness.

Future research should focus on improving sensor accuracy, reducing measurement errors, extending battery life, strengthening data security, developing standardized evaluation frameworks, and enhancing interoperability between

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devices and healthcare systems. With continued technological development, stronger clinical evidence, and appropriate regulatory oversight, wearable healthcare technologies are expected to become increasingly integrated into routine clinical practice and play a major role in precision medicine, chronic disease management, and personalized healthcare delivery.

Discussion

Wearable healthcare technologies have really made a difference in healthcare. They let us keep an eye on patients all the time manage them from away find diseases early and give them the right treatment. When we combine these sensors with the Internet of Things, cloud computing, mobile health platforms and artificial intelligence we can collect and analyse data in real time. This helps doctors make decisions especially for patients with long-term diseases like heart problems and diabetes. Wearable technologies also mean people do not have to go to the hospital much they get more involved in their care, and they can get healthcare from far away.

The quality of evidence is not the same for all technologies. Some devices, like ECG patches, continuous glucose monitors and smart blood pressure monitors are very good at diagnosing problems. We use them a lot to monitor the heart manage diabetes and check blood pressure at home. This is because they have sensors and algorithms that have been tested and proven to work. On the hand devices like smartwatches and fitness bands are mostly for staying healthy tracking exercise, sleep and preventing diseases. They are not really for diagnosing problems. New technologies, like biosensor patches and smart textiles have a lot of potential but we need to test them more before we can use them all the time in healthcare. So, when we choose a device, we need to think about what we want to use it for, how accurate it is, how easy it is to use how comfortable it is and what the evidence says.

With all the good things about wearable healthcare technologies there are still some big problems. We are worried about how accurate they're if our data is safe if they can work with other systems if people can afford them if they are approved by the government and if people will keep using them. These devices collect a lot of data, so we need to ensure it is safe and that patients agree to it. We also need to ensure the software is secure and that we follow the rules. Other problems include how much they cost to set up if insurance will cover them how the battery lasts, how comfortable they are and if the data is all in one place. This is especially a problem, in countries that're not as rich.

In the future artificial intelligence, predictive analytics and new biosensors will make healthcare technologies even better. We need to ensure they are safe, reliable and work well. We need to test them ensure we are evaluating them in the same way and work together with different experts. We should keep doing research to make them better ensure they work with systems make them cheaper and keep the data safe. If we can solve these problems more people will use healthcare technologies, and we will have better healthcare and outcomes for patients. Wearable healthcare technologies will be a part of making sure everyone gets the right treatment.

Wearable Technology	**Healthcare Application**	**Advantages**	**Limitations**	**Clinical Evidence**	**Usability**
Smartwatches	Monitoring heart rate, tracking physical activity, observing sleep patterns, ECG tracking	Non-intrusive, simple to operate, enables ongoing observation and distant medical care.	Restricted clinical precision, frequent recharging, reliant on user adherence	Moderate – Endorsed for tracking wellness and initial cardiovascular evaluation yet restricted for conclusive diagnosis.	High – Comfortable, easy to operate, and widely accepted for daily use

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Fitness Bands	Physical activity tracking, calorie expenditure, heart rate monitoring	Affordable, lightweight, promotes healthy lifestyle and preventive healthcare	Limited diagnostic capability, lower sensor accuracy than medical-grade devices	Low to Moderate – Mainly confirmed for tracking fitness and lifestyle instead of clinical diagnosis.	Very High – Simple to wear, user-friendly, and suitable for long-term daily monitoring
Wearable ECG Devices	Continuous cardiac monitoring, arrhythmia detection	Early detection of cardiac abnormalities, supports remote patient monitoring	Motion artifacts, higher cost, requires clinical validation	Strong – Extensive clinical validation and routinely used in cardiovascular care	Moderate to High – Comfortable for prolonged monitoring but requires correct placement
Smart Blood Pressure Monitors	Blood pressure monitoring and hypertension management	Facilitates at-home tracking, decreases hospital visits, aids in managing chronic illnesses.	Measurement accuracy may vary depending on user technique and calibration	Strong – Recommended for home blood pressure monitoring when clinically validated	High – Easy to operate with minimal training
Wearable Biosensors	Monitoring glucose, temperature, oxygen saturation, respiration, biochemical markers	Continuous physiological monitoring, supports early disease detection and personalized healthcare	Sensor degradation, calibration requirements, relatively high development cost	Moderate – Growing clinical evidence; additional validation is required for broader clinical implementation	Moderate – Comfortable designs available, although maintenance requirements vary
Continuous Glucose Monitors (CGMs)	Continuous glucose monitoring for diabetes management	Real-time glucose measurements, improves glycaemic control, reduces finger-prick testing	High cost, sensor replacement required, slight physiological lag	Strong – Well-established clinical evidence for diabetes management and personalized treatment	High – Suitable for long-term continuous use despite periodic sensor replacement

