



KEMENTERIAN PENDIDIKAN TINGGI



اؤنۋېرسىتى تېكنىكىل مالېسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PROCEEDINGS OF INTERNATIONAL INNOVATIVE RESEARCH AND INDUSTRIAL DIALOGUE 2026

iIRID2026

Advancing Malaysia's Higher Education Transformation: Fostering
AI-Driven University-Industry Collaboration for Smart Manufacturing Excellence

14 – 15 OCTOBER 2026

Universiti Teknikal Malaysia Melaka

THEME:

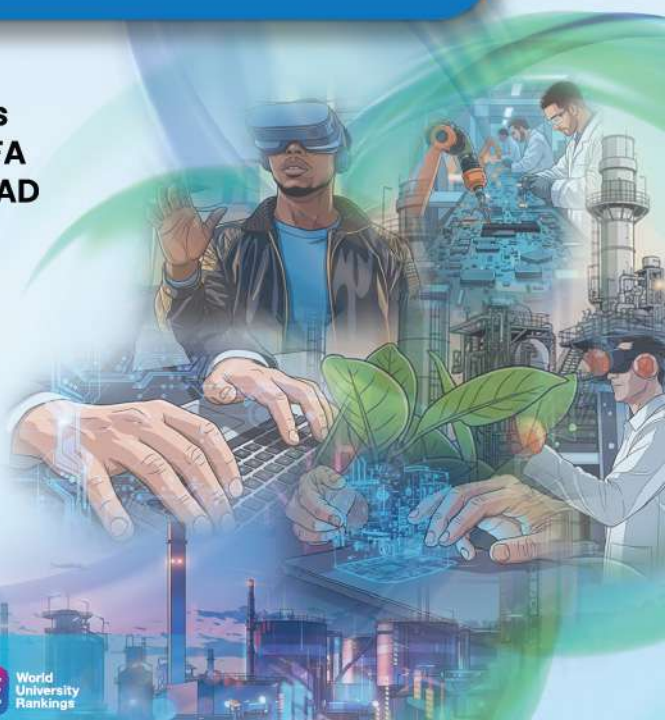
**"Fostering Industry–Academia Innovation:
Sustainable Design, Technopreneurship,
and Quality Systems"**

**Chief of Editors
ZALEHA MUSTAFA
EFFENDI MOHAMAD**

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Universiti Teknikal Malaysia Melaka

2026

© Universiti Teknikal Malaysia Melaka
eISBN: 978-629-7130-01-9

FIRST PUBLISHED 2026

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Member of the Malaysian Scholarly Publishing Council (MAPIM)
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Published in Malaysia by

Penerbit UTeM Press
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
Phone: +606 229 2133 Fax: +606 229 2433

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PREFACE

The 6th International Innovative Research and Industrial Dialogue 2026 (iIRID 2026), hosted by the Faculty of Industrial and Manufacturing Technology and Engineering (FTKIP), Universiti Teknikal Malaysia Melaka (UTeM), provides an important platform for advancing research, innovation, and collaboration in engineering and technology. The event is jointly organised by FTKIP, the RICE UTeM–Melaka Collaboration Management Centre, and the Centre of Smart Systems and Innovative Design (CoSSID).

Guided by the overarching theme “Advancing Malaysia’s Higher Education Transformation: Fostering AI-Driven University–Industry Collaboration for Smart Manufacturing Excellence,” iIRID 2026 reflects the growing importance of artificial intelligence, digitalisation, and smart manufacturing in strengthening industrial competitiveness. It brings together researchers, academics, industry practitioners, and postgraduate students to exchange knowledge, present research findings, and explore emerging technological developments.

These proceedings, with the focus title “**Fostering Industry–Academia Innovation: Sustainable Design, Technopreneurship, and Quality Systems,**” bring together contributions in sustainable and human-centred design, product innovation and technopreneurship, and quality engineering.

The papers examine innovation from technical, human, environmental, entrepreneurial, and quality perspectives. They address the development of sustainable products and systems, the translation of research into commercially relevant solutions, and the application of quality principles to improve organisational and operational performance. Collectively, these studies demonstrate that meaningful innovation requires not only technological advancement but also a clear understanding of user needs, environmental responsibility, market readiness, and consistent quality.

Through its industrial forums and online research presentation sessions, iIRID 2026 strengthens engagement between universities and industry. It encourages the practical application and commercialisation of research while contributing to the development of future-ready talent. It is hoped that the contributions presented in these proceedings will inspire further collaboration and support the development of responsible, sustainable, and industry-relevant solutions within Malaysia and beyond.

We sincerely thank all authors for their valuable contributions and the reviewers for their time, expertise, and constructive feedback. We also acknowledge the editors, session chairs, organising committee members, collaborating institutions, industry partners, and sponsors for their dedication and continued support in making this publication possible.

Zaleha Mustafa
Effendi Mohamad

iIRID2026

**ERGONOMICS, BIOMEDICAL
& SUSTAINABLE DESIGN**



User Driven Sustainable Sanitation Design Framework for Public Toilets

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Abstract. Public toilets are an important component of the urban service system, and their effectiveness directly impacts public health, convenience, accessibility and the environment. Sustainable design of public toilet facilities often focuses on technical issues and lacks a systematic approach to translating user requirements into measurable engineering priorities. The objective of this study is to analyze the use of Quality Function Deployment (QFD) as a tool for designing sustainable public toilets. The data source is a survey of 50 public toilets users in Malang, Indonesia. The survey instrument included 36 statements on a five-point Likert scale, grouped into nine user requirements dimensions: design and comfort, materials and construction, supporting facilities, maintenance and upkeep, cleanliness and hygiene, functionality and efficiency, user behavior and awareness, location and accessibility, and water management. An analysis of the House of Quality was performed to investigate the importance weights of the customers. Conventional QFD relationship coding was used to prioritize technical responses. The average score was 4.19, indicating that there was strong contextual support for environmentally sustainable public restrooms. The requirement dimension of cleanliness, hygiene and water management was the most rated with the mean score of 4.33. The QFD results reveal five major technical priority areas, namely: ergonomic and efficient spatial configuration, durable antibacterial materials, natural ventilation and daylighting, cleaning automation assistance, and water conservation systems. This study provides a definitive decision support framework that links contextual user evidence, sustainability goals and implementable design strategies for the deployment of fixed and portable public toilets.

Introduction

Public toilets are minor urban infrastructures that play an important role in public health, user dignity, comfort, accessibility and perceived quality of public services. Many urban public restrooms are inconsistent in cleanliness, use water inefficiently, have poor ventilation, are not accessible, and do not adequately accommodate the needs of different user demographics [1]–[5]. Such constraints can undermine public confidence, as well as the overall effectiveness of sanitation services, even where the basic physical infrastructure is in place. Sustainability factors have added complexity to the planning of public toilets. Modern facilities are expected to decrease water consumption, use sustainable and resilient materials, improve energy efficiency, provide for efficient wastewater management, and sustain operational viability and ease of maintenance [6]–[8]. Environmental goals are intrinsically linked to user experience as sanitation facilities tend to be accepted when they are perceived as clean, safe, comfortable and reliable. Public toilets design should be considered as a socio-technical challenge, requiring municipalities and designers to systematically translate user expectations into clearly prioritized engineering solutions.

Quality Function Deployment (QFD) is an effective approach for this purpose, as it converts user feedback into technical design specifications by means of the House of Quality (HoQ) [9]–[12]. The application of QFD for product and service development is widespread; however, the use of QFD for integrating contextual factors and specific user requirements, sanitation sustainability and viable public toilet design solutions is still significantly limited, especially in the case of Indonesia. This research proposes a practical QFD framework for sustainable public toilets design in Malang, Indonesia. The study aims to develop a clear decision support framework for early-stage municipal design priorities.

Methodology

This research was conducted using an exploratory design approach by conducting a contextual survey of environmentally sustainable public toilet facilities in Malang, Indonesia. The first sample consists of 50 respondents chosen from users of public toilets in the urban area through nonprobability convenience sampling. However, we did not keep detailed demographic quotas and site-specific sampling records in the archived documentation. Participant responses were quantified on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The data were derived from an applied design study rather than a comprehensive respondent-level statistical database; thus, the findings were contextual evidence for the determination of design priorities rather than representative estimates of the urban population. The survey instrument was composed of 36 evaluative statements that were organized into nine constructs. These constructs were design and comfort (A), materials and construction (B), supporting facilities (C), maintenance and upkeep (D), cleanliness and hygiene (E), function and efficiency (F), user behavior and awareness (G), location and accessibility (H), and water management (I). These factors were developed based on previous studies on public restroom design, sanitation service quality, accessibility, principles of sustainable design, and the use of Quality Function Deployment (QFD) to translate user needs into technical specifications [2]–[12]. The analysis started with a calculation of descriptive means at a construct and item level. We carried out a study to determine the most and the least strongly expressed user preferences and employed construct-level means as customer importance ratings in the House of Quality. In QFD approach, nine groups of customer requirements were identified as the WHATs, and ten proposed technical responses were considered as the HOWs. The usual QFD procedure was to represent the strength of the relationships by numerical values, 9 for strong, 3 for moderate and 1 for weak [9]–[12].

For each technical response, the absolute weight was calculated by summing up the products of customer importance ratings and relationship values. The relative priority of each response was obtained by dividing the absolute weight of each response by the total technical weight and expressing the result as a percentage. The rankings were taken as proxies of the priority of the designs, not as exact causes, particularly since many subsequent technical responses showed little difference in percentage weights.

Results and Discussion

The overall mean of all the factors was 4.19, which shows a high level of user endorsement for environmentally sustainable public toilet facilities in the setting of the survey. Of the nine factors, cleanliness and hygiene and water management were rated the highest, with an average of 4.33 each. Then, design and comfort (4.20), materials and construction (4.18), user behavior and awareness (4.18) and location and accessibility (4.16) were found. Supporting facilities had the lowest mean value but the score was still favorable with a mean of 4.07. This distribution suggests that users relate sustainability to concrete and pragmatic service results like cleanliness, dependable water availability, comfort and ease of use.

Table 2. Customer's level requirement weights.

Code	Customer requirement construct	Mean	Interpretation
A	Design and comfort	4.20	High agreement
B	Materials and construction	4.18	High agreement
C	Supporting facilities	4.07	Positive agreement
D	Maintenance and upkeep	4.12	Positive agreement
E	Cleanliness and hygiene	4.33	Very high agreement
F	Function and efficiency	4.12	Positive agreement
G	User behavior and awareness	4.18	High agreement
H	Location and accessibility	4.16	High agreement
I	Water management	4.33	Very high agreement

The results provide further evidence for this interpretation. The most important attributes were availability of clean water, users' awareness of toilet maintenance, effect of toilet conditions on the public perception of facilities, availability of soap, clean water and tissue. Senior and disabled facilities, robotic cleaning, the use of local materials and social responsibility were graded lower. Yet all these items had average values greater than 3.70. As such they should be considered secondary priorities for future improvement, not as redundant or unwelcome characteristics.

The House of Quality translated the nine categories of user requirements into ten technical responses for design. Ergonomic design and efficient use of space were given the highest relative priority with a weight of 11.5 per cent. This ranking indicates the importance of spatial planning in terms of user circulation, wet and dry zones, privacy, accessibility and maintenance efficiency. Durable and antibacterial materials ranked second at 10.8%, emphasizing the significance of material selection in achieving hygienic conditions, reducing maintenance requirements, and increasing the lifespan of the facility. The third was natural ventilation and daylight usage, at 10.4%, which highlights the need for passive environmental strategies to improve comfort, odor management, and decrease reliance on energy-intensive systems.

Fourth in importance (relative weight 10.2%) came cleaning automation or self-cleaning assistance, then water-efficient flushing systems (9.9%) and wastewater treatment and reuse technologies (9.7%). The findings collectively indicate that a sustainable design for a public toilet should include reliable hygiene performance as well as efficient management of water and other resources. Other priorities were the use of recycled and environmentally friendly materials, accessibility for the elderly and people with disabilities, visual cues to encourage hygienic practices and strategic site selection to improve the environmental aesthetics. The small differences in percentage weights imply that these technical responses are to be understood as elements of a common design strategy, rather than as discrete and separate metrics. The HoQ values indicate the relative importance of each design response. Municipal decisions on implementation must also consider funding constraints, technical capacities, maintenance resources, local conditions and trade-offs between expected benefits and operational feasibility.

Table 3. Technical responses using the house of quality.

Rank	Technical response	Priority (%)	Design implication
1	Ergonomic design and efficient spatial layout	11.5	Improves comfort, circulation, and usable floor efficiency.
2	Durable and antibacterial materials	10.8	Supports hygiene and reduces maintenance intensity.
3	Natural ventilation and daylighting	10.4	Enhances comfort while lowering energy dependence.
4	Cleaning automation or self-cleaning support	10.2	Improves service consistency and cleaning efficiency.
5	Water saving flush system	9.9	Reduces water consumption without undermining core function.
6	Wastewater treatment and water reuse	9.7	Strengthens environmental performance and circular water use.
7	Recycled and environmentally friendly materials	9.2	Supports lower material footprints and greener construction.
8	Accessible facilities for older users and users with disabilities	8.7	Improves inclusive access and service equity.
9	Visual education and cleanliness signage	7.3	Promotes hygiene compliance and user responsibility.
10	Strategic placement and environmental aesthetics	7.3	Improves visibility, safety perception, and contextual fit.

The priority framework was re-constructed into two conceptual alternatives. The stationary urban eco toilet is suitable for parks, terminals, markets and other permanent public places. It emphasizes ergonomic zoning, durable anti-bacterial finishes, passive ventilation, natural light, efficient flushing, grey water reclamation, localized wastewater management and routine cleaning support. The portable modular toilet is perfect for events, tourist attractions, temporary public areas and emergency situations. It has a small unidirectional setup, modular panels that are washable, antimicrobial surfaces, passive ventilation stacks, energy-efficient fans, minimal water use and service or treatment cartridges that are removable.

Sustainable planning of public toilets should start from user needs that mainly promote trust: clean water, hygiene, odor management, comfort and reliable maintenance. Even if its relative House of Quality rank is lower than the factors concerning hygiene, accessibility should be kept as a mandatory design criterion. The lower valuations of disability-friendly designs and amenities for older users may be related to unfamiliarity with these features in existing services rather than a reduced social importance. Thus, during value engineering and budget changes inclusive access needs to be protected with the highest rated technical solutions.

Figure 1 shows that the design concept has been translated into a full-scale portable toilet unit with a glossy green exterior, arched roof profile, louvered ventilation, a raised entrance threshold, and an interior equipped with a toilet bowl, washbasin, water-supply connection, exhaust fan, and ceiling-mounted water component. The visual evidence confirms the feasibility of the modular shell and basic sanitary installation. Compared with the design rendering in Figure 5, the prototype demonstrates stronger material realization and spatial usability, while still requiring further refinement in accessibility details, finishing consistency, internal drainage protection, and maintenance documentation before broader public deployment.



Figure 1. Full scale prototype of the portable public toilet.

Conclusion

This study proposes an exploratory application of Quality Function Deployment (QFD) to support sustainable public toilet design, drawing on contextual survey data collected from 50 users in Malang, Indonesia. The results indicate a strong preference for environmentally responsible toilet facilities, with cleanliness and hygiene as well as water management identified as the most critical groups of user requirements. Through the House of Quality, these expectations were converted into several priority technical responses, including ergonomic spatial arrangement, durable antibacterial materials, natural ventilation and daylight utilization, automated cleaning assistance, and water-efficient flushing systems.

The main contribution of this research is the development of a comprehensive decision support framework linking user requirements and sustainability objectives to viable engineering solutions for permanent and portable public toilet facilities. However, the study has limitations regarding the contextual scope of the sample and the use of aggregated archival data. These conditions do not allow for reliability assessment, factor validation, subgroup analysis or broader statistical inference. Further studies should be conducted with a larger and more diverse sample of participants, with complete respondent-level data sets, with additional weighting approaches such as Analytic Hierarchy Process or

fuzzy Quality Function Deployment, and with field evaluations to determine whether the proposed priorities lead to measurable improvements in hygiene, accessibility, maintenance effectiveness, and environmental performance.

Acknowledgement

The authors gratefully acknowledge the archived survey data and design synthesis resources that supported the development of this applied QFD framework. Any remaining limitations are the responsibility of the authors.

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Feasibility Study of Grid-Connected Solar Photovoltaic (GCPV) Carpark Rooftop at Public University by PVSyst

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Abstract— The increasing demand for clean energy in Malaysia has encouraged academic institutions to adopt renewable technologies to reduce grid dependence and carbon emissions. At Universiti Teknikal Malaysia Melaka (UTeM), rising electricity usage at FTKIP highlights the need for a sustainable and efficient power solution. This study designs and evaluates a grid-connected photovoltaic system for a carpark rooftop using the PVSyst simulation tool. Site data, meteorological conditions, and system parameters such as tilt angle, azimuth, and losses were analyzed under equatorial climate. The proposed system yields 558,285 kWh annually, with simulations at 5°, 10°, and 15° producing 545,693 kWh, 539,706 kWh, and 531,101 kWh. Although 5° provides the highest output, 10° is selected for better solar exposure, rainwater runoff, and reduced dust accumulation. The system supplies 539,706 kWh yearly, achieving a 77.90% performance ratio, 11.04% CUF, and lowering CO₂ emissions by 7,658.76 kg. The results demonstrate the practicality of solar car park rooftops in tropical universities.

Introduction

The global shift toward renewable energy is driven by concerns over fossil-fuel depletion, greenhouse gas emissions, and climate change [1] – [3]. Solar photovoltaic (PV) systems have become one of the most widely adopted renewable technologies due to their scalability, declining cost, and suitability for tropical climates [4], [5]. In Malaysia, solar PV adoption has accelerated through national initiatives such as the Net Energy Metering (NEM) and Self-Consumption (SELCO) schemes [6], [7].

At UTeM, the FTKIP building exhibits increasing annual electricity consumption, creating a pressing need for alternative energy sources. The problem addressed in this study is the absence of a sustainable, high-yield energy system capable of offsetting FTKIP's rising load. The scope of this work focuses on evaluating the feasibility of installing a grid-connected solar photovoltaic (GCPV) system on the FTKIP carpark rooftop. The objectives are to evaluate the electrical energy demand of the FTKIP building using collected annual energy consumption data and to model and simulate various photovoltaic system configurations for the FTKIP building using PVSyst software.

At UTeM, the FTKIP building exhibits increasing annual electricity consumption, creating a pressing need for alternative energy sources. The problem addressed in this study is the absence of a sustainable, high-yield energy system capable of offsetting FTKIP's rising load. The scope of this work focuses on evaluating the feasibility of installing a grid-connected solar photovoltaic (GCPV) system on the FTKIP carpark rooftop. The study scope includes the collection of 2022 annual energy consumption data obtained from the central energy monitoring system managed by the Pusat Alam Sekitar Pintar (CENSEi), Universiti Teknikal Malaysia Melaka (UTeM), design GCPV system using PVSyst, evaluate system performance under three tilt angles and identify the optimal configuration for tropical conditions. Assess energy yield and carbon reduction potential. Carpark PV systems have gained attention globally due to their dual functionality providing shade while generating electricity [8]. Studies in Thailand, Switzerland, and Saudi Arabia demonstrate their potential for high energy yield and efficient land use [9] – [11]. This study contributes to the growing body of knowledge on campus-based renewable energy deployment.

Solar PV systems are categorized into off-grid, hybrid, and grid-connected configurations, with grid-connected systems being the most common in institutional settings. Bifacial PV modules have shown improved performance due to rear-side irradiance capture, especially in open-rack or carpark installations. Performance indicators such as Performance Ratio (PR), Capacity Utilization Factor (CUF), and specific yield are widely used to evaluate system efficiency. In Malaysia, studies have demonstrated the economic and environmental benefits of PV adoption in universities and public facilities [12]. Carpark PV systems have been shown to outperform rooftop systems in certain conditions due to better ventilation and reduced thermal losses. Simulation tools such as PVSyst are widely used for PV system design and performance prediction, offering detailed modelling of shading, losses, and irradiance [13].

Methodology

The proposed site (Figure 1) is the rooftop car park of the Faculty of Industrial and Manufacturing Technology and Engineering (FTKIP), Universiti Teknikal Malaysia Melaka (UTeM) in Durian Tunggal, Melaka, Malaysia (2.31°N, 102.30°E). The academic complex includes an auditorium, lecturer blocks and rooms, the main FTKIP lobby, classrooms, and several laboratories in Blocks A and B. The rooftop was chosen because it is large and minimally shaded, making it suitable for solar PV to serve the faculty. FTKIP's annual energy use is about 160,000 kWh, with fairly steady monthly demand and higher loads at the start of semesters and during exams; the yearly consumption peaks in March and is lowest in December. A 407 kWp PV system is proposed, the available area (1,817 m²) can generate more than twice the faculty's annual demand. Using a specific yield of 1,327 kWh/kWp/year, the system is estimated to produce 539,706 kWh/year ($\approx 337\%$ of the building's consumption), allowing surplus export under Malaysia's NEM or self-consumption with battery storage. Besides cost and emissions reductions, the installation supports teaching, training, and research on energy management, grid export, self-consumption, and Battery Energy Storage System (BESS) operation.

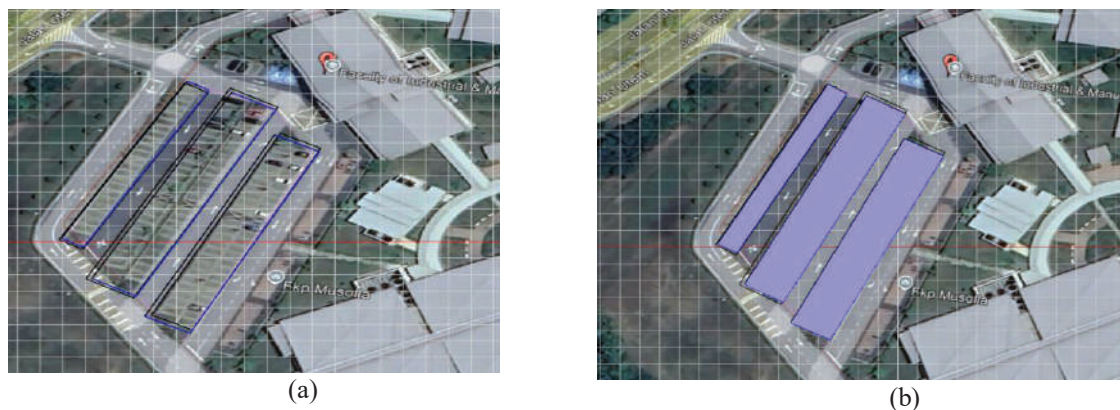


Figure 1: (a) Proposed area for the PV system and (b) Proposed area with solar panel using PVSyst software

Results and Discussion

Three tilt angles (5°, 10°, and 15°) were simulated (Table 1). The 5° tilt produced approximately 545,693 kWh/year with a performance ratio (PR) of 78.20%. The 10° and 15° tilts yielded 539,706 kWh/year and 531,101 kWh/year, with PRs of 77.86% and 77.42%, respectively. Although each tilt gives slightly different energy yields and PRs, 10° was selected for this study because it comfortably exceeds the faculty's annual demand of 160,000 kWh. While a 15° tilt is often cited as optimal for Malaysia, a 10° inclination is a practical compromise that balances energy yield with structural and rainfall considerations. Conventionally, PV arrays in the Northern Hemisphere face south and those near the equator

face east; however, several studies show that a southeast orientation can increase annual energy output by up to 20%. Accordingly, this study adopts a southeast-facing orientation with a 10° tilt to optimize performance under Malaysian climatic conditions. Estimated CO₂ savings for the three tilt options are 7,751.84 tons, 7,658.76 tons, and 7,524.98 tons, respectively. The carbon balance (CB), representing net CO₂ reduction over the system lifetime, is calculated using equation (1), where E_{grid} is the annual energy exported to the grid, Project Lifetime is in years, LCE_{grid} denotes grid life-cycle emissions, and LCE_{system} denotes the PV system's life-cycle emissions (kg CO₂) [14].

$$CB = (E_{grid} \times Project\ Lifetime \times LCE_{grid}) - LCE_{system} \quad (1)$$

Table 1: Simulation of different tilt angles

Tilt angle	5°	10°	15°
Production Energy (kWh/year)	545,693	539,706	531,101
Performance Ratio (%)	78.20	78.86	77.42
CO ₂ Emissions (tons)	7751.84	7658.76	7524.98

As for sun path orientation, performance ratio and normalized production, the incidence angle modifier varies based on the system's tilt angle during installation. Different tilt angles result in different incidence angle modifiers at specific locations. As in Figure 2(a) stated that fixed plane 10° and tilts of -61°. Other than that, it has shown the value of attenuation for diffuse and albedo for 0.016 and 0.377 respectively. This is also known as the sun path or diagram of the site. The shading in PVSyst requires the use of a horizon line. The longest day is 22 of June and the shortest day is 22 of December, March and September are two months whereas the day and night are equal. Shading losses occurred mostly in the morning between 0730 until 0930 throughout the year. For example, in June, at 0800 and 15° sun height, it has 10% of shading losses. These losses occurred in the rest of the month with a different sun height and within the time in between 0800-0830. To summarize, as the sun's height increases, the shading losses will decrease.