Conclusions

Wearable healthcare technologies have changed the way we take care of people's health. They let us keep an eye on what's going on in our bodies all the time find diseases early take care of patients from far away and give them the right treatment. This is especially helpful for people with heart problems, diabetes and other long-term health issues.

When we connect sensors to the Internet and use artificial intelligence, mobile health apps and cloud computing we can get information in real time and make good decisions about what to do next. This also makes it easier for people to get the healthcare they need.

There are still some problems that stop these technologies from being used everywhere. People are worried about how accurate the measurements if they can work with other healthcare systems if their information is private and safe if they can afford it and if it is approved by the government.

We need to ensure these technologies are safe and work well in the run. We have to test them all the time ensure we are evaluating them in the way keep people's information safe and make them work with the healthcare systems we already have.

In the future we will have better biosensors, artificial intelligence, Internet of Things and digital health technologies. These will make wearable healthcare systems more useful.

If we keep doing research coming up with technologies and making sure the government is watching over everything, we can make wearable healthcare technologies a normal part of taking care of people. This will help us stop diseases from happening take care of long-term health issues make medicine more precise and give people the healthcare that's just right for them. Wearable healthcare technologies will be very important, in healthcare.

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References

1. Lu L, Zhang J, Xie Y, Gao F, Xu S, Wu X, Ye Z. Wearable health devices in health care: narrative systematic review. JMIR mHealth and uHealth. 2020 Nov 9;8(11): e18907.
2. Chen C, Ding S, Wang J. Digital health for aging populations. Nature medicine. 2023 Jul;29(7):1623-30.
3. Guze PA. Using technology to meet the challenges of medical education. Transactions of the American clinical and climatological association. 2015; 126:260.
4. Siddall AG, Powell SD, Needham-Beck SC, Edwards VC, Thompson JE, Kefyalew SS, Singh PA, Orford ER, Venables MC, Jackson S, Greeves JP. Validity of energy expenditure estimation methods during 10 days of military training. Scandinavian journal of medicine & science in sports. 2019 Sep;29(9):1313-21.
5. Haghi M, Thurow K, Stoll R. Wearable devices in medical internet of things: scientific research and commercially available devices. Healthcare informatics research. 2017 Jan 31;23(1):4-15.
6. Guk K, Han G, Lim J, Jeong K, Kang T, Lim EK, Jung J. Evolution of wearable devices with real-time disease monitoring for personalized healthcare. Nanomaterials. 2019 May 29;9(6):813.
7. Qian RC, Long YT. Wearable chemosensors: A review of recent progress. ChemistryOpen. 2018 Feb;7(2):118-30.
8. cheol Jeong I, Bychkov D, Searson PC. Wearable devices for precision medicine and health state monitoring. IEEE Transactions on Biomedical Engineering. 2018 Sep 24;66(5):1242-58.
9. Loncar-Turukalo T, Zdravevski E, Da Silva JM, Chouvarda I, Trajkovik V. Literature on wearable technology for connected health: scoping review of research trends, advances, and barriers. Journal of medical Internet research. 2019 Sep 5;21(9):e14017.
10. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. Health information & libraries journal. 2009 Jun;26(2):91-108.
11. Koydemir HC, Ozcan A. Wearable and implantable sensors for biomedical applications. Annual Review of Analytical Chemistry. 2018 Jun 12;11(1):127-46.
12. Wang Q, Markopoulos P, Yu B, Chen W, Timmermans A. Interactive wearable systems for upper body rehabilitation: a systematic review. Journal of neuroengineering and rehabilitation. 2017 Mar 11;14(1):20.
13. Liang J, Xian D, Liu X, Fu J, Zhang X, Tang B, Lei J. Usability study of mainstream wearable fitness devices: feature analysis and system usability scale evaluation. JMIR Mhealth Uhealth. 2018; 6 (11): e11066 [Internet].
14. Liang J, Xian D, Liu X, Fu J, Zhang X, Tang B, Lei J. Usability study of mainstream wearable fitness devices: feature analysis and system usability scale evaluation. JMIR mHealth and uHealth. 2018 Nov 8;6(11):e11066.
15. Powell L, Parker J, Martyn St-James M, Mawson S. The effectiveness of lower-limb wearable technology for improving activity and participation in adult stroke survivors: a systematic review. Journal of medical Internet research. 2016 Oct 7;18(10):e259.