The simulated 407 kWp monocrystalline photovoltaic system achieved an annual average Performance Ratio (PR) of 77.9%. Figure 12(b) illustrates the monthly variation in PR values and Figure 12(c) shows the normalized production parameters, including collection losses, system losses, and useful energy output per installed capacity, expressed in kWh/kWp/day. The collection loss (L_c), system loss (L_s), and final yield (Y_f) were recorded as 0.12, 0.13, and 3.64, respectively. Overall system losses are reflected through the relationship between the Performance Ratio, final photovoltaic system yield (Y_f), and reference yield (Y_r). The calculation of PR as given in (2) [15],[16],[17],[18].

$$PR = \frac{Y_f}{Y_r} \quad (2)$$

The energy generated by the PV panels differs from the energy injected into the grid due to conversion processes and system losses, as the PV array produces DC electricity that must be converted into AC before grid integration, with additional losses occurring from inverter inefficiencies and AC wiring. On a yearly basis, the 407 kWp monocrystalline PV system injects approximately 539,706 kWh of AC energy into the grid, with the highest monthly output recorded in March at 51,184 kWh and the lowest in June at 39,213 kWh. The system performance is influenced by site-specific meteorological conditions, where key parameters include global horizontal irradiation (1719.3 kWh/m²), horizontal diffuse irradiation (949.89 kWh/m²), ambient temperature (27.46 °C), global incident irradiation on the collector plane (1705.0 kWh/m²), and effective global irradiance (1617.2 kWh/m²), with all monthly and annual values summarized in Table 2. Based on these irradiation conditions, the system generates 558,285 kWh of DC energy annually, which reduces by approximately 3.33% after

conversion to AC energy due to inverter and system losses, resulting in the final exported energy of 539,706 kWh.

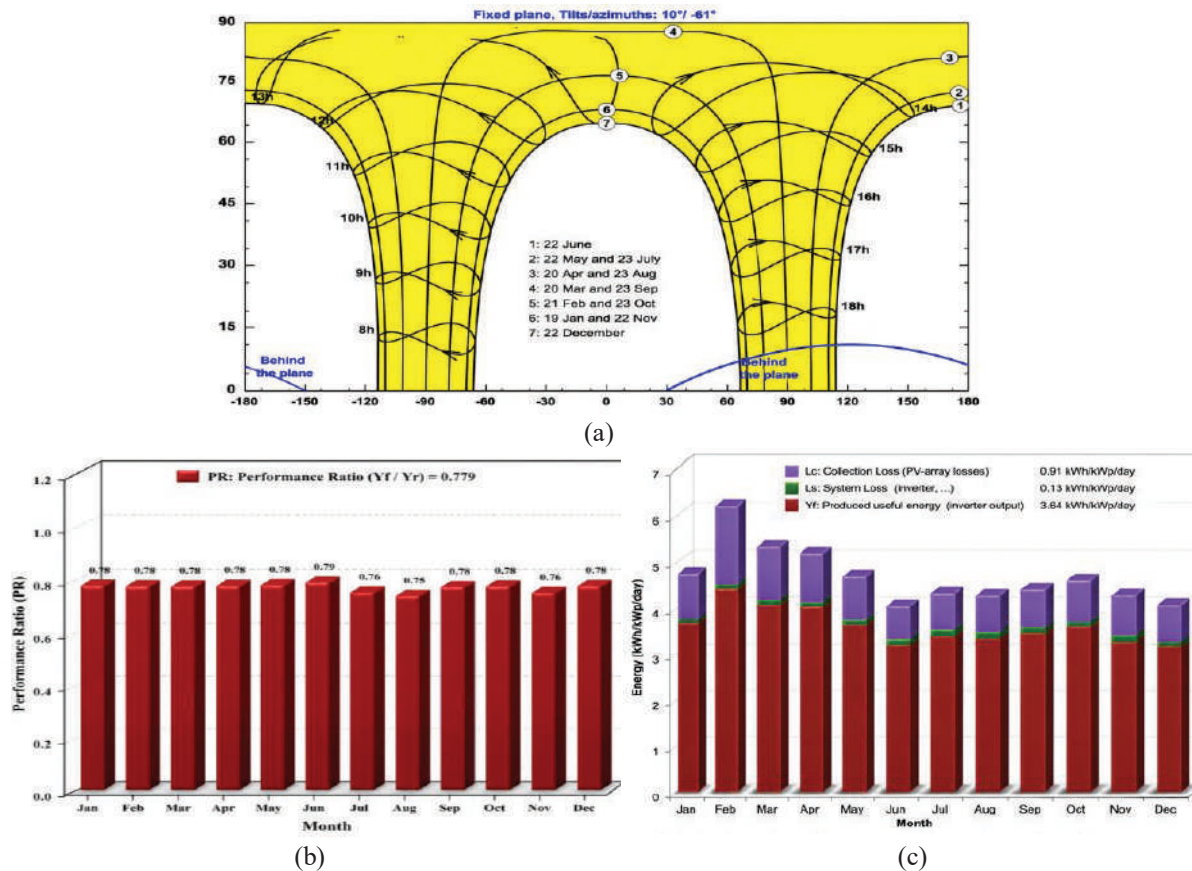


Figure 2: (a) Sun path moving direction, (b) Performance Ratio (PR) and (c) Normalized Energy Production per Installed kWp

Table 2: Balances and main results

Month	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray kWh	E_Grid kWh	PR ratio
January	148.0	69.62	26.90	151.6	143.4	49517	48354	0.784
February	154.3	76.00	27.49	156.6	148.8	51139	49997	0.785
March	161.9	87.69	27.87	160.7	152.6	52406	51184	0.784
April	159.8	84.31	27.71	155.4	147.9	50940	49736	0.787
May	159.8	70.10	28.27	144.3	137.3	47203	46034	0.785
June	159.8	72.66	27.71	122.4	116.1	40231	39213	0.788
July	140.4	85.62	27.73	136.6	129.5	44906	42315	0.762
August	141.3	81.93	27.57	136.9	130.0	44903	41848	0.752
September	138.2	82.81	27.11	134.7	127.6	44151	43081	0.787
October	142.7	82.65	27.57	143.8	136.3	46978	45836	0.784
November	129.5	79.33	26.71	132.6	125.3	43494	40753	0.756
December	126.3	77.17	26.89	129.3	122.2	42418	41356	0.787
Year	1719.3	949.89	27.46	1705.0	1617.2	558285	539706	0.779

Conclusion

This study demonstrates that a 407 kWp GCPV carpark rooftop system at FTKIP is technically feasible and capable of generating substantial surplus energy. The 10° tilt angle is identified as the optimal configuration for Malaysia's equatorial climate, balancing energy yield and maintenance considerations. The system significantly reduces carbon emissions and supports

UTeM's sustainability objectives. Future work may explore battery energy storage integration and real-time performance monitoring for enhanced system optimization.

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Artificial Intelligence Approach versus Statistical Approach for Building Energy Consumption Forecasting

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Abstract- Building energy consumption forecasting is important for reducing operational cost, supporting demand-side management, and improving sustainability in commercial and academic buildings. This paper compresses and compares Artificial Intelligence (AI) and statistical approaches for energy consumption forecasting based on previous studies. AI techniques such as Machine Learning, Support Vector Regression (SVR), Random Forest (RF), Artificial Neural Network (ANN), Deep Learning (DL), and Long Short-Term Memory (LSTM) models are reviewed together with statistical models such as ARIMA, Multiple Linear Regression (MLR), Response Surface Methodology (RSM), and Weibull-based approaches. The comparison is organised according to forecasting horizon, input data requirements, model strengths, and limitations. The review indicates that AI methods are suitable for high-resolution and non-linear forecasting tasks, while statistical methods remain useful when interpretability, limited data, and lower computational cost are required.

Introduction

Global energy demand continues to increase due to population growth, economic development, and the wider use of electrical technologies. The energy sector therefore requires reliable forecasting methods to support energy security, cost reduction, and sustainability planning [1]. In commercial and institutional buildings, energy consumption is affected by operational schedules, weather conditions, occupancy, lighting, office equipment, and heating, ventilation and air-conditioning systems. Accurate forecasting helps building operators identify peak demand, plan maintenance, optimise energy use, and evaluate conservation measures [2], [3].

Previous studies show that building energy forecasting can be developed using data-driven AI models or conventional statistical methods. AI models are effective for complex, non-linear, and high-frequency data because they can learn hidden relationships from historical patterns [4]-[8]. In contrast, statistical approaches remain useful because they provide clearer model interpretation, simpler implementation, and lower data requirements [5], [9]. This paper compares both approaches in terms of forecasting horizon, modelling suitability, advantages, and limitations. Fig. 1 summarises the role of forecasting horizon in energy planning.

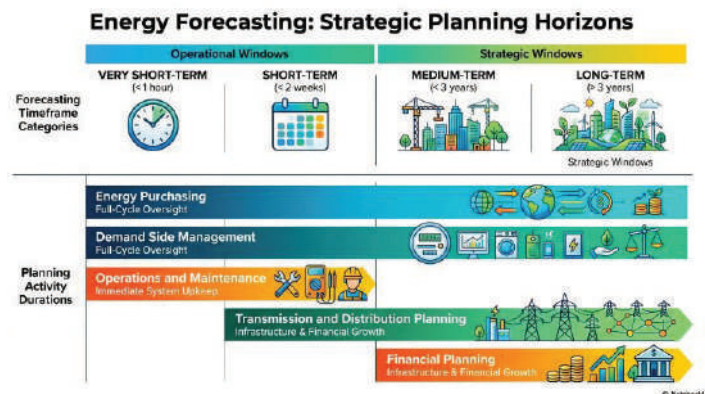


Fig. 1 Energy forecasting horizon and planning applications.

Methodology

The study uses a comparative review method. Publications related to building energy consumption forecasting were selected from the provided reference list, with emphasis on

studies discussing AI, statistical modelling, building applications, and forecasting horizons. The review considers four main aspects: input data type, forecasting horizon, model capability, and practical implementation. AI methods considered include SVR, RF, ANN, LSTM, GRU, and hybrid models [10]–[14]. Statistical methods include ARIMA, MLR, RSM, and probabilistic distribution models [9], [15], [16]. Forecasting performance is commonly assessed using error-based indicators such as RMSE, MAE, MAPE, MSE, and the coefficient of determination, with lower error values indicating better predictive accuracy [24], [25].

AI techniques are generally grouped under ML and DL. ML models such as SVR and RF can forecast energy consumption using weather, time, and historical load variables, while DL models such as ANN and LSTM are stronger for sequential data and long-term dependency learning [4], [7], [10], [18]. Statistical models such as regression and RSM are selected when the objective is to explain the influence of variables and support transparent decision-making [9], [15], [16], [22].

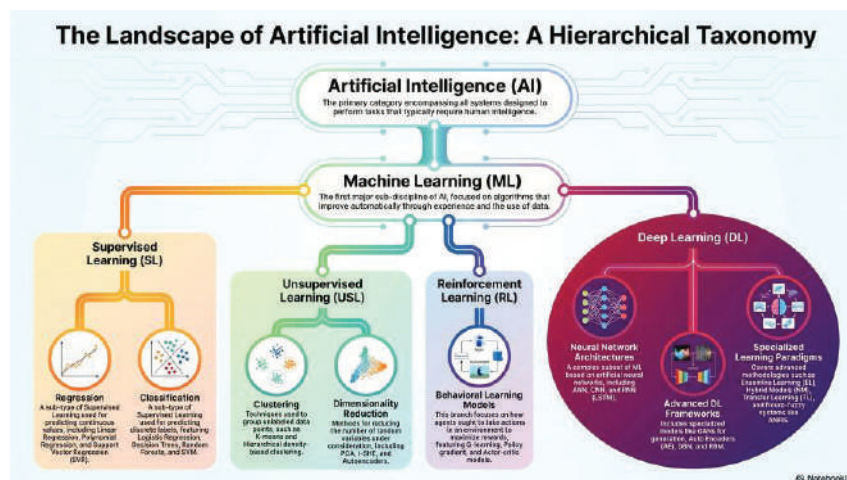


Fig. 2 Classification of AI and machine learning techniques for forecasting.

Table 1 Comparison of forecasting horizons for energy consumption studies.

Horizon	Typical sampling / duration	Main application	Common model tendency
Very short-term	Seconds to minutes; high-frequency sensor data	Real-time monitoring, demand response, automated HVAC control	AI models such as ANN, RF, SVR and LSTM capture rapid non-linear variation [4], [10].
Short-term	Hourly to daily data; one hour to several days	Load scheduling, operational planning and peak demand forecasting	AI, hybrid and regression models are widely used for building operation [7], [12], [13].
Medium-term	Weekly to monthly data; several weeks to months	Maintenance planning, performance evaluation and energy management	Hybrid AI-statistical models and regression support seasonal analysis [11], [14], [20].
Long-term	Monthly to yearly data; several months to years	Strategic planning, infrastructure investment and policy studies	Statistical, RSM and hybrid approaches are preferred for interpretability [15], [16], [21], [22].

Results and Discussion

The reviewed studies show that AI-based forecasting is highly suitable for building energy applications with rapidly changing load patterns and non-linear relationships between energy use, weather, occupancy, and operational variables. Deep learning models, particularly LSTM and GRU, are effective for time-series data because they learn temporal dependencies from past consumption patterns [7], [10], [11]. Machine learning models such as RF, SVR, and ensemble algorithms also perform well when temperature, humidity, historical load, and time

indicators are used together as input variables [4], [12], [18]. Therefore, AI is more practical for very short-term and short-term forecasting where high-frequency data and fast operational decisions are required.

The comparison of forecasting horizons in Table 1 indicates that model selection should be linked to the objective of prediction. Very short-term forecasting supports real-time monitoring, demand response, and automated control, while short-term forecasting is useful for daily load scheduling and energy cost reduction. For medium-term and long-term forecasting, the focus shifts to maintenance planning, benchmarking, infrastructure investment, and policy-related decisions. In these horizons, statistical approaches such as regression, ARIMA, RSM, and Weibull-based models remain useful because they are simpler to interpret and require lower computational effort [9], [14]–[16], [21].

Statistical approaches remain important when data availability is limited or when the main aim is to explain the relationship between variables. Regression models can identify how input factors influence energy consumption, while RSM supports interaction analysis among building design, environmental conditions, and operating schedules [15], [16], [22]. However, statistical models may be less accurate when energy profiles are affected by sudden weather changes, irregular occupancy, or highly non-linear behaviour. As summarized in Table 2, AI offers stronger adaptability and prediction capability, whereas statistical methods provide clearer interpretation and easier implementation for baseline and planning studies.

Table 2 Advantages and limitations of AI and statistical approaches.

Approach	Advantages	Limitations	Best use
Artificial intelligence	Learns non-linear patterns; handles large data; suitable for high-resolution forecasting; adapts when new data are added [3], [18].	Requires high-quality data; needs tuning; difficult to interpret; may overfit unseen data; training can be computationally costly [5], [19].	Short-term and very short-term prediction with complex time-series data.
Statistical approach	Transparent model structure; lower data requirement; easier interpretation; suitable for limited computing resources [9], [24].	Limited ability to represent complex non-linear behaviour; sensitive to assumptions; needs domain knowledge [14], [25].	Medium- and long-term planning, benchmarking and explanatory analysis.

Conclusion

This review concludes that AI and statistical approaches are complementary rather than directly substitutable. AI methods are more suitable for high-frequency, non-linear, and short-term building energy forecasting, while statistical methods are more suitable for limited-data cases, explanatory studies, benchmarking, and long-term planning. Future studies should compare AI, statistical, and hybrid methods using the same dataset and consistent performance indicators such as RMSE and R².

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AHP-TOPSIS-Based Conceptual Design Selection of an Adjustable Tube-Holding Puck for Tube Filling and Sealing Operation

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Abstract - Tube-holding pucks are critical tooling components in tube-filling and sealing operations in the pharmaceutical, cosmetic, and chemical packaging industries. It supports and positions the tubes throughout the eight packaging stages, including tube insertion, rotational positioning, filling, sealing, trimming, and removal of tubes from the puck. However, conventional dedicated pucks are commonly designed for specific tube sizes and profiles, which increases tooling lead time, production costs, and inventory requirements, and manufacturing downtime when a new puck must be ordered from the supplier for each tube design change. Therefore, this study proposes four adjustable tube-holding puck concepts and applies an integrated Analytic Hierarchy Process and Technique for Order Preference by Similarity to Ideal Solution (AHP-TOPSIS) method to select the most suitable concept. The selection criteria were derived from industrial observations, technician discussions, and supervisor consultations. Identified criteria, including puck durability, machine compatibility, dimensional accuracy, puck weight, fabrication time, rotational positioning, cost-efficiency, and flexibility to accommodate multiple tube sizes and profiles. Puck durability recorded the highest AHP weight, with a score of 0.257, 0.180 for machine compatibility, and 0.174 for dimensional accuracy, with an acceptable consistency ratio below 0.10. The Interchangeable Slot-Locking (Concept B) shows the balance score with 0.780 of the TOPSIS Closeness coefficient, followed by Concepts A, D, and C. The selected concept is recommended for further detailed Computer Aided Design (CAD) modeling, prototyping, analysis, and industrial validation.

Introduction

Tube filling and sealing is an important packaging process in most cosmetic and pharmaceutical industries. Filling plastic tubes with precise solution volumes and sealing them hygienically and accurately are priorities in this process. The sealed tube is used as primary packaging and is safely boxed, stored, transported, or used directly by consumers, with dosage consistency and packaging preservation as key concerns across industries (Ramezan, Kamkari, & Pourramezan, 2026). In current industrial practice, the tube-holding puck was used as a dedicated fixture that held, supported, rotated, and positioned the tube throughout six packaging stages, including loading, orientation, filling, sealing, trimming, and tube ejection from the puck. The puck was custom fabricated for a specific tube size and profile, either elliptical or cylindrical, and requires new puck set development if minor changes in tube sizes, which increases fabrication lead time, tooling costs, storage requirements, and ultimately causes production delays (Arnaoutis, Rosic, & Lutters, 2023). Customized and flexible tooling jigs and fixtures have been shown in past studies to be important manufacturing tools for enhancing production output, quality, stability, and repeatability (Kitagawa et al., 2025). Additive Manufacturing (AM) has also been explored for tooling applications, with the potential for the development of complex geometries, lower development costs, faster design iterations, and shorter lead times for low production volumes (Bhatia et al., 2026). The previous articles motivate the development of an adjustable or flexible tube-holding puck that accommodates multiple tube dimensions and profiles in a single puck, while considering multiple design criteria and requirements to enhance production flexibility. However, adjustable or flexible tooling requires a structured data architecture for AM to achieve those design criteria or requirements (Li, Feng, Kuan, & Lu, 2024). Therefore, this study aims to investigate the most suitable design concepts for an adjustable tube-holding puck of tube-filling and sealing packaging operations.

Methodology

This study used an integrated AHP-TOPSIS approach (Vincent, 2023) to evaluate the Design Concept (DC) proposed for a flexible tube-holding puck for tube-filling and sealing packaging operations (Ma et al., 2024). Criteria design identification was collected through industrial observation, interviews with technicians, and consultations with the research supervisor, as described by Ulrich et

al., (2020) in determining customer and technical requirements. Eight design criteria have been established, including durability, machine compatibility, dimensional accuracy, target weight, flexibility, fabrication time, rotational positioning accuracy, and cost-efficiency, as shown in Fig. 1. These criteria reflect the functional, performance, design, and process requirements, particularly its ability to maintain tube stability, magnetic base durability, black mark alignment capability, and able to withstand repeated impact throughout the operations while maintaining AM practicality, AHP was first used to determine the relative weight of each criteria by using the weighted formula in Equation (1). Saaty's 1 to 9 scale was used in this process to determine the relative importance between criteria through expert-based pairwise comparison (Peci, Dervishaj, & Puška, 2025). The AHP weight findings were then applied in the TOPSIS analysis to rank the four design concept alternatives and identify the most suitable flexible tube-holding puck concept.

$$W_i' = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}, i, j = 1, 2, \dots, n \quad (1)$$

Notes: W_i = Weight of criterion i , n = Number of criteria, a_{ij} = Pairwise comparison value between criterion i and j , $\sum_i a_{ij}$ = Total value of column j , $a_{ij}/\sum_i a_{ij}$ = Normalized value, $1/n \sum$ = Average of normalized row values

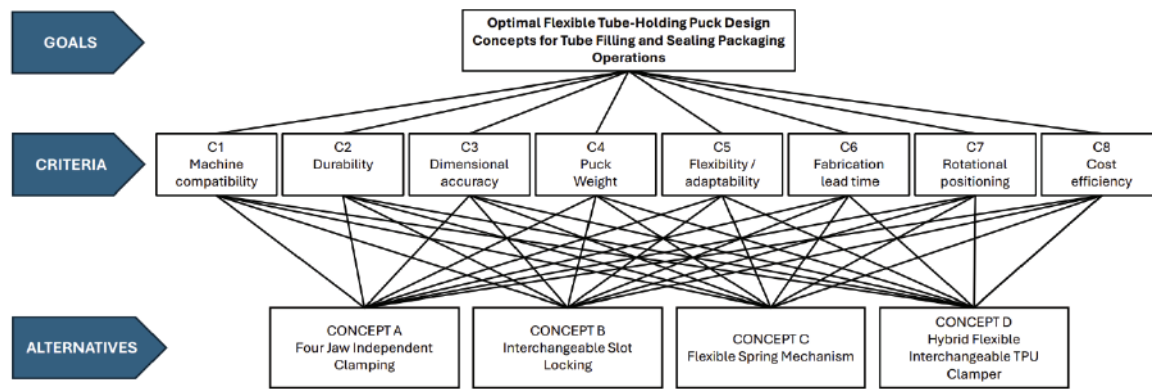


Fig.1 AHP-TOPSIS decision hierarchy for design concept selection

Results and Discussion

Based on the calculations from Equation (1), the AHP weights indicate that the criteria ranked as tube-holding puck durability (1st), machine compatibility (2nd), and dimensional accuracy (3rd) were the highest-weighted criteria, with puck weight (4th) and flexibility (5th) assigned as medium AHP weights, as listed in Table 1. It highlights that durability and accuracy should be prioritized, since puck function and performance were mostly influenced by the ability to withstand repeated impact cycles (up to 10,000 production), the accuracy of fabrication, and stability in holding the tube throughout the operational packaging stages. This indicates that operational reliability, machine compatibility, and accurate positioning should be prioritized when selecting the ideal puck concept. Flexibility criteria rank 5th in the AHP weights, indicating that adaptability is important but should not compromise puck durability and dimensional accuracy. The consistency ratio recorded below 0.10, indicating that expert judgment was acceptable for subsequent TOPSIS analysis.

Four conceptual designs were developed, including Four-Jaw Independent Clamping (Concept A), Interchangeable Slot-Locking (Concept B), Flexible Spring Mechanism (Concept C), and Hybrid Flexible-Interchangeable TPU Clamper (Concept D), as shown in Fig. 2. The Interchangeable Slot-Locking concept of Concept B recorded 0.780 of TOPSIS closeness coefficients, which was the highest rank for the most preferred or ideal concept in flexible tube-holding puck development, as shown in Table 2. It indicates that the concept had the best overall balance among the eight AHP-weighted criteria listed in Table 1. Meanwhile, Concept A ranked second with a 0.694 closeness coefficient, and the possibility of complexity in fabrication and assembly was expected to yield a lower rank than

Concept B, even though its independently adjustable jaw provides greater adaptability to the variety of tube sizes and profiles. The requirement for multiple interchangeable TPU clamber parts to accommodate tube variations ranks the Concept D third, which may increase changeover time, workload, and parts inventory. Concept C had the lowest TOPSIS closeness coefficient, 0.122, due to a spring mechanism that may affect accuracy, tube stability, and maintenance over long-term use. Therefore, Concept B was selected as the most promising concept for further detailed design and prototype validation.

Table 1: Tube-holding puck criteria and AHP weight with rank

Rank	Code	Criterion	Description	AHP Weight
1 st	C1	Puck Durability	Ability to withstand repeated cycle operation, impact drop, clamping force, and stability without failure	0.267
2 nd	C2	Machine Compatibility	Fit and function well for each tube filling and sealing packaging operation stage	0.180
3 rd	C3	Dimensional Accuracy	Ability to maintain smooth tube insertion and removal, including stability during filling, sealing, and trimming processes.	0.174
4 th	C4	Puck Weight	Should be 300 g with tolerance ± 20 g, same as the original puck used in current production for stability, and tube support	0.111
5 th	C8	Flexibility to Adapt Multiple Tube Profiles	Ability to accommodate cylindrical and elliptical tube profiles with minimal redesign or component parts replacement.	0.086
6 th	C5	Fabrication Time	Lower lead time is preferred, especially 3d printing, post-processing (if any), assembly, and preparation	0.078
7 th	C6	Rotational Positioning Accuracy	Orient the tube with a machine-rotational magnetic base and the ability to withstand repeated-cycle operation.	0.065
8 th	C7	Cost Efficiency	Reduce fabrication, replacement, maintenance, and inventory costs compared with dedicated pucks.	0.038

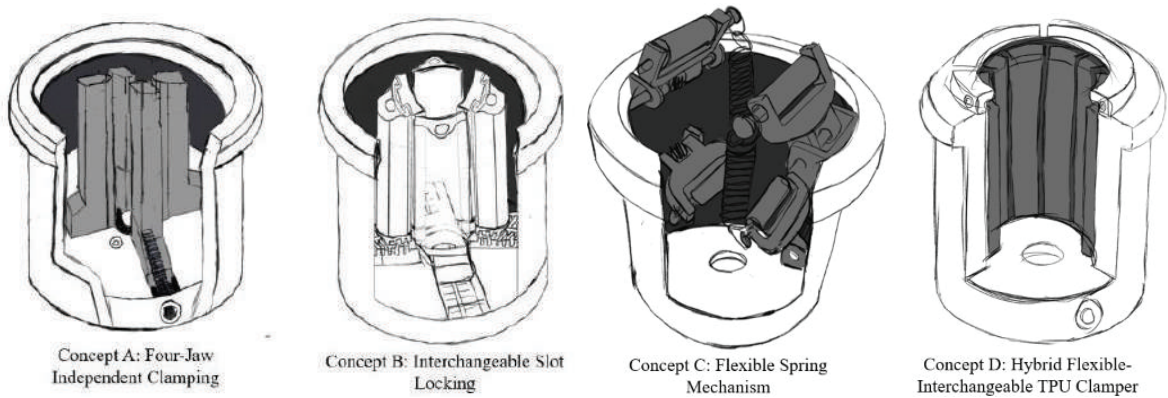


Fig. 2 Conceptual Design of Concept A (Four-Jaw Independent Clamping), Concept B (Interchangeable Slot-Locking), Concept C (Flexible Spring Mechanism), and Concept D (Hybrid Flexible-Interchangeable TPU Clamber).

Table 2: AHP-TOPSIS Evaluation Results of Proposed Puck Concepts

Rank	Concept	Concept Principle	TOPSIS Closeness Coefficient
1	Concept B	Interchangeable Slot-Locking	0.780
2	Concept A	Four-Jaw Independent Clamping	0.694
3	Concept D	Hybrid Flexible-Interchangeable TPU Clamber	0.453
4	Concept C	Flexible Spring Mechanism	0.122

Conclusion

In conclusion, the evaluation of the ideal concepts for the flexible tube-holding puck for tube-filling and sealing packaging operations was conducted using an integrated AHP-TOPSIS approach. AHP

weight ranking shows that puck concept should not be based solely on flexibility or adaptability for design concept selection, but overall balance, especially durability, machine compatibility, and dimensional accuracy should be prioritized since they affect the puck function and performance through repeated impact cycle in six operational packaging stages. The findings indicate that the reliability of the puck-and-tube fit meets the industrial requirements for implementing AM to achieve production flexibility and reliability of tooling components. Based on the TOPSIS ranking, Interchangeable Slot-Locking (Concept B) design concept recorded the highest closeness coefficient and was selected as the most ideal concept alternative for further design modeling and analyses. It provides a practical balance score between targeted criteria, particularly on fabrication simplicity, functional performance, and industrial needs. However, the result is limited to conceptual evaluation based on expert judgment and preliminary design scoring, and has not yet been experimentally validated in real production settings. The approach can support a structured decision-making process during early-stage tooling design and detailed CAD development; prototype fabrication, puck performance, and industrial validation are recommended for future work.

Acknowledgment

The authors would like to thank the industry partner, Universiti Teknikal Malaysia Melaka, and Universiti Sultan Zainal Abidin for the support, technical input, and guidance throughout this study.

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Hand Grip Force Measurement and Development of an Ergonomic Hand Gripper for Manual Handling Tasks

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Abstract - Manual handling activities that involve hand-intensive tasks and prolonged gripping activity can cause muscle fatigue and increase risk of work-related musculoskeletal disorders. The purpose of this study was to measure grip force, and design and develop a prototype of ergonomic hand gripper for manual handling applications. A total of 70 healthy male adults aged from 20 to 39 years took part in a cross-sectional experiment. Grip force was tested using a Jamar dynamometer in sitting and standing position with 3 wrist postures (neutral, pronation, supination). An electromyography (EMG) was performed on the flexor digitorum superficialis and flexor digitorum profundus and normalized to %MVC. A Tekscan pressure sensing glove was used for the evaluation of grip pressure distribution. The grip force obtained during standing and pronation were higher than those obtained during sitting and supination. The use of the ergonomic hand gripper resulted in a significant decrease in muscle activation which ranged from 68.9% decrease in %MVC, and improved pressure distribution by reducing localized maximum pressure at the palm. Potential of the proposed prototype as an assistive device for manual handling tasks is demonstrated by reducing the demand of the muscles and improving grip ergonomics. Future work will focus on long-duration usability testing and validation across broader and more diverse occupational user populations.

Introduction

In industrial settings, manual handling activities often involve holding and sustained or repetitive gripping, creating a risk of hand fatigue, discomfort and the development of work related musculoskeletal disorders (WMSD), such as manufacturing, construction and logistics workers (Rani et al., 2026; Wan Harun et al., 2025). Good grip strength is important for effective and safe execution of a task because poor or unstable grip leads to increased physical load and risk of injury. There is significant inter-personal and inter-environmental variability in grip strength, which is related to hand anthropometry, body position and wrist posture and suggests the need for user-specific product design (Alam & Khan, 2025; Mokhtarinia et al., 2025). Many commercial gripping devices are based on generalized anthropometric data and fixed dimensions, which are not reflective of these variations (Contreras-Bolívar et al., 2021), can lead to uneven pressure of palm and fingers, higher activation of forearm muscles and non-neutral wrist orientations during extended use, increasing risk for fatigue and WMSD. Additionally, there is limited research that has incorporated forearm muscle activation, hand-device contact pressure, and grip force in the design and biomechanics testing of wearable hand gripping devices, with most studies evaluating device performance along a single dimension rather than an integrated set of biomechanical measures (Zhang et al. 2026).

The objectives of this study were to measure hand grip force, and to develop a hand gripper prototype that combines servo-driven finger actuation with elastic mechanical assistance to support gripping tasks. Its ergonomic performance was evaluated through grip force measurement, surface electromyography (EMG) and contact pressure distribution.

Methodology

Participants and Grip Force Measurement

The present research was aimed at a sample population of 70 healthy young Malaysian adults, in this case male participants, aged from 20 to 39 years and recruited by using both convenience

and stratified random sampling. The inclusion criteria were followed in the recruitment process as each participant was not known to have any history of upper limb musculoskeletal disorders, neurological problems, or recent orthopedic traumas that would confound the measurements of the strength (Askary et al., 2025). Hand anthropometric measurements were obtained using a measuring tape and a digital Vernier caliper, in accordance with standard anthropometric procedures (Jaafar et al., 2023; Mohamed et al., 2025).

Grip force of the dominant hand was measured using a Jamar hand-held dynamometer (Sammons Preston, USA) following an established procedure recently reviewed (Gurung et al., 2025). Measurements were expressed in kilogram (kg). Grip force measurements were conducted under three wrist postures (neutral, pronation, and supination) in both sitting and standing positions. The participants in the sitting position were directed to sit upright in an armless chair with flat feet on the ground and a neutrally rotated shoulder adducted (Quattrocchi et al., 2024). For standing position, participants stood upright in the anatomical position, facing forward with feet slightly apart. The non-dominant arm rested naturally at the side. Participants were instructed to squeeze maximally for three seconds. Each participant completed two trials, and the higher value was used for analysis.

Development of the Ergonomic Hand Gripper Prototype

A prototype of an ergonomic hand gripper was developed by combining a wearable glove and a built-in mechatronic control system to assist a user of the hand gripper with performing tasks involving manual handling. The prototype was made using an ESP32 microcontroller, HC-SR04 ultrasonic sensor, MG995 high torque servo motor, limit switch, elastic strings, wristband, a portable battery and connecting wires. The ESP32 microcontroller was used as the main control unit, which was responsible for reading the data from the sensors and sending commands to the servo motors. An ultrasonic sensor HC-SR04 was used to detect whether there is object in the range of 5 to 15cm. After the object was detected, the ESP32 triggered the MG995 servo motor to provide mechanical help through elastic linkages which gave controlled gripping assistance. A limit switch was added as a safety element to prevent the motor from moving too far and to ensure safe operation when gripping the parts.

Elastic strings created mechanical tension that was evenly distributed throughout to help fingers flex with natural hand motion. For the stable operation and better wearing comfort of the prototype, a wristband was used while for power supply, a portable battery was utilized for the entire system, which allowed for untethered and portable use. These mechanical, electronic and sensing components were integrated to create a lightweight ergonomic hand gripper to ease manual gripping and to decrease physical effort for repetitive handling. The ergonomic hand gripper prototype was tested for hand grip force measurement in three different wrist positions: neutral, pronation and supination (shown in Fig. 1).

Surface Electromyography (EMG) and Contact Pressure Analysis

Forearm muscle activity was measured using a Delsys Trigno wireless surface EMG system. The EMG electrodes were placed over the flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP), the primary muscles responsible for power gripping (Garkisch et al., 2022). The recorded EMG signals were processed to obtain the root mean square (RMS) values and normalized to each participant's maximum voluntary contraction, allowing direct comparison of muscle activation between bare-hand gripping and prototype-assisted gripping.

Contact pressure at the hand-gripper interface was evaluated using a Tekscan GripTM (Tekscan, USA) pressure-sensing glove (Thompson et al., 2026). The pressure sensors recorded the real-time distribution of contact pressure across the palm and fingers during gripping tasks, enabling the identification of high-pressure regions (pressure hotspots). To prevent electrical interference between the EMG electrodes and the pressure-sensing system,

the contact pressure measurements were conducted in a separate experimental session from the EMG assessment. The combined EMG and contact pressure analyses provided a comprehensive biomechanical evaluation of the prototype by quantifying muscle activation and grip pressure distribution. These measurements were used to determine the effectiveness of the ergonomic hand gripper in reducing muscular effort and redistributing contact pressure during manual gripping tasks.

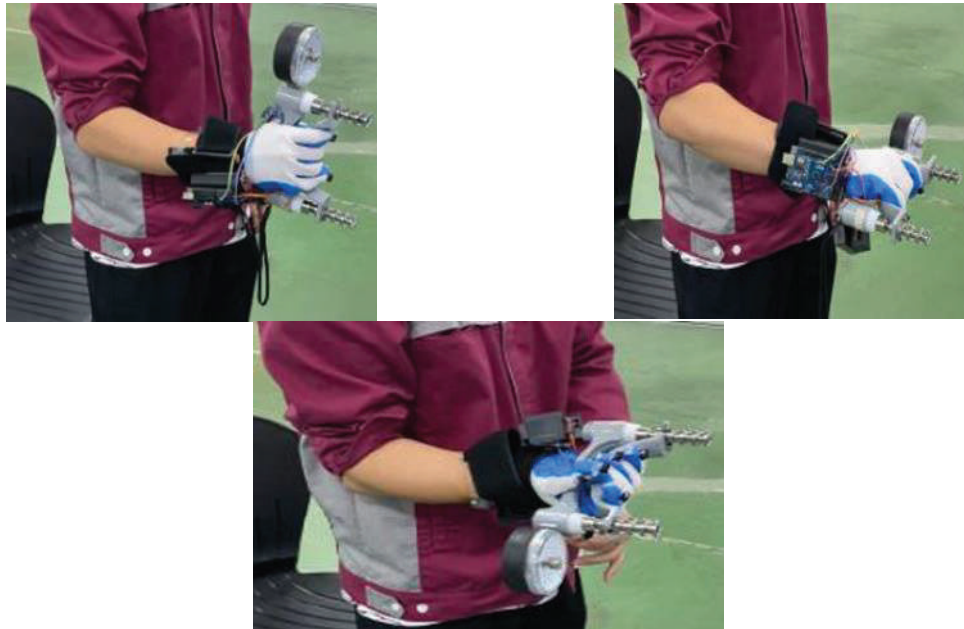


Fig. 1 Testing of the ergonomic hand gripper prototype during hand grip force measurement under three wrist postures: neutral (left), pronation (middle), and supination (right).

Results and Discussion

Hand Grip Force

As shown in Table 1, the mean hand grip force in the standing neutral posture was 35.59 kg, which was 6.9% higher than the sitting neutral posture (33.30 kg). This indicates that an upright standing posture is associated with higher grip force output compared to sitting position. Pronated wrist postures were consistently produced the highest grip strength in both standing and sitting positions. The maximum values recorded were 36.17 kg (standing) and 33.91 kg (sitting), respectively. In contrast, supination resulted in the lowest grip strength values for both postural conditions, with 35.20 kg in standing and 32.84 kg in sitting. Overall, grip strength was influenced by both body posture and wrist orientation, with standing posture and pronated wrist position demonstrating higher force generation. These findings suggest that postural alignment and forearm orientation may influence force transmission and muscular efficiency during gripping tasks. These postural findings are consistent with Kawase et al. (2025), who similarly reported standing as the posture eliciting the highest grip strength, followed by sitting, across a range of body positions. The elevated grip force observed in standing in the present study therefore supports the broader consensus that upright, weight-bearing postures favor greater voluntary force output than seated postures, likely due to increased postural stability and proximal muscle recruitment. In contrast, the present finding that pronation produced higher grip strength than supination diverges from Hartavi & Kasirga (2026), who reported reduced grip strength in pronation relative to neutral and supinated positions. This discrepancy may reflect differences in sample demographics, measurement protocol, or wrist stabilization between studies. These findings suggest that the effect of forearm rotation on grip strength may not generalize consistently across populations, inviting further investigation in future work.

Table 1: Descriptive statistics of hand grip force measurements

Body position	Wrist Posture	Mean HGS (kg)	SD	Min	Max
Standing	Neutral	35.59	3.82	29.00	42.00
Standing	Pronation	36.17	3.04	29.00	42.00
Standing	Supination	35.20	3.20	29.00	41.00
Sitting	Neutral	33.30	3.73	25.00	40.00
Sitting	Pronation	33.91	3.98	24.00	40.00
Sitting	Supination	32.84	4.20	25.00	39.00

Comparison between Bare-Hand Gripping vs. Prototype-Assisted Gripping

Participants conducted the grip force tests and endurance tests with the ergonomic prototype hand gripper. In endurance testing, they performed a maximum voluntary contraction (MVC) until fatigue occurred and the time until fatigue occurred is reported in seconds (s). The standing position had mean grip force values of 36.17 kg for pronation, 35.59 kg for neutral and 35.20 kg for supination. Average weights in the sitting position were 33.91 kg (pronation), 33.30 kg (neutral), and 32.84 kg (supination). Results showed that overall, the patterns of grip force were similar for all wrist positions and were higher for pronation and lower for supination, regardless of whether the person was standing or sitting. The duration of endurance was dependent on posture and wrist orientation. In the standing position the best endurance time was obtained in the supination position (8.27 s), followed by the pronation position (8.04 s) and the neutral position (7.74 s). The sitting position was different, with the neutral position having the longest endurance time (5.85 s) compared with pronation (4.03 s) and supination (4.00 s).

Muscle contraction or muscle effort was assessed by analyzing surface EMG signals from the FDS and FDP muscles. Muscle activation was normalized to MVC and expressed as %MVC to enable comparison between bare-hand and prototype-assisted gripping conditions. The results showed a substantial reduction in normalized muscle activation when participants used the ergonomic hand gripper prototype compared to bare-hand gripping. In the sitting neutral posture, muscle activation decreased by 59.2%, while in the standing neutral posture, a reduction of 68.9% was observed. These findings indicate that the use of the prototype reduces the activation level of key finger flexor muscles during gripping tasks. The reduction in %MVC suggests a lower physiological demand on the forearm musculature when using the assistive device, which may contribute to reduced muscle fatigue during repetitive or prolonged manual handling tasks.

Table 2 summarizes grip force, muscle activation, and endurance time for bare-hand and prototype-assisted gripping in the neutral wrist posture. Grip force with the prototype matched the bare-hand baseline, consistent with maximal voluntary grip force being a physiological ceiling that an assistive device is not intended to raise. Muscle activation was substantially lower with the prototype, and endurance time to fatigue was recorded under prototype-assisted conditions.

Table 2: Comparison of bare-hand gripping and prototype-assisted gripping (neutral wrist posture)

Posture	Metric	Bare-hand	Prototype-assisted
Standing	Grip force (kg)	35.59	35.59
	Muscle activation (%MVC)	Baseline	↓ 68.9%
	Endurance time (s)	Not measured	7.74
Sitting	Grip force (kg)	33.30	33.30
	Muscle activation (%MVC)	Baseline	↓ 59.2%
	Endurance time (s)	Not measured	5.85

Maximum Contact Pressure Analysis

As shown in Table 3, the ergonomic hand gripper prototype consistently reduced maximum contact pressure across all tested body positions and wrist postures. In the standing position,

contact pressure decreased from 42 to 35 kPa (16.7%) in the neutral posture, from 39 to 32 kPa (17.9%) in pronation, and from 39 to 33 kPa (15.4%) in supination. Similarly, in the sitting position, pressure decreased from 38 to 33 kPa (13.2%) in neutral, from 35 to 30 kPa (14.3%) in pronation, and from 37 to 32 kPa (13.5%) in supination. This may contribute to improved comfort and reduced localized mechanical stress during prolonged or repetitive gripping tasks.

Table 3: Comparison of maximum contact pressure (kPa) between bare-hand gripping and ergonomic hand gripper prototype

Body position	Wrist Posture	Bare-Hand (kPa)	Prototype-assisted (kPa)	Reduction (%)
Standing	Neutral	42	35	16.7
Standing	Pronation	39	32	17.9
Standing	Supination	39	33	15.4
Sitting	Neutral	38	33	13.2
Sitting	Pronation	35	30	14.3
Sitting	Supination	37	32	13.5

Conclusions

The ergonomic hand gripper prototype had reduced up to 68.9% less muscle activity in normalized %MVC for both FDS and FDP muscles than bare-hand gripping. Contact pressure analysis also revealed decreased contact pressure and enhanced pressure distribution at the hand–grip interface. The prototype shows promise with respect to decreasing the muscular demand and biomechanical burden when performing repetitive gripping movements. Further research should include longer duration testing and validation in a variety of users and occupational contexts.

Acknowledgment

This preliminary study was supported by Universiti Teknikal Malaysia Melaka (UTeM) under the grant number ANTARABANGSA(IRMG)-PSU/2025/FTKIP/A00082. The authors gratefully acknowledge the Faculty of Industrial and Manufacturing Technology and Engineering (FTKIP) and the Centre for Research and Innovation Management (CRIM), UTeM for their continuous support throughout this study.

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Mechanical Performance of 3D Printed Bio-Composite Hexagon-Based Pattern of Honeycomb Core Sandwich Structure

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Abstract—The purpose of this research is to tackle material performance of biocomposite through the fabrication and design of honeycomb sandwich structure (HCSS) utilizing 3D printing technology and natural fiber materials. Three different HCSS patterns (regular hexagon, double hexagon, and triangular hexagon) were selected to go through the mechanical performance investigation and 3D printing using sugar palm fiber composite filament. It was found that double hexagon pattern obtained the greatest tensile strength, flexural strength and flatwise compression strength as much as 11.7 MPa, 26.2 MPa and 32 MPa respectively. In addition, the highest tensile modulus and flatwise compression modulus are 1.75 GPa and 174 MPa respectively obtained by triangular hexagon. Double hexagon obtained the highest flexural modulus which is 1.07 GPa compared to others. Based on these results, it can be concluded that reinforced ribs and additional hexagon in regular hexagon pattern could improve the mechanical properties of the HCSS. The more reinforced elements like ribs and smaller size of cell pattern would higher the strength and improve the elasticity of the structure.

Introduction

Sandwich structures are extensively utilized in load-carrying applications within the aerospace, automotive, and locomotive industries due to their exceptional strength and stiffness combined with low weight. These structures comprise two thin, dense, and stiff face-sheets bonded to a relatively thick, low-density core. Both metallic and fiber-reinforced polymer (FRP) face-sheets are employed in sandwich structures, however, FRP presents several advantages over metallic alloys, including enhanced fatigue properties, greater design flexibility, a higher strength-to-weight ratio, and superior chemical stability and corrosion resistance. The most common reinforcements in FRP face-sheets are synthetic fibers such as glass, carbon, and aramid. Despite their benefits, synthetic fibers pose environmental and sustainability challenges, including limited recycling options, non-biodegradability, and greenhouse gas emissions during production.

The primary objective of this structural design is to attain high rigidity and strength while maintaining a low overall weight. The structures can be broadly categorized into two types. The first type is a hexagon reinforced with ribs, commonly referred to as a triangular hexagonal configuration and the cell size is smaller than the regular hexagon pattern geometrically. The second type features a hexagon with additional ribs and an inner hexagonal core, often termed a double hexagonal structure and the cell size is smallest compared to the other two patterns.

Study has been conducted by Oliveira et al., [1] to investigate the mechanical properties of bio-composite HCSS under loading. In their study, they obtained higher shear stiffness of 132 MPa and resistance of 3.33 MPa from their bamboo rings. Djoudi et al., [2] have developed wood composite as sandwich core and concluded that this type of material is an inexpensive option for the sandwich structure in bio-construction area. Ayrilmis et al., [3] have presented the study on the wood composite sandwich core structure where they found that the mechanical properties of the core structure were influenced by the thickness of the face sheet. For better mechanical performance of bio-composite sandwich core, they suggested that the face sheet's thickness is higher than 2 mm. Dukarska et al., [4] examined the properties of wood/walnut shell composite core of sandwich board as potential material in sandwich board construction. They suggested to use high-density fiber board with walnut shells composite board for sandwich board structure to enhance the bending strength and modulus of elasticity of the

structure. Miranda et al., [5] mentioned in their study that the design of honeycomb core structure influenced the mechanical properties of the sandwich panel such as its stiffness, energy absorbing capacity and strength. More recently, Mirzaei et al. [6] reported that core orientation and skin material strongly govern the compressive and flexural response of 3D-printed honeycomb sandwich panels, while bio-inspired nested-hexagon cores have been shown to further enhance flexural performance of sandwich panels with natural-fibre face sheets [7].

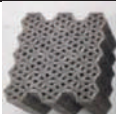
Therefore, in this study, investigation on the design of sandwich cores based on hexagonal honeycomb structures was performed. To assess the viability of employing bio-composites in this design, mechanical testing was conducted to evaluate their strength. The results demonstrate the potential of bio-composites for use in sandwich core structures and suggest their promising suitability as substitute materials for structural applications.

Methodology

Fabrication Process

The printing process for three different sugar palm fiber composite HCSS involves hexagonal, triangular and double hexagonal cell patterns. These designs, as in Table 1, were created using SolidWorks CAD software and then exported as STL files. 3D printing parameters for the cellular core of the sandwich structures include a nozzle extrusion temperature range of 190-220°C and a bed temperature range of 60-90°C. The deposition layer height was set at 0.2 mm, with a layer width of 0.8 mm. The optimal printing speed for the honeycomb core fabrication was 40 mm/s.

Table 1: Design of Honeycomb Core Structure

No	Pattern Design	Pattern Name	Size
1		Hexagon	50 mm x 50 mm x 9 mm
2		Triangular Hexagon	
3		Double Hexagon	

Mechanical Testing

Using a Universal Testing Machine with a crosshead speed of 30mm/min, ASTM D7250 tensile characteristics were determined. Three-point bending tests were conducted in accordance with ASTM C393, the Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure under ambient conditions using a 100 kN universal testing machine. The flatwise compression strength values of the samples were determined using ASTM C365, which is the Standard Test Method for Flatwise Compressive Strength of Sandwich Construction as the testing was performed.

Results and Discussion

The results that are depicted in Fig.1, demonstrate that the addition of reinforced ribs and extra hexagonal cells correlates with an increase in tensile strength. These results can be attributed to the inherent structure of the pattern, which exhibited more voids in the triangular and

hexagonal configurations compared to the double hexagon pattern that features more ribs. The presence of these voids significantly increases the likelihood of localized maximum stresses and compromises the interfacial bonding within the structure.

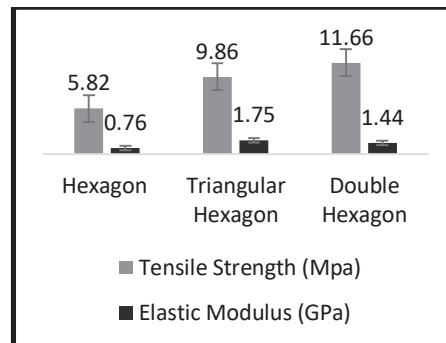


Fig. 1 Tensile Properties for Three Different Patterns of HCSS

As shown in Fig.2, the addition of reinforced ribs and hexagonal cells enhances flexural strength. The double hexagon pattern, which includes both reinforced ribs and additional hexagonal cells, demonstrates superior flexural strength compared to the regular hexagonal and triangular patterns. These results also have been supported by study from Zhong et al., [8] that concluded that reinforced ribbed-hexagon cell pattern in lattice structures improves the mechanical performance of the regular hexagon cell from the tensile and impact test that were conducted. They also clarify the results from the mechanism of failure modes. Zhang et al. [9] suggest that the highest load that implies from the force-displacement load is related to the stress concentration and to improve this, the structure of the HCSS must comply with the uniform stress distribution which is confirm from the pattern of triangular hexagon and double hexagon.