16. Xu J, Bao T, Lee UH, Kinnaird C, Carender W, Huang Y, Sienko KH, Shull PB. Configurable, wearable sensing and vibrotactile feedback system for real-time postural balance and gait training: proof-of-concept. Journal of neuroengineering and rehabilitation. 2017 Oct 11;14(1):102.
17. Mokhtari F, Cheng Z, Raad R, Xi J, Foroughi J. Piezofibers to smart textiles: A review on recent advances and future outlook for wearable technology. Journal of Materials Chemistry A. 2020;8(19):9496-522.
18. Maddison R, Cartledge S, Rogerson M, Goedhart NS, Ragbir Singh T, Neil C, Phung D, Ball K. Usefulness of wearable cameras as a tool to enhance chronic disease self-management: scoping review. JMIR mHealth and uHealth. 2019 Jan 3;7(1):e10371.
19. Ray PP, Dash D, De D. A systematic review of wearable systems for cancer detection: current state and challenges. Journal of Medical Systems. 2017 Nov;41(11):180.
20. Takei K, Honda W, Harada S, Arie T, Akita S. Toward flexible and wearable human-interactive health-monitoring devices. Advanced healthcare materials. 2015 Mar;4(4):487-500.
21. Baig MM, Afifi S, GholamHosseini H, Mirza F. A systematic review of wearable sensors and IoT-based monitoring applications for older adults–a focus on ageing population and independent living. Journal of medical systems. 2019 Aug;43(8):233.
22. Jung S, Hong S, Kim J, Lee S, Hyeon T, Lee M, Kim DH. Wearable fall detector using integrated sensors and energy devices. Scientific reports. 2015 Nov 24;5(1):17081.
23. Mackintosh KA, Chappel SE, Salmon J, Timperio A, Ball K, Brown H, Macfarlane S, Ridgers ND. Parental perspectives of a wearable activity tracker for children younger than 13 years: acceptability and usability study. JMIR Mhealth Uhealth. 2019 Nov 04; 7 (11): e13858. 10.2196/13858 [Internet].
24. Sequeira L, Perrotta S, LaGrassa J, Merikangas K, Kreindler D, Kundur D, Courtney D, Szatmari P, Battaglia M, Strauss J. Mobile and wearable technology for monitoring depressive symptoms in children and adolescents: A scoping review. Journal of affective disorders. 2020 Mar 15; 265:314-24.
25. Prioreschi A, Nappey T, Westgate K, Olivier P, Brage S, Micklesfield LK. Development and feasibility of a wearable infant wrist band for the objective measurement of physical activity using accelerometery. Pilot and Feasibility Studies. 2018 Mar 1;4(1):60.
26. Bachiri M, Idri A, Fernández-Alemán JL, Toval A. Mobile personal health records for pregnancy monitoring functionalities: Analysis and potential. Computer methods and programs in biomedicine. 2016 Oct 1; 134:121-35.
27. Godinho C, Domingos J, Cunha G, Santos AT, Fernandes RM, Abreu D, Gonçalves N, Matthews H, Isaacs T, Duffen J, Al-Jawad A. A systematic review of the characteristics and validity of monitoring technologies to assess Parkinson's disease. Journal of neuroengineering and rehabilitation. 2016 Mar 12;13(1):24.
28. Van Andel J, Ungureanu C, Aarts R, Leijten F, Arends J. Using photoplethysmography in heart rate monitoring of patients with epilepsy. Epilepsy & Behaviour. 2015 Apr 1; 45:142-5.
29. van der Heide I, Poureslami I, Mitic W, Shum J, Rootman I, FitzGerald JM. Health literacy in chronic disease management: a matter of interaction. Journal of Clinical Epidemiology. 2018 Oct 1; 102:134-8.
30. Sun J, Guo Y, Wang X, Zeng Q. mHealth for aging China: opportunities and challenges. Aging Dis. 2016 Jan; 7 (1): 53–67. 10.14336/AD. 2015.1011 [Internet].