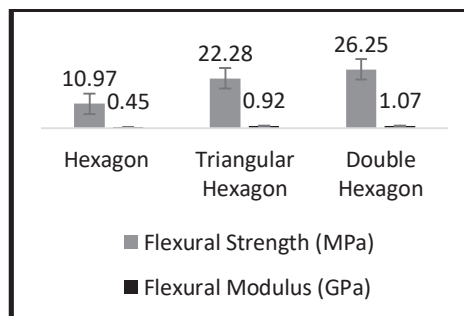


Fig. 2 Flexural Properties for Three Different Patterns of HCSS

The effect of the reinforced rib and additional hexagonal cell on the flatwise compression properties are depicted in Fig.3. The double and triangular hexagon pattern exhibited the similar value of 32 MPa, which is higher than the regular hexagon cell pattern. The regular hexagon pattern showed the lowest compression strength, measuring 18.05 MPa. The overall results indicate a lack of accuracy in determining the average flatwise compression strength. Consequently, the findings suggest that the ribbed hexagonal pattern possesses better flatwise compression strength compared to the regular hexagonal pattern.

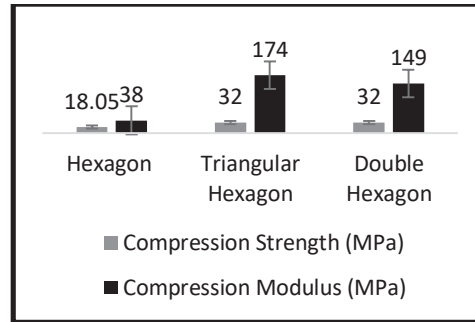


Fig. 3 Flatwise Compression Test Properties for Three Different Patterns of HCSS

Conclusions

Tensile, flexural and flatwise compression tests for the HCSS that are made from bio-composites were carried out experimentally and it was found that by reinforcing the regular hexagon HCSS with ribs and double hexagon pattern, the mechanical properties of these structures improved significantly. It was found that the increasing number of ribs improved the tensile, flexural and flatwise compression strength where the double hexagon pattern exhibited higher strength with 100%, 139% and 77% of improvement respectively. Therefore, it can be concluded that the increasing number of ribs or smaller cell size in the hexagon HCSS will increase density of the HCSS. However, the improvement of their mechanical performance is higher and double hexagon of HCSS can be considered as the most suitable design pattern for HCSS that is made from bio-composite materials.

Acknowledgement

The authors would like to thank Ministry of Higher Education of Malaysia and Universiti Teknikal Malaysia Melaka for funding this research through Fundamental Research Grant Scheme (FRGS), no. FRGS/1/2024/SS02/UTEM/02/3.

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XRD Characterization of Furnace-Treated Bone-Derived Material: Phase Composition, Structural Evolution, and Research Gaps

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Abstract— In this contribution an extended abstract is presented. First a narrative–analytical review of the thermal treatment of bone materials is presented. Then an XRD case study of a furnace-treated animal-bone sample is presented. XRD analysis was performed using a PANalytical X'PERT-3 diffractometer with Cu K α radiation. Diffraction patterns were recorded in a 2θ range of 5–70°. The diffraction patterns show strong reflections at approximately 32.21°, 37.37°, 53.88°, 64.17°, and 67.40° corresponding to crystalline CaO. In addition to these reflections' strong reflections at approximately 42.90° and 62.29° corresponding to MgO are observed. Only weak reflections in the region of 32–34° 2θ corresponding to hydroxyapatite are found. However, full-pattern Rietveld refinement of the diffractograms supports a three-phase model consisting of CaO, MgO, and Ca(OH)₂. Thus, the highly crystalline sample can be best described as a highly crystalline, CaO-dominated multiphase material. However, the full-pattern analysis also clearly shows the limitations of XRD in terms of the analysis of amorphous carbon and minor phases. Therefore, other analytical techniques have to be used for a complete characterization.

Introduction

Bone-derived chars are of great interest for a variety of applications, such as adsorption, catalytic reactions, soil amendment, nutrient recovery and environmental remediation [1], [3]. The adsorption, catalytic, agricultural and environmental applications of bone-derived chars are influenced by the mineral content, crystallinity and the carbon structure of the chars, which can strongly be affected by the thermal treatment [4], [5].

In this review we consider the influence of thermal treatment on bone-derived chars. The bone mineral is mainly composed of calcium-phosphate. The treatment can increase the crystallinity and can promote a phase transformation [6], [7]. The carbon structure is influenced in a similar way as for other char-like materials, and increasing ordering of the carbon atoms with increasing severity of the treatment is observed [8], [9]. For this review XRD was used to characterize the bone-derived chars. However, as XRD is only able to detect crystalline phases, in a separate XRD case study the results from the experiments are distinguished from the results found in the general literature, and other methods such as FTIR, Raman spectroscopy, SEM-EDX, NEXAFS, solid-state NMR are used to detect functional groups, the elemental composition and non-crystalline parts of the bone-derived chars [10], [11].

Methods

In a narrative–analytical review, the use of thermally treated bone char/biochar and related calcium-phosphate materials was reviewed. The review comprised a description of the XRD patterns, the phase constitution, the crystallinity and the structure–property relationships of the materials under review [1], [7]. For the experimental part of the review a waste-animal-bone sample was furnace-treated. The main method of characterization was XRD, in order to identify the crystalline phases, and for complementary characterization where appropriate [10], [11].

Powder diffractometry was performed on a PANalytical X'PERT-3 diffractometer. The measurement was carried out using Cu K α radiation ($\lambda = 1.541874$ Å) at 40 kV and 30 mA in

reflection geometry. Measuring was performed using a spinning sample holder. Measured data were recorded in the 2θ range of 4.992° to 69.999° with a step size of 0.0167° . This led to a total of 3,890 data points. Peak positions, d-values, FWHM-values and corresponding phase assignments were retrieved from the complete intensity– 2θ data set. A full-pattern Rietveld refinement was performed for the quantitative evaluation of the phase composition.

For quantitative phase analysis, a Rietveld refinement of the 3,890 points data set was performed. Experimental, calculated and difference profiles are depicted in Fig. S1. In the three-phase model (CaO, MgO and $\text{Ca}(\text{OH})_2$) refinement was performed.

Table 1. Key XRD Analytical Parameters

Parameter	Parameter
Diffractometer System	PANalytical X'PERT-3
Wavelength ($K\alpha$)	$1.541874 \text{ \AA}$
Generator Settings	40.0 kV, 30.0 mA
Scan Range ($^\circ$)	$5.00^\circ - 70.00^\circ$
Step Size ($^\circ$)	0.0167°
Counting Time	15.24 s per step
Scan Mode	Continuous

Results and Discussion

Thermal treatment of bone derived materials leads to changes in the phase composition and the crystallinity of these materials. Lower temperature treatment leads to less crystalline calcium-phosphate structures. Higher temperature treatment increases the crystallinity, the structural ordering and can induce phase transformations [6], [7]. The complete diffraction pattern was used for the interpretation of the present experimental data, and not a single peak.

This diffractogram contains sharp peaks. The highest peak at $2\theta = 37.37^\circ$ (24,396 counts) is assigned to the CaO reflection at 37.37° . Other main peaks are found at approximately 32.21° , 37.37° , 53.88° , 64.17° and 67.40° . These peaks correspond to the CaO reflections. The MgO reflections are found at 42.90° and 62.29° . Due to an overlap with the hydroxyapatite peak at $2\theta = 32.21^\circ$, peak-position matching is not sufficient for a correct phase quantification [13]. [14].

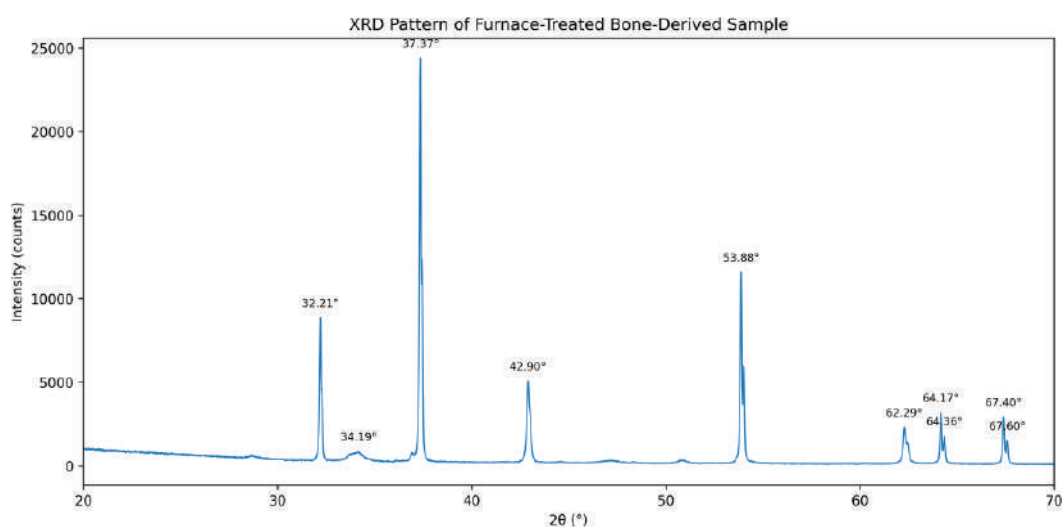


Fig. 1. XRD pattern of the furnace-treated bone-derived sample based on the complete 2θ –intensity dataset.

There is some overlap with the HAp reflection at 32.21° and the weak feature at 34.19° could be considered HAp-related. However, a full-pattern refinement for the furnace-treated sample using a more robust multiphase model (CaO, MgO and $\text{Ca}(\text{OH})_2$) gave refined

crystallite sizes for the major CaO and MgO phases of 124.5 nm and 78.2 nm respectively. Thus, the furnace-treated sample is a highly crystalline, multiphase calcium-based material, primarily composed of CaO and MgO [10], [11].

Table 2. Peak positions and tentative phase assignments from the experimental XRD dataset

2 θ (°)	Intensity	FWHM (°)	d (Å)	Tentative phase	Interpretation
32.206	8,857	0.106	2.777	CaO + HAp	Overlapping region
34.195	854	0.809	2.620	HAp	Weak HAp-related reflection
37.370	24,396	0.093	2.404	CaO	Strongest reflection
42.902	5,077	0.210	2.106	MgO	MgO-related reflection
53.881	11,586	0.096	1.700	CaO	Strong CaO reflection
62.287	2,302	0.272	1.489	MgO	MgO-related reflection
64.175	3,195	0.106	1.450	CaO	CaO-related reflection
67.400	2,911	0.101	1.388	CaO	CaO-related reflection

Note: FWHM values in Table 2 are uncorrected for instrumental broadening. Phase assignments are qualitative and thus subject to change after full-pattern Rietveld refinement (Table 3).

Table 3. Quantitative phase and crystallite-size results from Rietveld refinement of the complete raw XRD dataset

Refined phase	wt%	Crystallite size (nm)	Key fit indicator
CaO	67.70 $\pm$ 1.20	124.5 $\pm$ 5.2	R _p = 2.14%
MgO	24.64 $\pm$ 0.85	78.2 $\pm$ 3.6	R _p = 2.88%
Ca (OH) ₂	7.66 $\pm$ 0.45	21.4 $\pm$ 1.8	R _p = 3.45%

Rietveld refinement of XRD data of the study material in a full-pattern approach was done by a three-phase model (67.70 wt% CaO, 24.64 wt% MgO and 7.66 wt% Ca(OH)₂) with agreement factors of R_p = 4.82%, Rwp = 6.35% and χ^2 = 1.53. Refined crystallite size of the three phases were calculated to be 124.5 $\pm$ 5.2 nm for CaO, 78.2 $\pm$ 3.6 nm for MgO and 21.4 $\pm$ 1.8 nm for Ca(OH)₂. Based on these results from the XRD analysis no inclusion of hydroxyapatite in the crystalline phases is required.

Conclusion

A full literature review of this work has been presented. Here we present full raw XRD data from experimental sample and results of its Rietveld refinement. Quantitative refinement of experimental sample composition resulted in following amounts of phases in it: 67.70 wt% CaO, 24.64 wt% MgO and 7.66 wt% Ca(OH)₂. Rwp = 6.35% and χ^2 = 1.53. Thus, furnace treatment significantly changed the mineral crystalline structure of the bone-derived materials. Experimental sample is a multiphase structure of oxide and hydroxide phases rather than a crystalline hydroxyapatite-based structure. As full-pattern analysis is much better than assignment of phases from individual peaks, XRD analysis identified crystalline phases present in the sample. Other techniques, however, are required to determine amounts of amorphous carbon as well as to get information on functional groups and on elemental distributions.

Acknowledgement

The authors wish to express their sincere appreciation to the Universitas of Brawijaya and Universiti Teknikal Malaysia Melaka (UTeM) for the financial support and resources provided, which were essential to the successful completion of this research.

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A Comparative Analysis of Maintenance Policies Using Preventive, Repair, and Performance Maintenance Methods on A Wheat Grain Roll Mill Machine (Case Study: PT.XYZ)

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Abstract— PT. XYZ is a flour-processing company that supplies wheat-based products. Throughout 2024, the Roll Mill machines on Line A and Line B experienced frequent breakdowns and downtime despite the company's existing maintenance policy. To address these issues, this study compares three maintenance strategies: Preventive Maintenance, Repair Maintenance, and Performance Maintenance, based on availability score and minimum maintenance cost as evaluation criteria. The results indicate that all three proposed strategies increase availability to 0.99 compared with the existing maintenance policy, which yielded an availability of 0.95. Based on minimum maintenance cost, Repair Maintenance proved to be the most economical option, with estimated monthly cost of Rp 2,420,808 for Class A and Rp 591,945 for Class B. Repair Maintenance is chosen as the recommended and preferred maintenance strategy.

Introduction

The growth of the food and beverage industry has increased the demand for reliable production systems, especially in wheat flour processing. In industrial manufacturing, machinery plays a central role in transforming raw materials into finished products, and its operational capacity strongly influences quality, output, productivity, efficiency, and conformity to production standards [1][2]. When machines are operated near maximum capacity, wear and the probability of failure tend to increase [3]. Maintenance is a strategic activity that preserves machine condition and supports production efficiency

This study focuses on the Roll Mill Line A and B machines at PT. XYZ, which represent the core stage of production in converting wheat into flour. Although the company operates continuously to meet market demand and stock requirements, unplanned downtime and recurring breakdowns were still observed throughout 2024. This indicates the current maintenance policy has not been fully effective. Therefore, this paper compares Preventive, Repair, and Performance Maintenance based on minimum cost and availability. The literature on maintenance shows that Preventive Maintenance (PM) is carried out through periodic inspection and scheduled actions to prevent failure [4]. Repair Maintenance (RM) is performed after a machine has failed and requires repair or component replacement [5]. Performance Maintenance (PrM) uses condition monitoring to predict possible failure before it occurs [6].

Methodology

This study employs a quantitative descriptive methodology to compare three maintenance approaches for the Roll Mill machines, namely Preventive, Repair, and Performance Maintenance. The analysis is based on breakdown data of Roll Mill Line A and B collected from January to December 2024. The assumption used in the three maintenance approaches is that total productive days per month are constant at 30 days, and the total manpower is 3 people from the Technical Division. The main objective is to determine the most effective maintenance strategy in terms of machine availability and total maintenance cost. The research flow diagram can be seen in Figure 1.

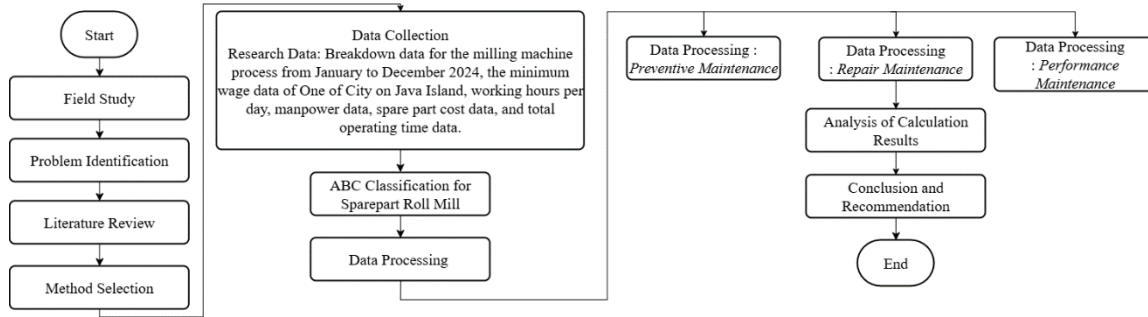


Fig. 2 Research Flow Diagram

The data processing approach used in this study for PM uses the three-parameters (Threshold (γ), Shape (β), and Scale (η)) Weibull distribution with Probability Density Function ($f(t)$), Cumulative Density Function ($F(t)$), Reliability ($R(t)$), and Hazard Rate ($h(t)$) to estimate failure risk [7][8]. The calculation that used in this research for PM relies on hazard rate for the period maintenance schedule, Total Maintenance Cost, and availability formulas that shown below:

Table 1: Preventive Maintenance Formulas

Function	Formula	Calculation (for Roll Mill Line A Class A, Exclude Availability)
$h(t)$	$= \frac{f(t)}{R(t)} = \frac{\beta}{\eta} \left(\frac{t-\gamma}{\eta} \right)^{\beta-1}$	$= \frac{2.79}{1.26} \left(\frac{0.9986111}{1.26} \right)^{1.79}$ $= 1.460460$
TMC	$= h(t) \times ((PM \text{ time} \times total \text{ manpower} \times manpower \text{ cost}) + sparepart \text{ cost})$	$= 1.460460 \times ((0.000328704 \times 3 \times Rp \ 10,330) + Rp \ 12,104,032)$ $= Rp \ 17,677,480$
Availability PM (Per Machine)	$= \frac{Operation \ Time \ PM}{Operation \ Time \ PM + Total \ Downtime}$	$= \frac{8585.2}{8585.2 + 21} = 0.99$

Based on hazard rate findings, researcher calculate how many time maintenances must conducted under the assumption of 12 month and 1 hour of PM time. The assumptions lead to the operation time PM for the availability calculation. Meanwhile, RM is based on machine failure probability and relies on Average runtime machine before breakdown (T_b), Total Maintenance Cost, and availability formulas that shown below [11]:

Table 2: Repair Maintenance Formulas

Function	Formula	Calculation (for Roll Mill Line A Class A, Exclude Availability)
T_b	$= \sum_i^n p_i T_i$, (P_i for probability of breakdown in periods 1, 2, 3, etc) (T_i for periods 1, 2, 3, etc)	$= (1 \times 0.32) + (2 \times 0) + (3 \times 0.08) + (4 \times 0.12) + (5 \times 0.08) + (6 \times 0.04) + (7 \times 0) + (8 \times 0.16) + (9 \times 0.12) + (10 \times 0) + (11 \times 0.04) + (12 \times 0.04) = 5 \text{ month}$
TMC	$= B.Cr$	$= 0.20 \times Rp \ 12,104,042 = Rp \ 2,420,808$
Availability RM (Per Machine)	$= \frac{Operation \ Time \ RM}{Operation \ Time \ RM + Total \ Downtime}$	$= \frac{8628.0}{8628.0 + 21} = 0.99$

After the T_b calculation, the result is used to estimate the probability of how many times RM will occur over a 12-month period. The assumptions for RM time is 3 hour for repair time, which then leads to operation time findings. PrM leans on Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) findings to assess operating and repair characteristics, the formulas shown below [8]:

Table 3: Performance Maintenance Formulas

Function	Formula	Calculation (for Roll Mill Line A, Exclude TMC)
MTBF	$\lambda = \frac{\sum \text{Frekuensi Breakdown}}{\sum \text{Operation Time}}, MTBF = \frac{1}{\lambda}$	$= \frac{1}{0.0098978} = 101.03$
MTTR	$= \frac{\sum \text{BreakdownTime}}{\sum \text{Frekuensi Breakdown}}$	$= \frac{21}{85} = 0.24$
TMC (Roll Mill Line A Class A)	$= \{(\text{MTTR} \times \text{total manpower} \times \text{manpower cost}) + \text{sparepart cost}\}$	$= \{(0.24 \times 3 \times \text{Rp } 10,330) + \text{Rp } 12,104,032\} = \text{Rp } 12,111,621$
Availability PrM (Per Machine)	$= \frac{MTBF}{MTBF + MTTR}$	$= \frac{101.03}{101.03 + 0.24} = 0.99$

Finding and Arguments

The spare parts analyzed in this study were selected based on the ABC classification results, with the highest unit price was taken as the representative component for further analysis. Based on this approach, Safety Valve Compressor Roll Mill was selected for Class A, Shaft Adapter for Class B, and Sight Glass Roll Mill for Class C. This selection method ensures that the study focus on spare parts with the most significant cost impact and maintenance relevance in the Roll Mill system.

In the PM analysis, the minimum Time to Failure (TTF) for each selected spare part class was used as the threshold value to determine the preventive maintenance interval. After the TTF values were obtained, the frequency breakdown data per class of Roll Mill Line A and Line B were processed using Arena Input Analyzer. The distribution followed the Weibull distribution, with different shape and scale parameters for each selected component class. Roll Mill Line A Class A had 0.001389 months, Roll Mill Line A Class B had 0.002083 months, Roll Mill Line B Class B had 0.001389 months, and lastly, Roll Mill Line B Class B had 0.007176 months. Based on the calculation results in Table 4, these findings indicate that PM is effective in maintaining a high level of availability, although it also requires substantial routine costs for inspection, servicing, and component replacement before failure occurs [9]. In this sense, PM is not a low-cost strategy in the short term, but rather an upfront investment to avoid larger failures and higher losses in the future [10].

Based on the calculation result in Table 4, these findings show that RM is more economical than PM in a similar context [11]. However, the limitations of RM should also be considered, because if more serious failures occur, they can cause production stoppages (downtime) that lead to opportunity loss in the form of lost production and decreased company productivity [12]. Meanwhile, the PrM result was then interpreted from the relationship between failure occurrence, repair response, and the total time the machine remained available for production. Line A with 21 hours breakdown time per year showed a higher breakdown burden than Line B with 15 hours breakdown time per year, indicating that its performance was more affected by repeated failure events and longer recovery time. PrM calculation results in Table 4 indicate that the maintenance cost in the PrM method is at an optimal point compared with the PM and RM methods [13]. However, because the maintenance period is very intensive leads to higher maintenance cost. This method also requires consistent, accurate, and complete historical data because the calculation of MTBF and MTTR heavily depends on machine characteristics [14]. The result of PM, RM, and PrM can be seen in Table 4.

Table 4: Preventive, Repair, and Performance Maintenance Calculation Results

Machine Type	Class	Preventive Maintenance			Repair Maintenance			Performance Maintenance		
		Period (month)	TMC (Rp)	Avail.	Period (month)	TMC (Rp)	Avail.	Period (month)	TMC (Rp)	Avail.
Roll Mill Line A	A	1.46	17,677,480	0.99	5	2,420,808	0.99	0.14	12,111,621	0.99
	B	0.25	1,218,620		8	591,945			4,735,549	
	C	-	-		-	-			-	
Roll Mill Line B	A	1.09	13,227,978	0.99	5	2,420,808	0.99	0.18	12,110,891	0.99
	B	0.95	4,540,871		8	591,945			4,735,549	
	C	-	-		-	-			-	

The implementation of the RM method improved the company's effective daily production output. The existing production output was obtained by multiplying the cycle time by the existing maintenance policy availability of 0.95 resulting in 547.2 tons per day. RM methods was calculated by multiplying the same cycle time by the improved availability of 0.99 resulting in 570.24 tons per day. Based on this comparison, the RM method increases production output by 23.04 tons per day or approximately 4.21% that indicating a measurable improvement in production performance.

Conclusions

In conclusion, PM, RM, and PrM all produced the same availability value of 0.99. However, RM is recommended as the company's maintenance policy because it resulted in the lowest total maintenance cost among the three methods. The comparative analysis shows reductions in maintenance costs when using RM compared to PM of 86.31% (Line A Classification A), 51.42% (Line A Classification B), 81.70% (Line B Classification A), and 86.96% (Line B Classification B), indicating significant efficiency in supporting machine operations. Even so, the company should still implement supporting maintenance policies to reduce the limitations of Repair Maintenance and help prevent more serious failures in the future.

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Design and Development of a Hydraulic Mini Lifter for Safe and Ergonomic Load Handling in Welding Workshop Environments

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Abstract— This paper describes the design, fabrication and preliminary testing of a hydraulic Mini Lifter with a compact size for ergonomics load handling in welding workshop at ADTEC JTM Kampus Pedas. This was due to difficulties in moving heavy equipment around tight spaces and potential musculoskeletal injury from manual lifting. The prototype was made of hollow mild-steel sections cut, welded, assembled and finished. The device had dimensions of about 1000 mm long, 700 mm wide, and 1200 mm high. It had an 8-ton hydraulic jack, caster wheels and locking brakes. The assessment included: An operational load test, A simple stress evaluation, Optical inspection, Penetrant Testing and a usability survey with 18 participants. The Mini Lifter was lifting loads of 100 kg and there was no noticeable deformation in the frame, hydraulic leaks or instability while operating. Based on the predicted performance of an 8-ton hydraulic jack ($>78,480$ N), this ratio is much larger than the actual load (981 N) tested; resulting in a hydraulic capacity ratio of 80:1. The calculated stress in the frame was 2.55 MPa, which is much lower than the mild steel yield strength of 250 MPa. The non-destructive evaluation of the welded connections revealed that there were no significant surface imperfections. Survey results showed strong user buy-in, with all 18 participants strongly agreeing on the safety, ergonomic design, and quality of construction. The results suggest that the Mini Lifter is a safe, efficient and user-friendly tool to be utilized in TVET welding workshops and similar light duty technical training environments.

Introduction

This development in such technology has increased the use of mechanical devices to enhance safety and efficiency of workshop environments. However, traditional lifting equipment such as forklifts and large hoists are often not suitable for use in tight or restricted areas as they require large, open spaces to operate. Without accessible or user-friendly tools, people are often forced to manually manage unwieldy objects, such as lifting, pushing, pulling, carrying, or supporting loads with little mechanical advantage. [1], [2]. This may increase the risk of musculoskeletal injuries, especially in jobs that require excessive force, awkward body positions, or repetitive physical actions [1], [3]. This study was motivated by the real problem in the welding workshop in ADTEC JTM Kampus Pedas. There was a need to move used materials, broken machinery, welding equipment and other large objects into a limited space. It got worse when the forklift broke down and required the students to put in a lot of hard work. Similar issues have been found in other studies on material handling, where the handling of large and bulky items can cause more physical strain, muscular effort, fatigue and discomfort. Ahmad et al. found that an ergonomic trolley lifter reduced muscle activity and was more usable, useful, and preferred than a standard hydraulic table cart [3]. Earlier research also suggests that lifting equipment should be checked based on its ability to carry weight, stability, ease of use, structural strength, and safety. For instance, Nur Irfan et al. noted that a workshop lifting frame safely carried 100 kg with a safety factor of 13.23 and minimal displacement of 0.04422 mm, while Akinsade et al. highlighted the importance of stress, bending, and safety analysis in mobile hydraulic lifting systems [4], [5]. Additional studies on hydraulic lifters and scissor lifts support the need to think about reducing physical strain, user satisfaction, stress, deformation, material choices, and structural reliability before repeated use [6], [7].

Therefore, this study introduces the design, fabrication, and initial performance assessment of a compact hydraulic Mini Lifter intended for use in TVET welding workshops. The device was built using hollow mild-steel units and was equipped with an 8-ton hydraulic jack, caster wheels and locking brakes. Its performance was evaluated through a series of tests including operational load testing, basic stress analysis, visual inspection, dye penetrant testing and user feedback. The aim was to see if the Mini Lifter could provide a safer, more ergonomic, compact and efficient way of load handling. Initial results indicate that the system has the ability to lift 100 kg and a hydraulic capacity ratio of 80:1. An anticipated frame stress of 2.55 MPa, no apparent surface-breaking weld defects and positive user feedback have been indicated.

Methodology

The Mini Lifter was developed in a systematic engineering process, including planning, design, manufacturing, evaluation, operational trials and user input. The machine was designed to incorporate the characteristics of a forklift and a hand pallet truck, with a focus on compact design, stability, cost-effective manufacture, and ease of use by a single operator. The final model measured approximately 1000 mm in length, 700 mm in width and 1200 mm in height. Hollow mild-steel square and rectangular profiles were chosen for their durability, ease of welding, availability and suitability for light-duty workshop applications. The fabrication process of the frame involved a number of processes such as material inspection, measuring, marking, cutting, drilling, welding, grinding, cleaning, and painting. The 8-ton hydraulic jack was used as the lifting mechanism, while caster wheels with locking brakes were used for mobility. The welds were visually inspected and subjected to dye penetrant testing before conducting performance testing. Engineering validation involved a hydraulic capacity analysis and stress analysis based on an assumed load of 100 kg. Testing included the use of loads that would be expected in a workshop, namely a workbench, SMAW machine, GMAW machine, and a long bench. This model was tested based on its lifting performance, ease of wheel movement, performance of brakes, stability, hydraulic leaks, and structure deformations. A final evaluation was based on a four-point Likert scale survey conducted on 18 participants and measured characteristics including handling, hydraulic performance, stability, safety, ergonomic design, brake performance, portability, load resistance, quality of construction, and recommendation.

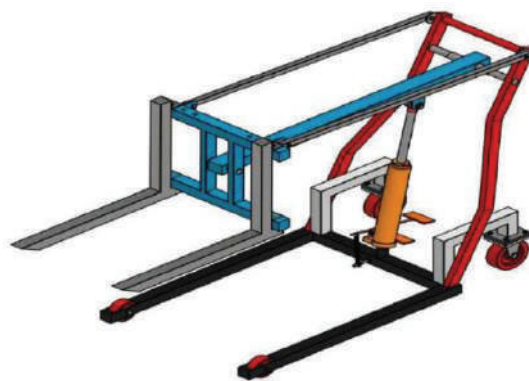


Fig. 1 Isometric design model of the Mini Hydraulic Lifter prototype.

Results and Discussion

The fabrication process has resulted in an easily assembled hydraulic Mini Lifter model that fits well with the overall design idea of using the device in a workshop setting. The assembly process involved the construction of a mild-steel structure that includes the frame, lifting fork, hydraulic jack frame, wheel assembly, brake, and welded joints. The model has shown appropriate dimensional fit and structural integrity, which demonstrates that measurement,

cutting, welding, assembling, and finishing operations have been done correctly. Testing has been carried out using typical workshop loads. The maximum test load was 100 kg, which correlates with the GMAW welding machine. During the entire period of testing for lifting and translation, the Mini Lifter lifted and transported the chosen test loads without showing any signs of damage to the structure, hydraulic leaks, or abnormal instability. The process of lifting was well-regulated and steady; moreover, the function of caster wheels played an important role in stabilizing the prototype. According to engineering calculations, the hydraulic jack has the capacity to lift up to 8 tons, which is equivalent to 78,480 N. Comparatively, the maximum test load is 100 kg or 981 N, and hence the ratio of the hydraulic capacity is 80:1. This finding suggests that there is indeed considerable safety factor for this hydraulic system, although it does not provide the ultimate load capacity for the Mini Lifter unit. The proof-loading process of the unit will be needed along with dimensional analysis and further structure evaluation. Stress analysis of the main hollow mild steel structure was done. The normal stress on a 50 mm x 50 mm x 2 mm mild steel hollow tube when loaded at 100 kg is approximately 2.55 MPa, which is quite low compared to the usual mild steel yield strength of around 250 MPa. Such difference justifies the lack of any deformity in the structure tested and confirms the suitability of the selected mild steel hollow structure for this purpose. The evaluation of welds is an indication of the structural integrity of the prototype. Through visual inspection and dye penetrant testing, it was found that there were no major cracks or surface flaws in the welded areas. This is especially important considering that welded areas may become the sources of stress concentration in lifting equipment. Nevertheless, since the weld evaluation was performed using visual inspection and basic NDT, it is recommended to conduct a full-fledged weld test in case the prototype will be used in practice. According to Table 1, the prototype showed a positive result in all performance tests including operational loading tests, hydraulic test, basic stress analysis, weld testing, and mobility parameters. Overall, these results show that the Mini Lifter meets the criteria of a small lifting device.

Table 1: Summary of prototype validation results

Evaluation item	Main result	Interpretation
Operational load trial	Representative loads up to 100 kg were lifted and moved without visible frame deformation or hydraulic leakage.	Prototype met the intended light-duty workshop load-handling requirement.
Hydraulic capacity ratio	8-ton hydraulic jack compared with 100 kg tested load produced a ratio of 80:1.	Large hydraulic reserve; complete-system rating still requires certified proof testing.
Simplified stress analysis	Estimated normal stress was approximately 2.55 MPa for the main hollow mild-steel frame.	Calculated stress was far below the nominal yield strength of mild steel.
Weld inspection	Visual inspection and dye penetrant testing showed no critical surface-breaking weld defects.	Welded joints were acceptable for preliminary workshop-use validation.
Mobility and braking	Caster wheels enabled movement, while locking brakes reduced uncontrolled movement.	Mobility and stationary stability were suitable for workshop use.

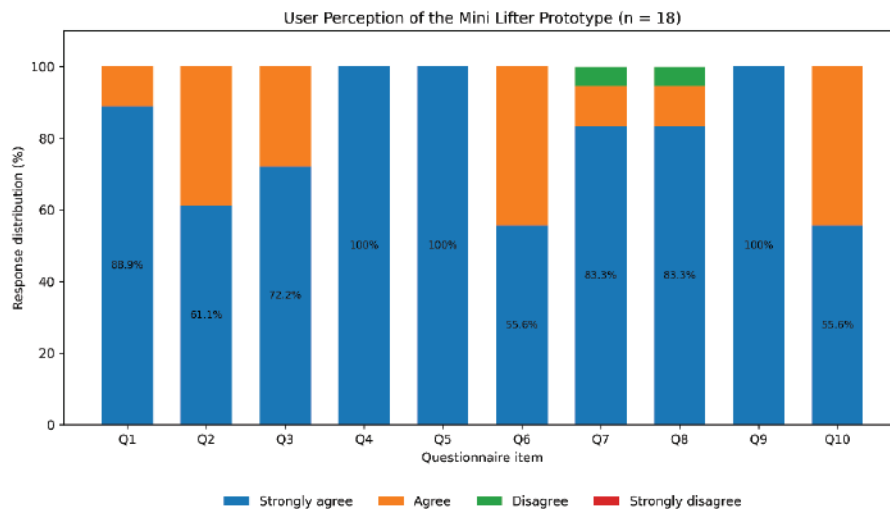


Fig. 2 User perception of the Mini Lifter prototype based on questionnaire responses (n = 18).

The results obtained in Figure 2 show a positive response from users on all ten points with "Strongly agree" responses falling to 55.6% to 100%. The highest percentage agreement was noted with regard to safety perceptions, ergonomic placement of the wheels, fork and handle, and material qualities as well as manufacturing quality, where 100% of users agreed strongly. Other areas with high level of agreement included operability, lifting stability, suitability for narrow areas, and loading durability. Despite low rates of "Strongly agree" responses for the performance of hydraulic lifting, braking, and willingness to recommend the product, the total of "Agree" and "Strongly agree" responses remained significant. Thus, one may conclude that the product received good response from users with possible improvements related to its operability, braking, and user interface. Overall, technical and user evaluation results show that the Mini Lifter successfully achieved its goal of being a compact hydraulic lifting tool designed to be manually operated in welding workshop. Usage of mild steel hollow sections, strong hydraulic jack, wheels with brakes, and properly welded joints helped to develop a reliable and well received prototype. Therefore, the results obtained prove that the Mini Lifter can reduce physical efforts related to lifting operations, provide safety and increase efficiency of TVET training workshops.

Conclusion and Recommendations

In conclusion, the present study has shown that the proposed hydraulic Mini Lifter is an efficient tool used to help in load handling within the welding workshops. The prototype has been able to lift loads weighing as much as 100 kg without showing signs of any deformation, hydraulic failure, or instability while operating. Through a stress analysis exercise, it was found out that the stress on the frame was 2.55 MPa, which is well below the yield strength of mild steel. Visually inspecting the prototype and using a dye penetrant test, no large-scale cracks were found on the surface or the welded areas. The users' feedback about their experience with the prototype revealed perceptions of safety, convenience, ergonomics, and quality of manufacture. Overall, it seems possible to reduce the amount of physical labor involved in load transportation due to the use of a mild-steel frame, hydraulic jack, and caster wheels in this case. However, it should be noted that the high capacity of the hydraulic jack means the extra capacity and not the maximum load capacity of the Mini Lifter. Future improvements should involve proof-load testing, finite element analysis, repeated-load testing, dimensional inspection, the use of heavier-duty polyurethane wheels, smoother brake performance, an adjustable ergonomic handle, and improved hydraulic control. To support Smart Manufacturing, the Mini Lifter can also be upgraded with IoT-enabled load sensors, automated

stability tracking, and digital maintenance logging. These improvements would enable real-time load monitoring, overload warnings, predictive maintenance, safer operation, better ergonomics, and more effective data-based equipment management in TVET workshops.

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Evaluating the Effectiveness of Generative Artificial Intelligence (GenAI) for Workshop-Based Learning in Mechanical Engineering: A Study of Malaysian Polytechnic Diploma Students

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Abstract- The rapid advancement of Generative Artificial Intelligence (GenAI) has significantly transformed educational practices by providing intelligent learning support, personalized feedback, and instant access to technical knowledge. Within Technical and Vocational Education and Training (TVET), particularly in mechanical engineering workshop courses, GenAI has emerged as a promising educational tool to enhance students' understanding of practical procedures, improve problem-solving skills, and support workshop-based learning activities. Despite its increasing adoption in higher education, empirical evidence regarding the effectiveness of GenAI in practical engineering workshop environments within Malaysian polytechnics remains limited. Therefore, this study aims to evaluate the effectiveness of GenAI for workshop-based learning among diploma students in Mechanical Engineering programmes at Malaysian polytechnics. A quantitative research design will be employed using a structured questionnaire to collect data from diploma students who have experience using GenAI to support their workshop learning activities. The collected data will be analysed using descriptive statistics, reliability analysis, Pearson correlation, and simple linear regression to examine the relationship between GenAI usage and learning effectiveness. The findings are expected to provide empirical evidence on the educational value of GenAI in enhancing workshop-based learning and offer practical recommendations for educators and institutional administrators on integrating GenAI into engineering education.

Introduction

The rapid advancement of Artificial Intelligence (AI), particularly Generative Artificial Intelligence (GenAI), has significantly transformed the landscape of higher education by reshaping how knowledge is delivered, accessed, and applied. Unlike conventional digital learning technologies, GenAI is capable of generating human-like responses, explaining complex concepts, producing technical content, assisting with problem-solving, and providing immediate feedback to learners. The objective of this study is to evaluate the effectiveness of GenAI for workshop-based learning among Mechanical Engineering diploma students in Malaysian polytechnics. This includes examining the level of GenAI utilisation, evaluating students' perceptions of learning effectiveness, and investigating the relationship between GenAI usages and learning effectiveness. The primary problem addressed is that practical engineering education requires students to develop procedural knowledge, psychomotor skills, safety awareness, and critical decision-making abilities that cannot be acquired solely through AI-generated explanations. Excessive dependence on GenAI may reduce opportunities for independent reasoning or experiential learning if not used appropriately. Furthermore, while existing studies have extensively examined students' acceptance of AI technologies, considerably fewer studies have investigated the effectiveness of GenAI within practical engineering workshop environments, particularly within the Malaysian TVET sector. This study employs a quantitative design to systematically collect and statistically analyze data via a structured questionnaire. The main results demonstrate that the utilisation of GenAI has a positive and statistically significant influence on students' learning experience and practical learning competency, which subsequently enhance overall learning effectiveness in workshop-based learning.

The methodology

This study employed a quantitative research approach to evaluate the effectiveness of GenAI for workshop-based learning. Population and Sampling: The target population comprised Diploma Mechanical Engineering students enrolled in Malaysian polytechnics who have experience using GenAI to support workshop-based learning activities. A multistage sampling technique was employed, targeting 150 to 230 respondents. Research Instrument: A structured questionnaire was designed to evaluate students' perceptions using a five-point Likert scale (ranging from 1 = Strongly Disagree to 5

= Strongly Agree). The questionnaire measured GenAI Utilisation, Learning Experience, Practical Learning Competency, and Learning Effectiveness. Data Collection and Analysis: Questionnaires were distributed electronically using an online survey platform. Data was analyzed using the Statistical Package for the Social Sciences (SPSS). Analysis techniques included descriptive statistics, reliability analysis (Cronbach's Alpha), Pearson correlation, and multiple linear regression.

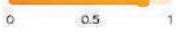
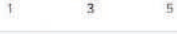
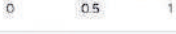
Findings and Arguments

The descriptive analysis indicates that students actively used GenAI applications to support their workshop-based learning. Table 1 summarizes the reliability of the constructs, while Table 2 outlines the descriptive statistics of the survey responses.

Table 1: Reliability Analysis of Study Constructs.

CONSTRUCT	NUMBER OF ITEMS	CRONBACH'S ALPHA	INTERPRETATION
 GenAI Utilisation	5	0.912	 Excellent
 Learning Experience	5	0.895	 Good
 Practical Learning Competency	5	0.901	 Excellent
 Learning Effectiveness	5	0.918	 Excellent

Table 2: Descriptive Statistics for Study Variables

Construct	Mean	Standard Deviation	Interpretation
 GenAI Utilisation Use of GenAI tools to support workshop-based learning	4.28 	0.56 	 High Respondents have a high level of agreement.
 Learning Experience Perceived improvement in engagement and understanding	4.31 	0.53 	 High Respondents have a high level of agreement.
 Practical Learning Competency Perceived improvement in practical skills and problem solving	4.17 	0.61 	 High Respondents have a high level of agreement.
 Learning Effectiveness Overall effectiveness of learning through GenAI integration	4.35 	0.49 	 High Respondents have a high level of agreement.

Hypothesis 1 (H_1): GenAI utilisation significantly predicts students' learning experience ($\beta = 0.782$, $p < 0.001$). The model explains 61.1% of the variance in learning experience ($R^2 = 0.611$).

Hypothesis 2 (H_2): GenAI utilisation has a significant positive influence on students' practical learning competency ($\beta = 0.731$, $p < 0.001$). The regression model explains 53.4% of the variance in practical learning competency ($R^2 = 0.534$).

Hypothesis 3 (H_3): Both learning experience ($\beta = 0.516$) and practical learning competency ($\beta = 0.401$) significantly contribute to learning effectiveness ($p < 0.001$). Together, they explain 76.4% of the variance ($R^2 = 0.764$).

Conclusions

The results of this study lead to several core principles and practical implications regarding GenAI in engineering education:

- **Principles Inferred:** GenAI serves as an effective complementary learning tool that positively influences students' learning experience and practical competency, subsequently enhancing overall learning effectiveness. Rather than directly influencing learning effectiveness alone, GenAI contributes indirectly by supporting conceptual understanding and problem-solving.
- **Exceptions and Problems:** While GenAI offers vast opportunities, researchers highlight concerns that excessive dependence on AI-generated content may reduce students' critical thinking, creativity, and independent problem-solving abilities if used without appropriate guidance. Practical skills remain fundamental and require direct engagement with equipment and authentic workplace environments.
- **Practical Implications:** Successful integration of GenAI requires institutions to design learning activities that encourage responsible usage while maintaining active engagement in hands-on workshop experiences.
- **Recommendations:** Lecturers should consider integrating GenAI into workshop preparation activities and learning support strategies. Furthermore, institutional administrators should develop guidelines and professional development programs that promote the ethical and effective use of GenAI within TVET.

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Ergonomic Risk Assessment and Intervention to Reduce Upper-Limb Musculoskeletal Disorders in Manual Food Production

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Abstract— Repetitive manual tasks in Small and Medium Enterprises (SMEs) within the food manufacturing sector expose workers to elevated risks of work-related musculoskeletal disorders (WMSDs). This study evaluated ergonomic risks in a traditional otak-otak production line and proposed an engineering-based intervention to reduce upper-limb exposure. Musculoskeletal discomfort was assessed using the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) and an initial Ergonomic Risk Assessment (ERA). CMDQ results identified the wrist (score = 40), shoulder (score = 28.5), and arm (score = 24.5) as the most affected body regions. Repetitive motion was the dominant risk factor, which was further analysed using the Occupational Repetitive Actions (OCRA) Checklist in accordance with ISO 11228-3, confirming high ergonomic risk for both upper limbs, particularly among female workers aged over 35 years. To address these risks, a semi-automatic staple-less wrapping mechanism was designed to reduce force exertion, repetition, and awkward wrist postures. Evaluation based on OCRA risk components indicates a substantial reduction in exposure levels. The study demonstrates that low-cost, engineering-based interventions can effectively mitigate ergonomic risks while maintaining productivity in SME food manufacturing.

Introduction

These Engineering-based ergonomic interventions are among the most effective approaches for controlling WMSDs. However, SMEs often lack resources to implement full automation. This study focuses on the development of a task-specific ergonomic aid to address repetitive upper-limb exposure in manual otak-otak production. Engineering controls are recognized as one of the most effective strategies for reducing ergonomic risks at their source. However, full automation is often impractical for SMEs due to cost constraints. As a result, many SMEs continue to rely on manual operations that expose workers to repetitive movements and sustained postures. This study focuses on the development of a task-specific ergonomic intervention aimed at reducing repetitive upper-limb exposure in manual food production. The proposed solution targets a high-risk wrapping task identified through prior ergonomic assessment.

Methodology

A field study was conducted at an SME producing otak-otak in Johor, Malaysia. Data collection involved worker interviews, on-site observations, and questionnaire surveys. CMDQ was administered to identify discomfort across body regions. An Initial ERA based on DOSH guidelines was used to screen ergonomic hazards. Tasks exceeding threshold values were further evaluated using the OCRA Checklist through video-based task analysis.

Advanced ERA (OCRA Checklists)

Based on the initial Ergonomic Risk Assessment (ERA) findings, repetitive motion was identified as the most critical ergonomic risk in the otak-otak production process. Consequently, an advanced ergonomic risk assessment focusing on repetitive motion was

conducted using the OCRA Checklist method. The OCRA Checklist scores were calculated using the formula given in Equation (1). The interpretation of the OCRA Checklist scores follows the exposure level classification provided in the Guidelines on Ergonomic Risk Assessment, as summarized in Table 2. The exposure levels are color-coded, ranging from green (acceptable or no risk) to red (high risk), to facilitate clear identification of the severity of repetitive motion risk. Higher OCRA Checklist scores indicate increased exposure and a greater likelihood of developing work-related musculoskeletal disorders (WMSDs), thereby highlighting tasks that require immediate ergonomic intervention.

$$(\text{Frequency} + \text{Force} + \text{Posture} + \text{Additional factors}) \times \text{Duration multiplier} \times \text{Recovery multiplier} = \text{OCRA Checklist} \quad (1)$$

Table 2 OCRA Checklists score and exposure level

OCRA Checklist Score		Exposure Level
Up to 7.5	Green	No risk (acceptable)
7.6-11.0	Yellow	Very low risk
11.1-14.0	Red Light	Light risk
14.1-22.5	Red Medium	Medium risk
≥ 22.5	Red High	High risk

Based on the initial Ergonomic Risk Assessment (ERA), repetitive motion was identified as the most critical ergonomic risk in the otak-otak production process. Therefore, an advanced ergonomic risk assessment focusing on repetitive motion was conducted using the OCRA Checklist method. The OCRA Checklist scores were calculated using the formula presented in Equation (1). The interpretation of the OCRA Checklist scores was based on the exposure level classification specified in the Guidelines on Ergonomic Risk Assessment. As shown in Table 2, the exposure levels range from acceptable (green) to high risk (red), providing a standardized framework for evaluating the severity of repetitive actions. Higher OCRA Checklist scores indicate greater exposure to repetitive motion and an increased risk of work-related musculoskeletal disorders, thereby identifying tasks that warrant ergonomic intervention. The final OCRA Checklist scores for the otak-otak production task are presented in Table 3. The assessment was conducted separately for the right and left upper limbs to capture asymmetric exposure during task execution. As shown in Table 3, the total OCRA Checklist scores were 40.7 for the right upper limb and 31.45 for the left upper limb. According to the exposure level classification presented in Table 2, both scores fall within the high-risk category (≥ 22.5), indicating a very high level of exposure to repetitive motion and a substantial risk of developing work-related musculoskeletal disorders. A comparison of the contributing factors reveals that force exertion, awkward wrist and hand postures, and repetitive action frequency were the primary contributors to the elevated scores. The right upper limb exhibited a higher overall score than the left, mainly due to greater force exertion and higher repetition frequency, reflecting task dominance and uneven workload distribution. High scores associated with wrist and hand postures for both limbs suggest sustained non-neutral positions during handling and shaping activities. Additionally, the lack of task variation contributed equally to both limbs, indicating limited recovery opportunities during the production cycle. The combined effect of high repetition, forceful exertion, awkward postures, and insufficient variation underscores the cumulative nature of the ergonomic risk associated with the task. Overall, the OCRA Checklist results clearly identify the manual otak-otak production process as ergonomically critical, particularly for the right upper limb. These findings highlight the need for immediate ergonomic interventions, such as task redesign, work–rest cycle optimization, and the

introduction of assistive tools or job rotation, to reduce repetitive motion exposure and mitigate the risk of musculoskeletal disorders.

Table 3 Final score for OCRA Checklists

Type of activity		Score	
		Right	Left
Frequency		3	1
Force		8	0
Additional factor		4	4
Awkward posture	Arms	6	6
	Elbow	4	4
	Wrist	8	8
	Hand	8	8
Lack of variation		3	3
Total Score		44	34
OCRA Checklist final score		40.7	31.45



(a)



(b)

Fig. 7 Ergonomic Risks in production line (a) A worker manually handling otak-otak during the sealing process; (b) Worker's arm placement

Given these findings, the implementation of appropriate control measures is essential to reduce ergonomic risk. Recommended interventions include workstation redesign to encourage neutral postures, the introduction of mechanical aids to minimize repetitive and forceful movements, optimization of work–rest schedules, and the provision of ergonomics training. These measures are critical to improving worker well-being and supporting long-term productivity.