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EP 03

A Quantitative Study on the role of emotion regulation and resilience on physical health outcomes in Sri Lanka

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Background:
Physical health (PH) is a fundamental component of overall well-being and is influenced by a complex interplay of psychological and sociocultural factors. Emotion regulation, resilience, and cultural orientation have been identified as potential determinants of health outcomes; however, limited research has examined these relationships within the Sri Lankan context.
Objective/s:
This study aimed to investigate whether emotion regulation strategies, resilience, and collectivism predict physical health outcomes among adults in the Western Province of Sri Lanka.
Methods:
A predictive correlational design was employed. A convenience sample of 123 adults was recruited through a web-based survey. Participants completed the Emotion Regulation Questionnaire–Short Form, Brief Resilience Scale, Individualism and Collectivism Scale, and SF-12 Health Survey. As normality assumptions were violated, Spearman's rank-order correlation and hierarchical multiple regression analyses were conducted.
Results:
No significant associations were found between emotion regulation strategies, resilience, collectivism, and PH outcomes. The final hierarchical regression model was not statistically significant **(**$R^2 = .032$, Adjusted $R^2 = -.036$, $F(8,114) = 0.47$, $p = .87$**),** indicating that the psychosocial variables did not predict PH. An exploratory secondary analysis found that emotion regulation strategies significantly predicted resilience, with cognitive reappraisal positively and expressive suppression negatively associated with resilience. The null findings may partly reflect the predominantly young convenience sample.
Conclusion/s:
The study contributes to understanding psychosocial determinants of PH in Sri Lanka. Although no significant predictors of PH were identified, the association between emotion regulation and resilience suggests that adaptive emotional regulation may support psychological resilience. As cultural and contextual influences were not directly measured, their potential role requires further investigation. Given the convenience sampling approach, the findings should be interpreted cautiously and may have limited generalisability. Future research should examine these relationships in larger, more representative Sri Lankan samples.

Keywords: *Physical Health (PH), Cognitive Reappraisal, Expressive Suppression, Resilience, Collectivism*

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EP 04

A Psychological Exploration of Sri Lankan Youth's Lived Experiences during 2022 Economic Crisis

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Background: The 2022 economic crisis in Sri Lanka severely disrupted young adults' education, employment, and identity formation. Limited qualitative research has explored how Sri Lankan youth made sense of these experiences and sustained psychological wellbeing.

Objective/s: This study examined how the 2022 crisis reshaped Sri Lankan youth's purpose, meaning, and future orientation, and identified factors enabling resilience.

Methods: A qualitative design using Interpretative Phenomenological Analysis (IPA) was adopted, chosen over thematic analysis or grounded theory for its idiographic, meaning-centred focus. Six participants aged 23–27, resident in Sri Lanka throughout 2022, took part in semi-structured interviews (50–60 minutes). Purposive sampling captured variation in gender and region. A sample of six reflects IPA guidance for single-researcher studies, prioritising depth and information power over breadth. Analysis followed Smith et al.'s (2009) six-stage process, supported by a reflexive journal.

Results: Three master themes emerged within this sample. First, disrupted futures and reconstructed purpose: participants with intrinsically grounded purpose appeared to experience less disruption than those with externally anchored plans, a pattern observed in this sample rather than a general claim. Purpose was rebuilt through values-level reframing. Second, meaning-making and self-transformation: meaning emerged through relational, vocational, service-based, faith-based, present-moment, and civic pathways, with self-transcendent, civic-oriented purpose appearing across all six accounts. As one participant reflected on the Aragalaya (the 2022 citizen protest movement): "it gave me hope." Third, resilience appeared supported by family, spiritual practice, cognitive reframing, and collective solidarity, without formal mental health support.

Conclusion: Within this small sample, intrinsic purpose appeared to buffer collective adversity, and resilience seemed supported by informal, relational resources rather than individual traits. Findings are context-specific and may not transfer to all Sri Lankan youth but point to the value of cultivating intrinsic purpose and community connection before crises arise. Future research should use longitudinal, more diverse samples.

Keywords: *economic crisis, interpretative phenomenological analysis, meaning-making, purpose, resilience, youth experience*

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