Conclusions

In conclusion, this study successfully achieved its research objectives by identifying and evaluating ergonomic risk factors present in the Otak-Otak Ledang production line. Based on the Initial Ergonomic Risk Assessment (ERA), workers are regularly exposed to multiple ergonomic risks during daily operations, particularly repetitive movements and prolonged static postures. These conditions place workers at a high risk of developing work-related musculoskeletal disorders (WMSDs), especially those affecting the upper limbs. The Advanced Ergonomic Risk Assessment conducted using the OCRA Checklist in accordance with ISO 11228-3 proved effective in quantifying repetitive motion risks. The overall scores indicated that the right hand recorded a higher exposure than the left, reflecting the task characteristics in which movements and exertions are predominantly performed using the right hand. The final OCRA scores 40.70 for the right hand and 31.45 for the left-hand fall within the very high-risk category. This confirms that the current work tasks expose workers to a

substantial risk of developing upper-limb musculoskeletal disorders and highlights the asymmetrical workload distribution between hands. Overall, the findings emphasize the critical need for ergonomic improvements to mitigate musculoskeletal disorder risks among production workers. The implementation of appropriate ergonomic interventions targeting the identified risk factors has the potential to significantly enhance worker comfort, safety, and productivity. Furthermore, the outcomes of this study provide valuable guidance for Otak-Otak Ledang in planning ergonomic improvements and may serve as a useful reference for similar small and medium enterprise (SME)-based food production industries.

Acknowledgement

The author would like to express sincere appreciation to Universiti Tun Hussein Onn Malaysia (UTHM) for the academic support provided throughout the course of this research. Gratitude is also extended to the UTHM Publisher's Office for their guidance and assistance during the publication process. Special thanks are given to the supervisor, participants, and colleagues for their valuable contributions, constructive feedback, and continuous support, which were essential to the successful completion of this study.

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Design and Development of an Ergonomic Manhole Cover Lifter for Petrol Stations in Malaysia

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Abstract - Maintenance work on underground fuel storage systems requires petrol station workers to remove manhole covers regularly. These covers can be heavy, and repeated manual handling may place considerable physical strain on workers and contribute to musculoskeletal injury. Existing lifting devices can reduce this effort, but some are expensive, bulky, mechanically complicated, or designed for only certain types of covers. This study therefore focused on developing a manhole cover lifter that is practical and suitable for routine use at petrol stations in Malaysia. The design process included market benchmarking, a user survey, Quality Function Deployment (QFD), Pugh Matrix concept selection, Computer-Aided Design (CAD), Finite Element Analysis (FEA), and prototype fabrication. Forty petrol station owners and managers participated in the survey, with 92.5% reporting that they still used conventional manual lifting tools. The design was then developed and checked through CAD modelling and FEA before a functional prototype was produced. The resulting lifter is intended to make manhole cover removal easier and safer while keeping the mechanism simple enough for routine maintenance work.

Introduction

Regular inspection and maintenance of underground fuel storage systems are necessary at petrol stations. During this work, the manhole cover has to be removed to gain access to the underground system. Depending on its size and material, a cast-iron cover can weigh as much as 50 kg. Handling a cover of this weight repeatedly can place substantial strain on workers, particularly when the task involves bending, reaching, and lifting in an awkward posture [1,2].

Several types of manhole cover lifters are already available, but they are not equally suitable for everyday petrol station maintenance. A simple hook-type tool still requires the operator to apply a relatively large lifting force. Hydraulic and pneumatic systems can reduce the effort needed, but their mechanisms are more complicated. Magnetic lifters also have a clear limitation because they can only be used with ferromagnetic covers. More recent approaches, including battery-powered tools and passive exoskeletons, have been investigated as ways of reducing manual handling effort [3–6]. Even so, these options may require additional equipment or higher investment, which can make them less attractive for routine maintenance. Portability and ease of use are also important considerations in the petrol station environment.

This study therefore focused on developing a manhole cover lifter specifically for petrol station use in Malaysia. The design requirements were obtained from market observations and questionnaire responses from users. These requirements were then carried through the design process using Quality Function Deployment (QFD), concept evaluation, Computer-Aided Design (CAD), Finite Element Analysis (FEA), and prototype development [7–9].

Methodology

Figure 1 illustrates the overall research methodology adopted for the design and development of the proposed manhole cover lifter. The workflow integrates market benchmarking, user requirement analysis, concept development, engineering validation, and prototype fabrication.

The selected concept was then developed using Computer-Aided Design (CAD) and validated through Finite Element Analysis (FEA) to assess its structural performance under the expected loading conditions. Finally, a functional prototype was fabricated to evaluate its practicality, usability, and suitability for routine manhole lifting operations at petrol stations.

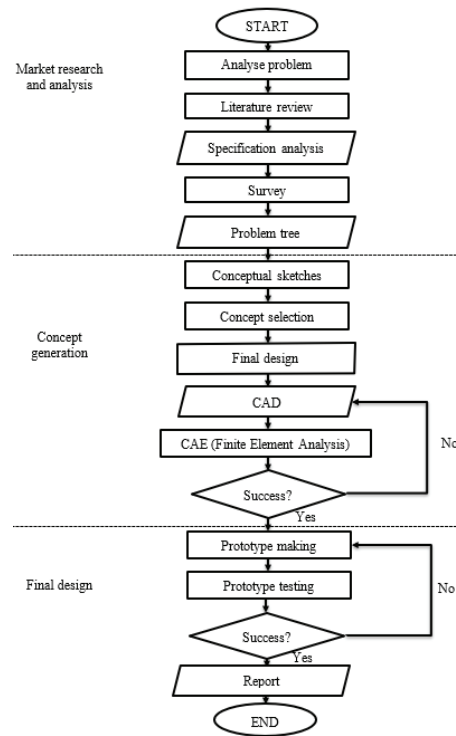


Fig. 1 Engineering Design Process of the Proposed Manhole Cover Lifter

Results and Discussion

The products examined during the market benchmarking showed that no single type of lifter fully met the needs identified for petrol station maintenance. The basic manual tools were relatively simple, but they still placed a considerable physical demand on the operator. Hydraulic and pneumatic alternatives reduced the lifting force but introduced more complicated mechanisms and higher costs. Magnetic systems were restricted to ferromagnetic covers, and some other products were too bulky to be convenient for regular transport and storage. These observations helped define the main requirements for the new design.

Table 1 summarizes the specification analysis of representative commercial products together with their major limitations. The finding suggest that an ideal lifting device should combine ergonomic operation, simple mechanism, reasonable manufacturing cost, and compatibility with different manhole cover materials.

Table 1: Summary of Commercial Manhole Cover Lifting Devices

Mechanism	Representative Product	Main Limitation
Manual Hook	T-Hook	High operating force and poor ergonomics
Magnetic	Allegro Manhole Cover Lid Lifter	Limited to metal covers and high cost
Hydraulic	Hydraulic Jack Manhole Cover Lifter	Complex mechanism and limited mobility
Hydraulic/Pneumatic	Manhole Jack with Hose Guide	High cost and poor ergonomics
Motorized	Manhole Cover Opening Machine	Bulky, expensive and impractical

The survey results supported the observations from the market study. Of the 40 respondents, 57.5% used cast-iron manhole covers and another 25% reported using both cast iron and fiberglass covers. Manhole lifting was a daily task for 55% of the respondents, while 92.5% continued to use conventional manual tools. The ratings in Table 2 show that safety received the highest average score (4.78), followed by time saving (4.68), durability and portability (4.63 each), compact size (4.60), and light weight (4.58). Low cost was also considered important, with an average rating of 4.25. These user responses were used as the

basis for the House of Quality (HoQ) and later for comparing the design concepts with the Pugh Matrix.

Table 2: Summary of User Preferences (Average Rating)

Criteria	Average
Aesthetic design	3.18
High durability material	4.63
Light weight	4.58
Compact size	4.60
Time saving	4.68
Safety	4.78
Portability	4.63
Low cost	4.25

After the concept selection stage, the chosen design was modelled in three dimensions using CAD. FEA was then carried out before fabrication to check the structural behavior of the design under the expected loading conditions [9]. A functional prototype was subsequently produced, as shown in Figure 2, to examine how the lifter worked in practice.



Fig. 2 Final Prototype of the Proposed Manhole Cover Lifter (Expanded on the Left and Folded on the Right).

Taken together, the prototype responds to the main issues identified during the benchmarking and survey stages. Its design places greater emphasis on ease of handling, practicality, and suitability for routine maintenance work at petrol stations.

Conclusion

This study resulted in the development of a manhole cover lifter intended for routine maintenance work at petrol stations in Malaysia. The survey confirmed that conventional manual tools are still widely used, while the market review showed limitations in the cost, portability, mechanism, and usability of several existing alternatives. The user requirements were used throughout the design process to guide the selection and development of the proposed lifter. The CAD model, FEA, and prototype provided an initial check of the design and its practicality. Further work is still needed before wider application, particularly full-scale fabrication, testing under actual petrol station conditions, ergonomic evaluation, and longer-term durability testing. These additional tests would provide stronger evidence of the lifter's performance and suitability for commercial use.

Acknowledgement

The authors gratefully acknowledge the support of the Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), and all petrol station personnel who participated in the questionnaire survey.

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Schedule waste valorisation in cement sand brick: mechanical performance, durability and circular economy implications

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ABSTRACT - Construction sector is a major consumer of natural resources and a major source of waste and greenhouse gas emissions. Rapid urbanization has raised the need for construction materials while planned industrial waste or residue continues to pile up in landfills which leads to environmental issues. The presence of residue in the cement sand bricks promote sustainable building and is in line with the United Nations Sustainable Development Goals (SDGs), such as responsible consumption and production (SDG 12) and climate action (SDG 13). Cement sand bricks are extensively used because of their low cost and good structural properties. However, the extraction of natural sand and the manufacturing of cement lead to resource depletion and carbon emissions. The replacement of natural sand with schedule waste residue might limit the dumping of natural sand in the landfill, which could save natural resources and reduce the environmental impact of the brick manufacturing. The research analyses SW501 scheduled waste as partial replacement (10-30%) of sand for cement sand brick with mechanical and durability tests. The result showed 20% replace reach maximum of compressive value (34.9MPa) and the mechanical test reduce while increasing of residue in the mixing. It also showed durability of the brick thru environment safety assessment which all element detected below than the maximum limit establishes by Environmental Quality (Scheduled Waste) Regulation. In addition the viability of valorizing waste, reducing natural sand consumption, promoting circular economy practices, and supporting sustainable infrastructure and national waste management programs.

INTRODUCTION

The building sector is one of the biggest drivers of economic growth and at the same time one of the biggest users of natural resources and contributors to environmental deterioration. Rapid urbanization has led to the rising demand for traditional masonry materials such as cement sand bricks that are highly dependent on natural aggregates and cement, resulting in huge depletion of resources and carbon emission. At the same time, industrial operations produce significant amounts of scheduled waste that is generally disposed of in landfills, raising environmental and public health problems. The use of residual materials in building has been increasingly investigated as a way to limit landfill disposal, preserve natural resources and promote circular economy principles [1]. Optimization of residue inclusion may result in better particle packing, a finer cementitious microstructure and enhanced compressive strength and durability. For example, [2] and [3] observed enhancement in mechanical performance of cement bricks using rice straw ash at optimal replacement levels.

However, the study of residue utilization is still restricted because of material unpredictability, possible expose to environmental and for long term performance. Further, conflicting results have been published on the impact of residue replacement on compressive strength and durability. These uncertainties indicate the need for comprehensive inquiry to assess the engineering performance and environmental safety of cement sand brick incorporated with residue.

It is necessary to assess the viability of using scheduled waste materials in a brick as a sustainable alternative to traditional raw materials. Identify the effect of replacement with scheduled waste on the mechanical performance and durability properties is particularly important for practical use in material construction. Addressing these elements may help to reduce landfill dependence, minimize emissions from raw material extraction and promote circular economy approaches in the building industry. This background influences the current study and the research topic.

METHODOLOGY

Raw material and preparation

Portland Cement certified to MS EN 197-1:2014, sand, water and residue were used to fabricate cement sand bricks as a partial sand replacement. The SW501 residue was collected from an e-waste recovery plant and ball milled to lower the particle size and enhance the particle distribution to minimise the coarse particles that may increase the porosity of the bricks [4][5]. Fig.1 shows the preparation of the raw materials. The use of the mix ratio of 1:6 was based on the earlier research [6][7][8][9] and [10] in which the residue of SW501 was added at certain replacement levels of sand as indicate in Table 1 with 0.5 water cement ratio. The cement, sand, residue, and water were weighed individually using a digital weight scale before mix all materials to verify correct proportions according to the propose mix design. Accurate weighing is critical for consistent mix results, homogenous specimen quality, and dependable physical and mechanical performance throughout testing.



Fig. 1 Material for mixing cement sand brick: (a) Weigh cement, (b) Weigh sand, (c) Weigh water, (d) Weigh treated SW501 residue and (e) Mix all material

Table 1: Mixing ratio

Sample	Water (g)	Cement (g)	Sand (g)	Residue (g)	Residue (%)
M0	162.5	325	1950	-	0%
M10	162.5	325	1755	195	10%
M20	162.5	325	1560	390	20%
M30	162.5	325	1365	585	30%

Manufacturing of cement sand brick

The brick dimension were 215mm x 100mm x 65mm, referencing EN 772-2:1998 [11]. The homogenised material is then poured into a hard brick mould of prescribed size so as to fill uniformly and to avoid trapping of air. The manual pre-compaction is carried out by pressing the mixture with a wooden plate at a nominal pressure of around 0.0161 N/mm². This process encourages the rearranging of particles, boosts packing density and creates first interparticle interaction between the mixing material of cement, sand and residue. Subsequently, the bricks were left to cure for up to 28days prior to testing.

Compressive strength test

Compressive strength of the cement sand bricks is evaluated by compressing prepared masonry units uniaxially under controlled and standardized conditions according to EN 772-1. To minimize the impact of free moisture on mechanical reaction, specimens are oven dried at $70\pm 5^{\circ}\text{C}$ to a constant mass. After drying, the bricks are conditioned at $20\pm 2^{\circ}\text{C}$ until it reach thermal equilibrium and tested within 24 hours to verify repeatability. Each specimen is placed centrally between the upper and lower platens of a calibrated compression testing machine. A continually increasing compressive load apply is 2000 N/s until failure, and the highest load at rupture is measured.

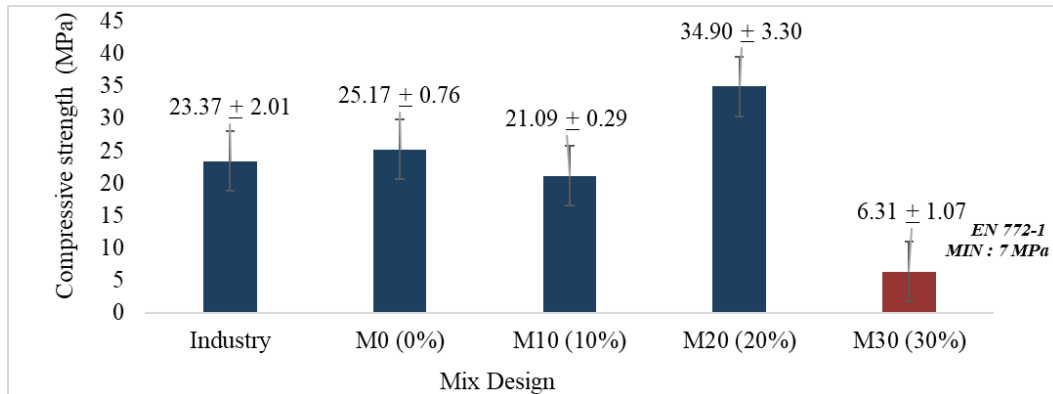


Fig. 2 Compressive strength

Environmental Safety Assessment (TTLC and TCLP)

The environmental safety of cement sand bricks incorporating SW501 industrial residue was evaluated using the Total Threshold Limit Concentration (TTLC) and Toxicity Characteristic Leaching Procedure (TCLP) in accordance with USEPA SW-846 and the Environmental Quality (Scheduled Waste) Regulation 2005 [11]. TTLC assessed the total concentration of 39 elements in the solid brick containing 30% residue. The solid brick after 28 days been crush until become powder before testing. For TCLP evaluated the leaching potential of 40 elements under three exposure conditions which first is flowing with water, soaking with water for 24 hours and in boiling water with temperature 100°C for 5 hours [12][13]. These tests were conducted to verify that the incorporation of SW501 residue does not pose significant long term environmental or health risks.

RESULT AND DISCUSSION

Compression performance

The mechanical test after curing 28 days showed the highest compressive strength of 34.90 MPa in the 20% residue replacement mix (M20) as shown in Fig. 2 and the lowest of 6.31 MPa in the 30% replacement mix (M30) which is below the minimum 7 MPa as required by Malaysian requirements [14]. Although the compressive strength normally decreases with the increase in residue concentration, the higher performance of M20 was related to enhanced compaction during fabrication, which indicates that a suitable residue amount can improve the particle packing and load transfer in the cement matrix. These findings show that industrial residue is a technically viable partial sand replacement at moderate replacement levels ($\leq 20\%$) where the filler effect and sufficient matrix densification dominate any unfavourable effects. However, at high replacement levels (30%), residue can inhibit cement hydration, reduce the interfacial bonding and increase the porosity, resulting in a drastic decrease of strength and indicating that high amount residue replacement is not recommended for structural masonry applications.

Environmental Safety Performance

TTLC

The TTLC analysis on the cement sand brick with 30% replacement residue identified 12 out of 39 elements analysed as tabulate in Table 2 which 11 element from heavy metal while 1 element from miscellaneous which is fluoride salts. For the other elements not detected due to too low or not exist. Based on the result, Zinc is the highest element (64.1mg/kg) followed by Barium (59.4 mg/kg) and Copper (39.8 mg/kg) but still all the element were below the maximum permissible limits set by the Department of Environment [15]. The results show that the incorporation of SW501 residue does not lead to excessive total concentrations of hazardous elements in the brick matrix, indicating that the produced bricks are chemically safe and do not fall under the category of hazardous materials as per the Environmental Quality (Scheduled Waste) Regulations 2005. This validates the use of SW501 residue as sustainable sand replacement material without having substantial hazards related with total elements contamination.

Table 2: TTLC result

Element	Result (mg/kg)	DOE maximum limit (mg/kg)
Zinc (Zn)	64.1	5,000
Barium (Ba)	59.4	10,000
Copper (Cu)	39.8	2,500
Chromium (Cr)	23.1	2,500
Vanadium (V)	14.2	2,400
Arsenic (AS)	10.4	500
Lead (Pb)	10.1	1,000
Molybdenum (Mo)	7.1	3,500
Nickel (Ni)	5.3	2,000
Hexavalent Chromium (Cr VI)	2	500
Silver (Ag)	1.5	2,000
Fluoride Salts	14	18,000

TCLP

Based on analysis result for TCLP on brick with 30% replacement with 3 condition environment which are flow water, soak water and boil hot water showed outstanding heavy metal immobilization performance. Only chromium was discovered in the analysis of the 40 elements, at 0.22 mg/L and 0.16 mg/L for soak water and boil hot water, respectively, which was below the DOE regulation limit of 5.0 mg/L as indicate in Table 3 below. But for flow water the result too low or not detected during testing. All other dangerous elements like lead, arsenic and cadmium were low enough not to be reported. These results indicate the efficiency of the cement matrix to stabilize and immobilize heavy metals in the brick and to limit the leaching of contaminants even under long term water exposure and also varies of temperature condition. Therefore, the residue incorporated with cement sand bricks are environmentally safe to soil and groundwater, thereby enabling the safe and sustainable use of scheduled waste as an alternative building material.

Table 3: TCLP result

Element	Result flow water (mg/L)	Result soak water (mg/L)	Result boil water (mg/L)	DOE maximum limit (mg/L)
Chromium (Cr)	<0.01	0.22	0.16	5

CONCLUSION

In conclusion, SW501 industrial residue can be utilized safely as a partial substitute of natural sand in manufacturing cement sand bricks. depend on the replacement amount. The best replacement level was 20% at which had the maximum compressive strength of 34.9 MPa. The M30 mix did not reach the necessary strength of 7 MPa due of the reduction in mechanical performance. Higher residue

concentration often led to lower compressive strength but the cement matrix was successful in immobilizing hazardous materials as demonstrated by TTLC and TCLP testing. All discovered heavy metals were below the Department of Environment (DOE) Malaysia guidelines even with 30% substitution, posing a little environmental risk. This research was confined to the 28 days curing period and long-term durability under environmental exposure. This replacement not only can reduce usage of sand but it also saves our environment to disposal hazard waste which need high cost. This promotes circular economy principles and sustainable waste valorization for the e-waste recovery business. Future research should focus on the optimization of the replacement levels of 20–30%, durability assessment in harsh conditions and application of the Design of Experiments (DOE) to improve the residue content, curing age and engineering performance.

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Why Engineering Alone Cannot Prevent Level Crossing Crashes: An Integrated Behaviour Regulation Model from the Indonesian Context

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Abstract- Railway level crossings in Indonesia remain critical safety hotspots despite continuous infrastructure improvements. Existing approaches often treat technical failures and human error in isolation, neglecting the systemic interaction between engineering conditions and user compliance. To address this, this study integrates Structural Equation Modelling (SEM-PLS) with the 5E framework and Hazard Identification (HIRA) to analyze the determinants of violation behavior. The findings reveal that Law Enforcement is the single most critical determinant of compliance, significantly surpassing the influence of infrastructure quality or safety education. Notably, the study uncovers a ‘safety paradox’ where improved physical environments without visible surveillance actually increase violation likelihood due to risk compensation. These results imply that capital-intensive engineering upgrades will remain ineffective without concurrent strict enforcement mechanisms, urging policymakers to prioritize automated surveillance systems over passive infrastructure expansion.

Introduction

Railway level crossings represent high-risk locations in transport safety, characterized by persistently high fatality rates (Borsos et al., 2016; Laapotti, 2016; Lee et al., 2025). In Indonesia, this risk is intensified by dense urban rail corridors and rapid vehicle growth outpacing infrastructure development. PT Kereta Api Indonesia recorded ~1,900 level crossing accidents between 2018 and 2023 (>1,400 victims, >500 fatalities), with 80–86% occurring at unguarded crossings that comprise most of the network. Local vulnerabilities are evident in high collision concentrations in Sidoarjo and Surabaya during peak hours (Wicaksono et al., 2025), non-standard geometry increasing skidding risks in Greater Bandung (Tanne et al., 2024), and fragmented governance leading to informal guarding (Ilham, 2024; Sekhuti & Purwadi, 2023). Beyond technical measures, safety depends on self-regulation (Lenggono et al., 2023), safety climate (Farida et al., 2024), and cognitive preparedness (Kuncowati et al., 2024). However, behavioral safeguards are undermined by weak law enforcement (Ilham, 2024) and sparse tech-based monitoring (Larue & Naweed, 2021).

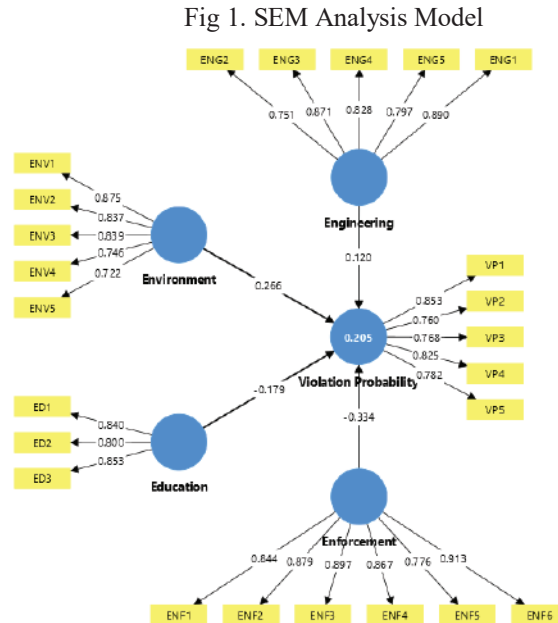
Method

This study employed an explanatory sequential mixed-methods design, beginning with a quantitative phase to test the structural model, followed by a qualitative observational phase to interpret findings. The quantitative phase utilized a survey analyzed via Structural Equation Modeling Partial Least Squares (SEM-PLS) to examine the determinants of violation probability, while the qualitative phase involved field observations using the 5E framework and Hazard Identification and Risk Assessment (HIRA).

- 1) Education (ED): Measures exposure to safety campaigns and personal discipline (Restuputri et al., 2022; Velantia et al., 2024).
- 2) Enforcement (ENF): Assesses perceived sanction strictness and consistency (Freeman & Rakotonirainy, 2017; Larue & Naweed, 2021), reflecting Indonesia's enforcement context (Ilham, 2024; Sekhuti & Purwadi, 2023).
- 3) Engineering (ENG): Evaluates infrastructure quality, such as detection systems and interlocking (Anagnostopoulos, 2025; Fayyaz et al., 2021).
- 4) Environment (ENV): Covers physical factors like visibility and road surface conditions (Laapotti, 2016; Macioszek & Kurek, 2020).
- 5) Violation Probability (VP): Captures self-reported likelihood of committing violations (Restuputri et al., 2022; Velantia et al., 2024).

Result and Discussion

All constructs demonstrate strong internal consistency and convergent validity, with Cronbach's alpha >0.70, Composite Reliability >0.86, and AVE >0.63 (exceeding the standard 0.50 threshold). These values align with typical AVE ranges (0.50–0.70) reported in driver violation studies across Australia and Indonesia. Outer loadings range from 0.722 to 0.913 across the 4E constructs and 0.760 to 0.853 for Violation Probability, indicating high indicator contribution. High loadings for ENF3 (0.897) and ENF6 (0.913) highlight strong sensitivity to enforcement consistency and immediate consequences, supporting findings that perceived sanctions heavily drive level-crossing compliance (Freeman & Rakotonirainy, 2017).



Integration of SEM, observations, and HIRA

The HIRA analysis confirms that the highest risk scenarios at level crossings do not stem from pure technical failure, but from road user behaviour that develops in environments characterised by weak enforcement and permissive social norms

Table 1. Summary of HIRA for risky behaviours at level crossings

Hazard	Main Causes	Likelihood (1 - 5)	Severity (1 - 5)	Risk Level	Main Recommendations
Violating closed barriers	Lack of sanctions, misperception of risk	4	5	Extreme	Automated enforcement cameras, routine patrols
Speeding through before barriers	Risk compensation	3	4	High	Alarm timing adjustment, risk based education
Stopping too close to the tracks	Permissive social norms	3	5	Extreme	Physical separators, safe buffer zones
Late barrier closure by operators	Procedural variation, workload	2	5	High	Critical scenario training, procedural audits
Copying others' violations	Spread of negative norms and behaviour	3	4	High	Safety norm campaigns, risk communication

Acknowledgement

This work was supported by the Institute for Research and Community Services (LPPM), Universitas Brawijaya

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Precision Ergonomics in Computer Work: Predicting Neck Pain Severity Using Wearable Sensors and Ordinal Logistic Regression

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ABSTRACT—Work-related musculoskeletal disorders (MSDs), particularly neck pain, represent a growing global health burden among the digital workforce, leading to productivity loss and long-term disability. Despite their prevalence, ergonomic risk assessments still predominantly rely on subjective questionnaires or observational tools, which lack the resolution required to capture real-time micro-postural deviations associated with pain onset. This study addresses this limitation by quantifying the relationship between objectively measured postural angles and MSD severity using a data-driven approach. A cross-sectional study was conducted involving 98 computer users equipped with IoT-based inertial sensors to continuously record cervical and trunk kinematics during computer work. Neck MSD severity was assessed using a modified Nordic Body Map with ordinal pain levels, and the data were analysed using Ordinal Logistic Regression. The results indicated a high prevalence of neck MSDs (65.3%) among young computer users. The regression analysis identified cervical flexion angle (angle 3) as a significant predictor of increased pain severity ($p < 0.01$), whereas trunk posture (angle 4) demonstrated a compensatory relationship. These findings indicate that wearable sensor data can reliably predict subjective pain severity and support proactive, human-centric ergonomic monitoring systems aligned with the Industry 5.0 paradigm.

Introduction

Musculoskeletal disorders (MSDs) have become an urgent global health crisis that threatens workforce sustainability and the well-being of the productive-age population. Recent studies report a significant rise in neck pain prevalence among younger populations (Jing et al., 2025), which hinders the achievement of worker health-related Sustainable Development Goals (Thetkathuek et al., 2025) and creates heavy economic losses through disability and lost productivity (Dagenais et al., 2008; Tang, 2022). High MSD rates are documented across diverse occupations, including weavers (Meher et al., 2025), construction workers (Kadir et al., 2025), preclinical doctors (Johnson & Rajan, 2024), orthodontists (Sankar et al., 2012), and surgeons (Abolfotouh et al., 2024; Xie et al., 2026). However, office workers and computer users consistently face the highest risk due to their sedentary work habits (Demissie et al., 2022; Navidi et al., 2021). Prolonged static computer work biomechanically alters spinal loading and correlates strongly with neck and back complaints (Demissie et al., 2024). Specifically, Forward Head Posture (FHP) serves as a primary predictor of neck pain (Naveed et al., 2025) and physical disability (Fan et al., 2022), as even minor cervical angle changes drastically elevate intradiscal pressure and shear forces at C5–C6 (Barrett et al., 2024; Kwon et al., 2018; Schneider et al., 2025). FHP also impairs postural balance (Youssef et al., 2025), decreases cervical proprioception (Peng et al., 2021), and links to systemic issues like hypertension (Muhammad Ahmed Javed et al., 2025). Although muscle stiffness varies (Kocur et al., 2018), workers frequently adopt unconscious trunk compensations (Arippa et al., 2022), making early

posture detection essential before corrective interventions are needed (Hamzelouie et al., 2025; Rasoulzadeh & Gholamnia, 2012).

Conventional ergonomic tools like self-reports, RULA, or REBA suffer from subjective observer bias (Baird et al., 2020; De Sousa et al., 2025) and miss dynamic micro-postures (Kalisch et al., 2022; Patra et al., 2025), while markerless photography lacks real-time capabilities (Hida et al., 2020). Aligning with Industry 5.0, wearable IoT sensors now replace these obsolete static tools (Ciccarelli et al., 2025; Safari et al., 2025). However, a critical research gap exists: while machine learning and IoT studies focus on accuracy (Shaikh & Mandal, 2025; Zhang et al., 2023; Zhao et al., 2023) or sensor validation (Kim et al., 2024; Rodrigues et al., 2022; Santos et al., 2024), they fail to quantitatively model how many degrees of postural deviation cause pain to escalate to clinically severe levels.

Methods

This analytical cross-sectional study evaluated secondary data from the open-access, anonymized MMD-MSD dataset by Markova et al., which adhered to institutional ethical guidelines. The target population comprised active computer workers seated for at least 4 hours daily, representing the highest risk group (Demissie et al., 2024; Navidi et al., 2021). A total of 98 productive-age participants (18–60 years) without prior spinal injuries were recruited via purposive sampling (Abolfotouh et al., 2024), while age, sex, and BMI were recorded as key confounding covariates (Meher et al., 2025; Patra et al., 2025). Replacing subjective observation methods (Rodrigues et al., 2022; Santos et al., 2024), objective kinematic data were captured continuously using calibrated IoT inertial measurement units (IMUs) in line with Industry 5.0 practices (Ciccarelli et al., 2025; Safari et al., 2025). Guided by biomechanical standards (Barrett et al., 2024; Kwon et al., 2018), the system tracked Cervical Angle (Angle 3) for FHP and Trunk Angle (Angle 4) for thoracic-lumbar posture. Subjective neck pain severity was assessed immediately after work using the gold-standard modified Nordic Body Map (NBM) (De Sousa et al., 2025; Kadir et al., 2025), categorized on a 5-level ordinal scale (0 = No pain to 4 = Severe pain).

Results

The study population represents a young, sedentary digital workforce with substantial exposure to postural risk. This study analysed secondary data obtained from the *MMD-MSD: A Multimodal Multisensory Dataset*, developed by Markova et al., an open-access dataset collected using standardized measurement protocols (Markova et al., 2024). A total of 98 computer users with complete data across all variables were included in the analysis.

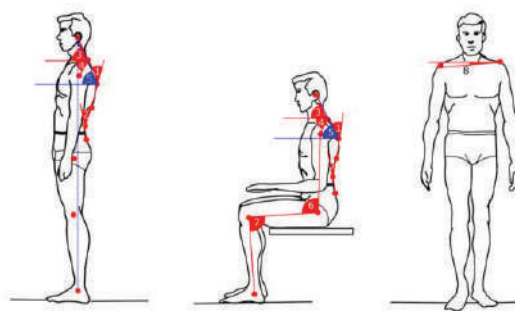


Fig 1. Angle Guide Fig

Age was also identified as a significant predictor ($\beta = 0.049$; $p = 0.007$), indicating that older participants were more likely to report higher levels of neck pain severity. In contrast,

other postural angles, BMI, and daily computer use duration did not show statistically significant associations with neck pain severity ($p > 0.05$). Schematic representation of biomechanical reference points and kinematic angles measured via wearable sensors across standing profile, sitting profile, and frontal views. Red dots indicate sensor/marker placement locations, while numbered angles (1–8) represent key postural biomechanics (e.g., forward head posture, cervical/thoracic flexion, hip/knee angles, and shoulder alignment) used as predictor variables in the ordinal logistic regression model.

Conclusion

In conclusion, the ordinal logistic regression model revealed that age is a significant predictor of neck pain severity among computer workers, whereas BMI, daily computer usage duration, and other measured kinematic angles showed no statistically significant association.

Acknowledgement

This work was supported by the Institute for Research and Community Services (LPPM), Universitas Brawijaya

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Waste Cooking Oil Processing for Sustainable Plasticizer Development: A Comparative Study

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Abstract— The increasing demand for sustainable polymer additives has encouraged the exploration of waste-derived resources as potential alternatives to conventional petroleum-based plasticizers. Waste cooking oil (WCO) is a promising candidate due to its low cost, widespread availability, and potential for value-added utilization. However, the chemical quality of WCO depends significantly on the treatment method employed prior to its application. In this study, three different WCO processing approaches, namely cornstarch-assisted physical refining, transesterification, and glycerol extraction, were comparatively evaluated as preliminary routes for sustainable plasticizer development. The processed products were characterized using Near-Infrared Spectroscopy (NIR) to determine their fatty acid composition, free fatty acid (FFA) content, iodine value (IV), moisture content, peroxide value (PV), and slip melting point (SMP). The results showed that all processing methods maintained similar fatty acid profiles, with palmitic acid (C16:0) and oleic acid (C18:1) remaining the dominant components. Cornstarch refining and transesterification produced comparable FFA values of 0.16% and peroxide values of approximately 21 meqO₂/kg, indicating relatively stable products. In contrast, glycerol extraction reduced the FFA content to 0.10% and moisture content to 0.14%, suggesting higher purification efficiency. However, the peroxide value increased markedly to 64.5 meqO₂/kg, indicating greater susceptibility to oxidative degradation. Overall, the findings demonstrate that the processing route has a significant influence on the chemical characteristics of WCO-derived products. Among the methods investigated, cornstarch refining and transesterification offered a better balance between product purity and oxidative stability, while glycerol extraction provided enhanced purification at the expense of oxidation resistance. This study provides important preliminary insights for the selection of suitable WCO-derived feedstocks in future bio-based plasticizer development and polymer applications.

Introduction

The increasing demand for sustainable materials has accelerated the search for environmentally friendly alternatives to conventional petroleum-based additives used in polymer industries. Among these additives, plasticizers play an important role in improving flexibility, processability, and overall performance of polymeric materials. However, concerns regarding the environmental impact and potential health risks associated with certain petroleum-derived plasticizers have encouraged researchers to explore renewable and waste-derived resources as alternative feedstocks [1], [2].

Waste cooking oil (WCO) has attracted considerable attention as a low-cost and readily available waste resource generated from households and food industries [3]. The valorisation of WCO not only reduces environmental pollution associated with improper disposal but also supports circular economy initiatives through the conversion of waste into value-added products [3], [4]. Due to its fatty acid content and organic composition, WCO has shown potential as a precursor for the development of bio-based plasticizers. Nevertheless, the quality and suitability of WCO-derived products are highly dependent on the processing method employed. The presence of impurities, moisture, free fatty acids (FFA), and oxidation products may affect the performance and stability of the final plasticizer [4].

Various processing techniques have been reported to improve the quality of WCO, including physical refining, transesterification, and glycerol recovery processes [5], [6]. Cornstarch-assisted refining is a simple and environmentally friendly method for removing impurities, while transesterification converts triglycerides into fatty acid methyl esters and generates glycerol as a by-product [6]. Glycerol extraction and purification, on the other hand, may produce a higher-purity product with potential applications in polymer formulations [7], [8].

However, comparative studies evaluating these processing routes from the perspective of sustainable plasticizer development remain limited [9]. The effects of different WCO processing methods on the chemical characteristics of the resulting products and their suitability as potential plasticizer feedstocks are still not well understood. Therefore, this study investigates how cornstarch-assisted physical refining, transesterification, and glycerol extraction influence the chemical properties of WCO-derived products. The processed samples were characterized using Near-Infrared Spectroscopy (NIR) to determine their fatty acid composition, free fatty acid content, iodine value, moisture content, peroxide value, and slip melting point. By comparing the effectiveness of these processing routes, this study aims to identify the most promising WCO-derived feedstock for future sustainable plasticizer and polymer applications.

Materials and Methods

Waste cooking oil (WCO) collected from local food premises was used as the raw material for this study. Prior to processing, the collected WCO was filtered through a fine mesh cloth to remove suspended food particulates and left to settle to reduce residual water content, providing a common starting material for the three processing routes. Three processing routes, namely cornstarch-assisted refining, transesterification, and glycerol extraction, were investigated and comparatively evaluated for their potential application in sustainable plasticizer development. The overall experimental workflow employed in this study is illustrated in Figure 1.

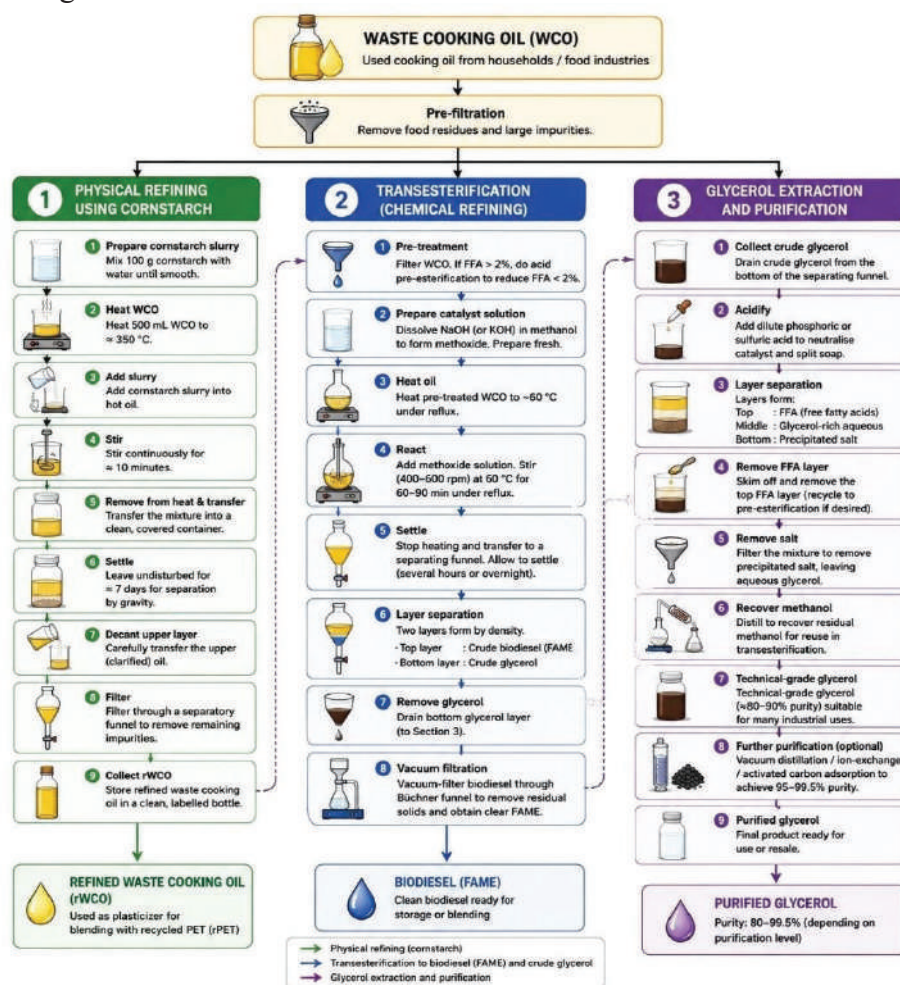


Fig. 3 Overall experimental workflow for the processing and characterization of waste cooking oil through cornstarch-assisted refining, transesterification, and glycerol extraction towards sustainable plasticizer development.

In the cornstarch-assisted refining process, 500 mL of WCO was treated with a cornstarch slurry prepared by mixing cornstarch with water. The mixture was heated and stirred to promote the adsorption and coagulation of impurities. After treatment, the oil was left undisturbed for seven days to allow gravitational phase separation before the clarified oil layer was collected and filtered to obtain refined WCO. This extended settling period reflects the reliance of cornstarch-assisted refining on passive gravitational separation, in contrast to the transesterification and glycerol extraction routes, which employ active phase separation (settling in a separating funnel followed by acidification) that proceeds on a much shorter timescale.

For the transesterification process, the pre-treated WCO was reacted with methanol in the presence of an alkaline catalyst (NaOH or KOH) at approximately 60°C under continuous stirring, following reaction conditions consistent with those reported for WCO-based transesterification [10], [11]. Following the reaction, the mixture was transferred into a separating funnel and allowed to settle, resulting in the formation of two distinct phases consisting of biodiesel and crude glycerol [12]. The crude glycerol recovered from the transesterification process was subsequently purified through acidification, phase separation, filtration, and methanol recovery, following purification approaches reported for biodiesel-derived crude glycerol [13], [14]. The resulting glycerol-rich product was collected for further characterization.

The products obtained from each processing route were characterized using Near-Infrared Spectroscopy (NIR), a rapid and non-destructive technique widely applied for fatty acid and oil-quality determination [15], [16]. The analysis was performed to determine the fatty acid composition, including palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3). In addition, free fatty acid (FFA) content, iodine value (IV), moisture content, peroxide value (PV), and slip melting point (SMP) were evaluated. The measured parameters were compared to assess the influence of processing methods on the chemical quality of WCO-derived products and their suitability as potential feedstocks for sustainable plasticizer development.

Results and Discussion

The chemical characteristics of the products obtained from the three-waste cooking oil (WCO) processing routes were evaluated using Near-Infrared Spectroscopy (NIR). The measured parameters included fatty acid composition, free fatty acid (FFA) content, iodine value (IV), moisture content, peroxide value (PV), and slip melting point (SMP), as presented in Table 1.

Table 1: NIR characterization results of WCO-derived products.

Parameter	Cornstarch Refining	Transesterification	Glycerol Extraction
C16:0 (%)	39.7	39.5	39.8
C18:0 (%)	6.1	6.1	5.2
C18:1 (%)	34.9	35.4	37.8
C18:2 (%)	13.7	13.7	13.1
C18:3 (%)	ND	ND	ND
FFA (%)	0.16	0.16	0.10
IV	63.2	63.2	63.6
Moisture (%)	0.21	0.20	0.14
PV (meqO ₂ /kg)	21.4	21.2	64.5
SMP (°C)	ND	ND	2.2

**ND = Not detected (below the detection/quantification limit of the NIR method)

The results indicate that the three processing methods produced relatively similar fatty acid compositions. No substantial shift in the major fatty acid fractions was observed among the processing route. Not Detected (ND) denotes values below the NIR method's

detection/quantification limit rather than a true zero value; this applies to the linolenic acid (C18:3) and slip melting point (SMP) readings for the cornstarch refining and transesterification products in Table 1. Palmitic acid (C16:0) and oleic acid (C18:1) remained the dominant fatty acids in all samples, suggesting that the processing routes did not significantly alter the fundamental chemical composition of the waste cooking oil. The iodine values were also comparable, ranging from 63.2 to 63.6, indicating that the degree of unsaturation was largely preserved throughout the processing treatments, consistent with NIR-based fatty acid quantification approaches reported elsewhere [15], [16].

The FFA and moisture contents are important indicators for evaluating the quality of potential plasticizer feedstocks. Glycerol extraction produced the lowest FFA content (0.10%) and moisture content (0.14%), demonstrating its effectiveness in removing residual contaminants and improving product purity. In comparison, cornstarch refining and transesterification yielded similar FFA values of 0.16% and moisture contents of approximately 0.20–0.21%. These findings suggest that the purification stages involved in glycerol extraction were more effective in reducing undesirable impurities, consistent with the low FFA and moisture levels considered desirable for WCO-derived plasticizer and bioplastic feedstocks [4], [9].

However, a contrasting trend was observed for the peroxide value. While cornstarch refining and transesterification recorded relatively low PV values of 21.4 and 21.2 meqO₂/kg, respectively, the glycerol extraction route exhibited a substantially higher PV of 64.5 meqO₂/kg. This spike is most plausibly attributed to the acidification, phase separation, and methanol-recovery steps involved in glycerol purification, which expose the oil-rich phase to acidic conditions, elevated temperature, and prolonged air contact, all of which are known to accelerate lipid autoxidation and hydroperoxide formation [8], [13]. In contrast, the shorter processing duration and reduced heat/air exposure in the cornstarch refining and transesterification routes likely limited oxidative attack on the unsaturated fatty acids. The elevated peroxide value indicates a greater extent of oxidative degradation, which may negatively affect long-term storage stability and subsequent polymer processing performance, an effect similarly noted in oxidation-sensitive WCO-derived bioplasticizer systems [1]. Therefore, despite achieving better purification, glycerol extraction may increase susceptibility to oxidation and would likely require an antioxidant stabilization step before use as a plasticizer feedstock. Since FFA, moisture content, and peroxide value are critical indicators of plasticizer feedstock quality, a comparative visualization of these parameters is presented in Figure 2.

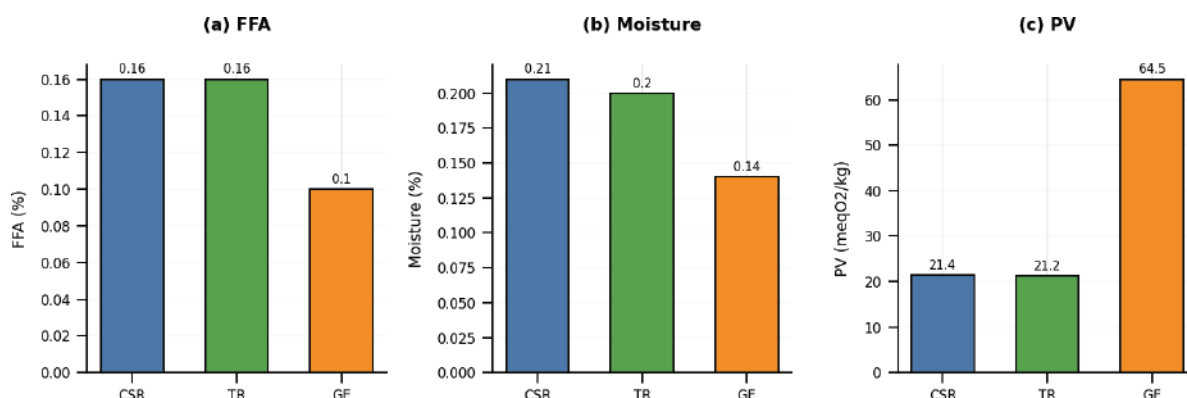


Fig. 2 Comparison of (a) free fatty acid (FFA), (b) moisture content, and (c) peroxide value (PV) of waste cooking oil products obtained from cornstarch-assisted refining (CSR), transesterification (TR), and glycerol extraction (GE). Glycerol extraction produced the lowest FFA and moisture contents but exhibited the highest peroxide value, indicating improved purification but reduced oxidative stability

Overall, the results demonstrate that processing routes significantly influence the chemical quality of WCO-derived products. As shown in Figure 2, the inverse relationship between FFA/moisture content and peroxide value across the three routes illustrates the underlying purification–oxidation trade-off: the same acidification and heating steps that most effectively strip moisture and free fatty acids from the glycerol-extraction route are also the steps most likely to expose the oil phase to oxidative conditions. Although glycerol extraction produced the lowest FFA and moisture contents, the substantially higher peroxide value may limit its direct utilization without additional stabilization. In contrast, cornstarch-assisted refining and transesterification offered a more balanced combination of purity and oxidative stability, making them promising candidates for future bio-based plasticizer development. Further studies involving polymer blending, thermal characterization, and mechanical performance evaluation are recommended.

Conclusion

This study compared three waste cooking oil (WCO) processing routes, namely cornstarch-assisted refining, transesterification, and glycerol extraction, as preliminary purification methods for sustainable plasticizer feedstock development. The results showed that all processing methods preserved the overall fatty acid composition of the WCO-derived products, while producing notable differences in product quality parameters. Glycerol extraction achieved the lowest free fatty acid (0.10%) and moisture content (0.14%), indicating superior purification efficiency. However, the substantially higher peroxide value (64.5 meqO₂/kg) suggested increased oxidative degradation, which may adversely affect storage stability and subsequent polymer processing. In contrast, both cornstarch-assisted refining and transesterification exhibited comparatively low peroxide values (approximately 21 meqO₂/kg) while maintaining acceptable FFA and moisture levels. Based on the overall balance between purification effectiveness and oxidative stability, cornstarch-assisted refining and transesterification were identified as the most suitable processing routes for further plasticizer development, whereas glycerol extraction would likely require additional antioxidant stabilization prior to utilization. These findings provide a basis for selecting appropriate WCO-derived feedstocks for subsequent plasticizer synthesis and evaluation in polymer systems. Building on these preliminary findings, future work will incorporate replicate measurements with statistical validation (e.g., ANOVA) and will extend the evaluation to actual plasticizer performance through direct incorporation of the WCO-derived products into a PVC matrix, followed by mechanical, thermal, and migration testing.

Acknowledgement

This research was fully supported by the Fundamental Research Grant Scheme (FRGS), grant number FRGS/1/2024/TK08/UTEM/02/4. The authors gratefully acknowledge the Ministry of Higher Education (MOHE) and Universiti Teknikal Malaysia Melaka (UTeM) for the approved funding.

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SOLAR POWERED MOBILE CHARGER WITH IoT-BASED MONITORING FOR OFF-GRID APPLICATIONS

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Abstract— The increased dependence on mobiles and portable devices has created the demand for efficient and eco-friendly charging solutions in other locations which do not have access to traditional AC power. The solar-powered mobile charger in this paper is designed, developed and tested along with an Internet of Things enabled monitoring system. The system design involves a foldable mono-crystalline solar panel which is a hybrid renewable energy source that will increase the charging reliability in different environmental conditions. For capturing the solar and wind energy, the collected voltage has been processed using DC–DC boost and buck converters to store it in a lithium-Ion battery pack. Real-time tracking of battery voltage, charging current, temperature and status has been accomplished using a smartphone application through an IoT system made up of an ESP32 microcontroller connected to a Blynk platform. To ensure system operation safety and extend battery life, safety attributes like over-current, overvoltage and overheating have been implemented. The charging efficiency of the two renewable sources has been tested in different weather states. The results show that the sun's energy is considerably more in the sunny weather than in the cloudy weather. The IoT system then issued warning signals when the system detected inappropriate operation conditions and successfully transmitted to the user. In conclusion, the prototype which has been built offers an efficient, mobile, and portable charging system suitable for camping, disaster and rural scenarios.

Introduction

The increasing use of mobile devices, especially in remote, off-grid, and outdoor areas where getting conventional electricity can be difficult, has made reliable charging solutions more crucial. Communication, education, healthcare, and emergency services all depend on mobile devices, which need a steady power source to operate properly. Solar energy is a sustainable and eco-friendly choice because it is abundant, renewable, and capable of producing electricity without the grid [1].

Furthermore, real-time tracking of battery status, energy generation, and electricity consumption is made possible by integrating Internet of Things (IoT) technology with renewable energy systems, which improves system efficiency and user satisfaction [2]. There are commercial solar chargers, but many of them are constrained by large designs, inconsistent charging performance in different weather conditions, and a lack of intelligent monitoring features. These restrictions limit their usefulness for outdoor enthusiasts like hikers, campers, and explorers and reduce their effectiveness in isolated areas without consistent electricity [3].

A small, efficient, and clever renewable-energy charging solution is needed to overcome these obstacles. The goal of this project is to develop a tiny, portable mobile charger that uses renewable energy and has Internet of Things (IoT) monitoring for real-time updates on energy consumption, battery condition, and charging performance. For off-grid situations, emergencies, and outdoor activities, the proposed system aims to provide a reliable, portable, and sustainable charging option.

Methodology

The three primary subsystems of the suggested portable charging system are power conversion and storage, renewable energy harvesting, and IoT-based monitoring and protection circuitry. A portable monocrystalline 5.5 V solar panel serves as the primary energy source. It has a fairly high conversion efficiency, is lightweight, and is easy to use. The charging circuit stores and processes the electricity generated by the solar panel. Power conditioning is accomplished using a boost converter (XL6009) and a buck converter (XL4015). While the boost converter increases the variable input voltage from the solar panel, the buck converter regulates the battery's charging voltage. To guaranty there is enough power to charge mobile devices, a set of 3.7 V lithium-ion rechargeable batteries is connected.

The ESP32 microcontroller is the system's primary controller. Battery voltage, current, and temperature are reliably monitored by voltage sensors, ACS712 current sensors, and NTC temperature sensors. By sending the collected data to the Blynk cloud platform via Wi-Fi, users can monitor charging conditions in real-time via mobile and web dashboards. Protective systems are able to detect anomalous conditions in order to ensure safe operation. The ESP32 automatically sends alert notifications via the Blynk platform and activates visual warning indicators when the battery temperature rises above the predetermined threshold of 40°C.

The hardware prototype was built and tested in various settings. We looked at charging time, voltage stability, current output, and IoT tracking features in order to evaluate the effectiveness and reliability of the proposed system. The efficiency of solar panels was assessed in both clear and cloudy environments. Figure 1 shows how an ESP32 microcontroller-based power management system operates.

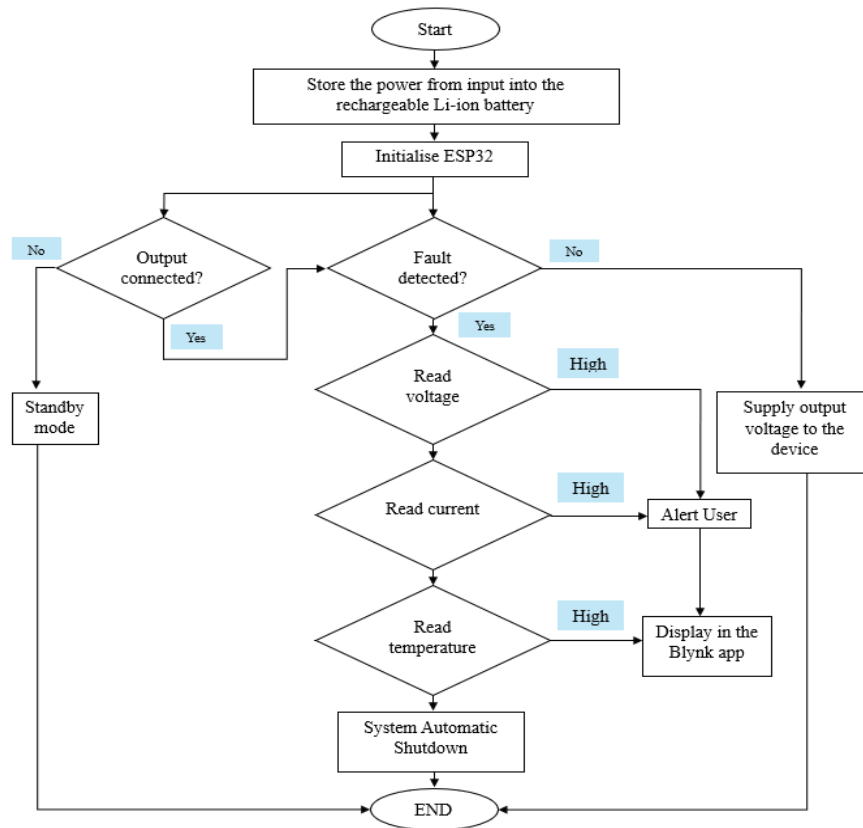


Fig 1: Flowchart of the solar mobile charging systems

Results and Discussions

The performance of the portable solar charging system was significantly impacted by environmental factors, according to the experimental evaluation. Shorter battery charging times and improved charging efficiency resulted from the solar panel producing more voltage, current, and power in sunny conditions than in cloudy ones.

These results support the notion that photovoltaic performance is highly influenced by solar irradiance. Prior to charging the lithium-ion battery pack, the XL6009 boost converter and the XL4015 buck converter effectively controlled the variable output of the solar panel. The converters minimized energy loss and safeguarded the battery and any connected electronics by maintaining a steady charging voltage during the whole charging process. The IoT monitoring subsystem operated effectively during the trials. Battery voltage, charging current, battery level, and battery temperature were all instantly transmitted via Wi-Fi, and the Blynk mobile app and web dashboard displayed all of the data with little delay.

Users would be able to keep an eye on the system's state and charging efficiency from any location. The battery safety system also performed as intended. When the battery temperature rose above 40°C, the ESP32 turned on the warning LED and sent a notification thru the Blynk app right away. By warning users before the battery overheats and has problems, these early alerts increase safety. In a compact, portable package, the cutting-edge solar-powered mobile charger integrates IoT monitoring, intelligent power management, and solar energy. It is appropriate for any circumstance, including off-grid lifestyles, emergencies, and a day in the outdoors, because it consistently charges phones, keeps track of power in real time, and operates safely.

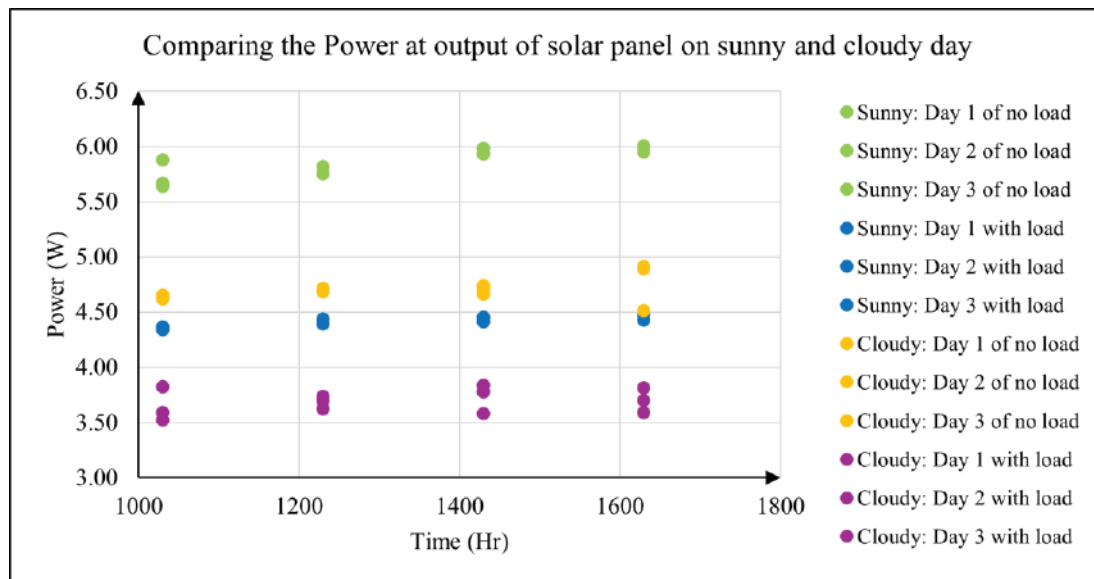


Fig 2: Output power solar panel on sunny and cloudy day

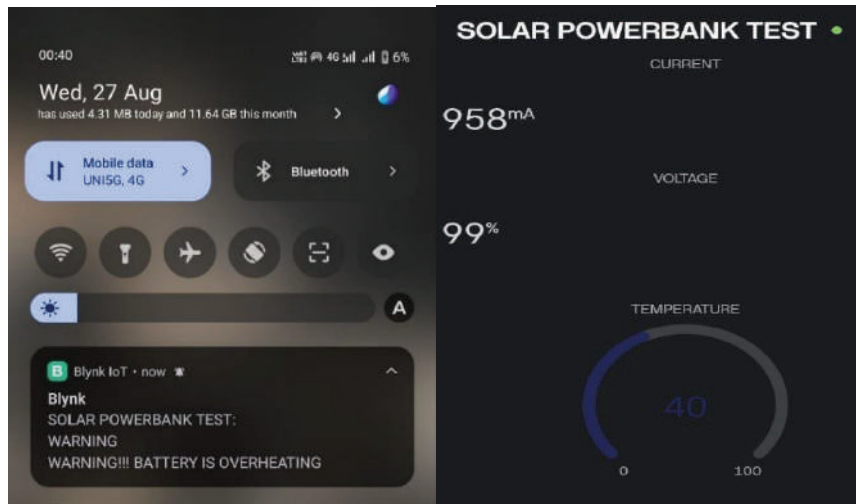


Fig 3: Blynk dashboard screenshot showing real-time monitoring.

Conclusions and Recommendation

This study developed a mobile charging system powered by renewable energy sources by combining solar, wind, IoT surveillance, and intelligent energy management. The Blynk platform and ESP32 allow you to remotely check the battery's condition and charging status. Because different resources can support one another when circumstances change, the hybrid approach—which uses both solar and wind—improves charging reliability. Tests showed that regardless of the weather, the system charges consistently and operates dependably. Outdoor activities, emergency situations, disaster relief, and remote areas without dependable electricity are all excellent uses for the prototype. Battery longevity and safety are improved by integrated temperature monitoring and automated alerts. There's still room for improvement. Investigating MPPT algorithms can assist in obtaining more energy from solar panels. You could add more renewable energy sources, like piezoelectric or thermoelectric energy harvesting, for increased dependability. The system's ability to adapt to changing weather conditions may be enhanced in the future by more intelligent energy management, possibly using AI and flexible charging algorithms.

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An Information-Driven Concurrent Engineering Framework for the Conceptual Design of Biocomposite Automotive Components

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Abstract— Concurrent Engineering (CE) has been widely adopted to support multidisciplinary product development by integrating design, manufacturing, material selection, and performance evaluation during the early stages of product development. Although numerous CE frameworks have been reported for biocomposite product design, they often differ in the selection of design tools, information flow, and sustainability considerations, resulting in a lack of a comprehensive and systematic framework. This paper presents a refined Concurrent Engineering framework, an extension of previous work to improve the integration of design activities and information throughout the conceptual design process. The framework was developed starting with literature reviews, analysis of existing CE frameworks, and identification of research gaps and framework requirements, followed by framework development, implementation, evaluation, limitation identification, and refinement. The refined framework clearly integrates CE tools, CE information, and information flow at each stage of product development to support systematic decision-making and interdisciplinary collaboration. The proposed framework offers a systematic guideline for the development of biocomposite automotive components, which is expected to make the conceptual design more efficient and to enhance the design quality, sustainability, and decision-making in the early phases of product development.

Introduction

Environmentalism and tech innovation are causing a major shift in the auto industry. The demand for environmentally friendly and lightweight vehicles and the requirement for low greenhouse gas emissions have accelerated the use of biocomposites in the design of automotive vehicles. Biocomposites are developed by combining natural fibers with polymer matrices. They have many advantages, such as low weight, renewability, and potentially lower CO₂ emissions than traditional composites. This can improve fuel efficiency and comply with stringent environmental regulations [1,2].

Nevertheless, variability in natural fibers, inadequate adhesion between fiber and matrix, and limited thermal resistance complicate biocomposite usage in rigorous automotive contexts [3–5]. These problems are often intensified by conventional sequential engineering (SE) approaches that result in changes throughout the later stages of design, increased cost, and shortened sustainability prospects [6]. Thus, concurrent engineering (CE) has emerged as a revolutionary approach to allow the parallel processing of design, analysis, and manufacturing planning, which reduces lead times, improves product quality, and promotes interdisciplinary collaboration [7]. It has also been further enhanced by the introduction of state-of-the-art information systems that allow real-time sharing of data, rapid iteration, and informed decision-making across geographically separated teams [8]. Nevertheless, a complete Concurrent Engineering (CE) framework is needed to explicitly guide the conceptual design process by specifying the relevant design activities, CE tools, and information flow at each level and thus promote systematic and informed decision-making.

Literature Review

Unlike SE, CE used a systematic approach, where all design activities are integrated and performed in parallel to shorten product development time, improve product quality, lower manufacturing costs, and better satisfy customer needs. In their paper, Hambali et al. [6] have stressed the significant role of concurrent engineering (CE) in the product development process

and its importance for industries to remain competitive in the global market. They investigate the basic principles of CE tools and their use and propose improvements to existing product development processes, from market analysis to detailed design as illustrated in Fig. 1, to work seamlessly and efficiently in a CE environment.

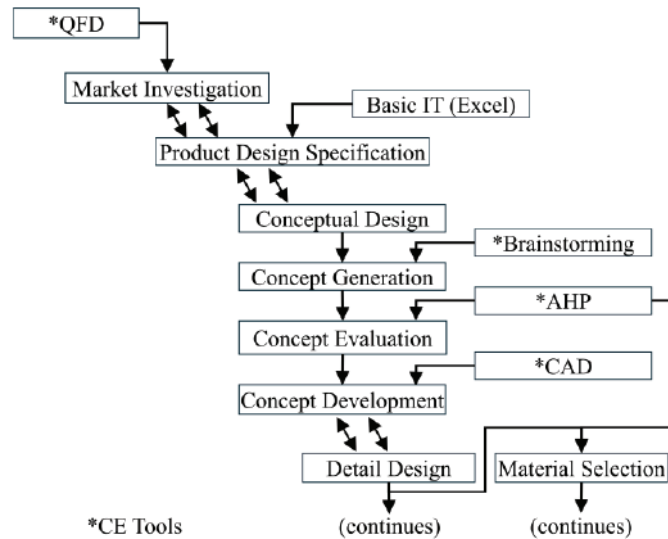


Fig. 4 Conceptual design development with CE environment (reproduced from Hambali et al. [6])

The CE concept has been developed as a significant paradigm for biocomposite product development, which integrates interdisciplinary processes such as design, materials selection, manufacturing, and performance evaluation since the early stages of product development. Recent studies in the automotive, marine, fire safety, packaging, home furniture, and electrical sectors have shown that CE facilitates systematic and collaborative development while reducing design time and improving product quality. Earlier, Azlan et al. have provided a structured comparison between each framework and research gap [9].

Methodology

Fig. 2 illustrates the methodology adopted for the development of the proposed CE framework. It started with a detailed literature analysis to explore the current CE frameworks, techniques, and design tools applicable to the production of biocomposite automotive components. Then the existing frameworks were analyzed for their strengths, limitations, and scopes of improvement. This analysis led to the identification of the research gaps and framework requirements needed to identify the necessary components for the proposed framework. The identified design stages, engineering tools, and information flow were then combined into a structured framework to build the suggested CE framework. The framework was applied in a case study on the conceptual design of a biocomposite automotive component to show its applicability. Then, the implementation outcomes were reviewed to find out the efficacy, completeness, and practicality of the proposed framework. Finally, the evaluation results were used to revise and improve the framework, leading to a more comprehensive and structured approach for sustainable biocomposite product creation.

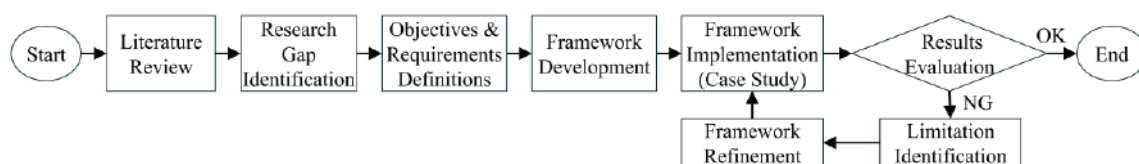


Fig. 5 Concurrent Engineering Framework Development Methodology

This study is a continuation of the work of Azlan et al., who developed a preliminary Concurrent Engineering (CE) framework [9]. The framework presented in this paper is an improved and refined version of the previous framework with the inclusion of improvements identified through further literature review, framework evaluation and subsequent refinement to provide a novel framework with information-driven architecture (CE information), a communication hub and information flow, explicit mapping of CE tools, and integration of sustainability considerations across conceptual design.

Results and Discussion

Fig. 3 presents the improved CE framework that was developed to more accurately represent the concurrent nature of product development, emphasizing parallel activities, clearly mentioned CE tools, as well as continuous collaboration and information exchange through the design process. The acronym of the CE tools presented in the framework are expended as follows: Analytic hierarchy process (AHP), Theory of Inventive Problem Solving (TRIZ), Bio-inspired design (BID), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), Life Cycle Assessment (LCA). The CE tools in the framework are illustrative examples and not mandatory methods. They are given to illustrate how appropriate design tools can be integrated in each step of the Concurrent Engineering process.

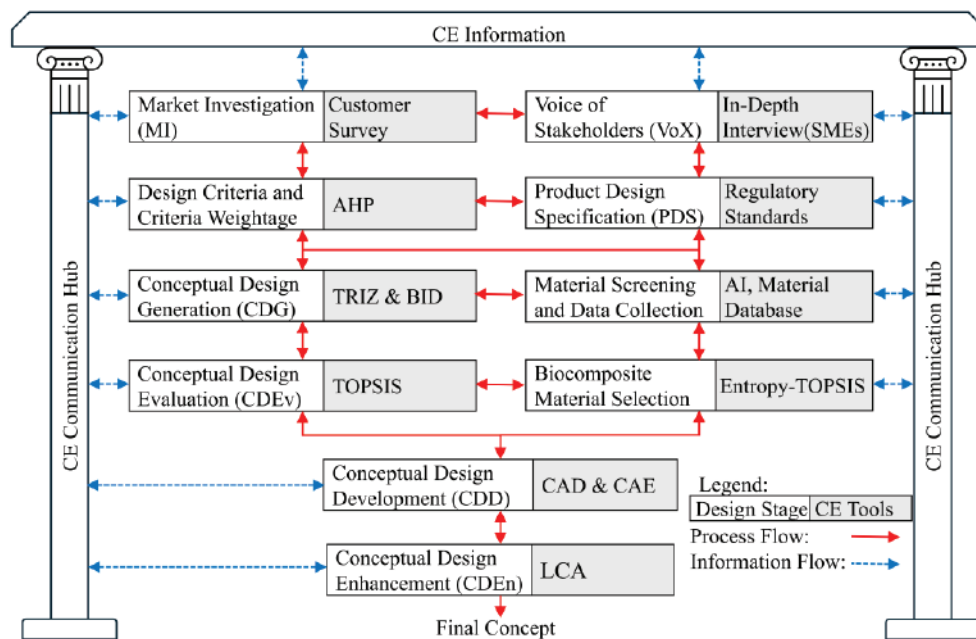


Fig. 6 Proposed Information-Driven Concurrent Engineering Framework

Activities on the same horizontal level can be performed in parallel. Red arrows denote process flow and process dependencies, while blue dotted arrows represent information flow. The double-headed arrows indicate the iterative nature of the concurrent design process, allowing processes, information, and decisions to flow bidirectionally between the stages.

Compared with the preliminary framework proposed by Azlan et al. [9], the proposed Information-Driven Concurrent Engineering Framework clearly emphasizes the roles of CE Information and the Communication Hub in supporting early information integration, continuous information sharing, and multidisciplinary collaboration. To emphasize the importance of getting complete information and sharing it as early as possible, the CE information is placed at the top of the framework. Getting relevant early information facilitates better decision-making, minimizes the number of design iterations, and enhances the efficiency

and sustainability of product development. The Communication Hub allows for a constant sharing of information and iterative feedback throughout the conceptual design process. It is not a particular software platform but rather meetings, digital communication tools, shared databases, and other collaborative channels, or a combination of these, that enable real-time information sharing and coordination throughout the design process. It is considered as the supporting pillars of the framework, stresses the importance of effective communication in coordinating multidisciplinary activities. If communication breaks down, information may not get through, and the whole framework collapses.

The framework also enhances the representation of concurrent activities like Market Investigation and Voice of Stakeholder, Design Criteria Weightage and Product Design Specification (PDS), Concept Design Generation and Material Screening & Data Collection, Concept Design Evaluation and Biocomposite Material Selection during the iterative refinement process of the design process. The framework is expected to reduce development time, design iterations, and associated costs by enabling early integration of information, parallel execution of suitable design activities, and continuous multidisciplinary communication, while the early integration of material screening and Life Cycle Assessment supports improved environmental performance.

Conclusion

This study introduced a refined Information-Driven Concurrent Engineering Framework for sustainable biocomposite product development. The framework is anticipated to improve the representation of concurrent activities by emphasizing early integration of information, efficient communication, and explicit integration of CE tools during the design process. The introduction of the communication hub emphasizes the importance of communication to ensure the continuity of information flow and to enable effective collaboration among multidisciplinary teams.

Acknowledgement

The authors thanks Universiti Teknikal Malaysia Melaka (UTeM) for its support throughout this project.

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Hazard Identification and Risk Assessment in Power Plant Warehouse Operation: A Case Study of PT. Paiton Operation and Maintenance Indonesia

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Abstract — This research applying the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method to contributes practical validation of the effectiveness of HIRARC in reducing occupational risks within power plant warehouse operations. Data were collected from field observations combined with historical safety logs and structure questionnaire assessment involved one internal expert work as warehouse specialist. From the hazard identification phase identified 23 hazards across 107 potential causes in 6 operational zones: the central warehouse, flammable oil storage, cylinder cage, container pipe yard, capital storage, and ash disposal area. The existing risk level concerns: 14,02% extreme risk, 41,02% high risk, 38,32% moderate risk and 6,54% low risk. Unassisted heavy lifting, severe ergonomic, overload during truck offloading, and lacerations from damaged pallets represented the primary extreme risk level. Considering recommended risk controls based on hierarchy of controls, combining the engineering controls use pallet jacks and hydraulic trolleys with administrative controls pre-use inspections, job rotation and use personal protective equipment cut resistant gloves, the residual risk improves significantly. Extreme risks are completely eliminated from 14,02% to 0%, high risk reduce from 41,12% to 1,87%. moderate risk from 38,32% to 67,29% and low risk from 6,54% to 30,84%. This finding the practical efficacy of the HIRARC method reduce risk level in industrial hazards in power plant warehouse operation. To sustain these safety improvements, the company should adopt digital safety inspection apps and monitoring systems that enable real-time tracking on the warehouse area.

Introduction

Electricity generation depends on reliable and uninterrupted supply chain mechanism, with the warehouse serving as one of its most critical operational components. In power plants, warehouses are not only storage facilities but also essential hubs for managing spare parts, heavy equipment, hazardous chemicals and other materials required to maintain continuous plant operations. If any disruption in warehouse activities can directly affect maintenance schedules and operation reliability. Power plant is inherently high hazard workplace where strict safety protocols are essential to protect workers from severe job risks [1]. Warehouse are fundamental to industrial operations because it ensure that materials are available whenever production and maintenance activities require them. Power plant warehouse presents a particularly complex set of hazards. Daily activities of employees work alongside heavy lifting equipment, maneuver through tight storage layouts, and handled heavy materials [2]. Reese explains that the interaction between workers, equipment, and stored materials can significantly increase the risk of musculoskeletal injuries, vehicle-related incidents, and material handling accidents unless supported by a comprehensive occupational safety management system [3]. PT. Paiton Operation and Maintenance Indonesia is one of the largest coal-fired power plants in the region, recognized the urgent need to evaluate safety vulnerabilities within its warehouse facilities. A preliminary observation of the company warehouse identified several hazards including non-ergonomic manual lifting, some storage racks showed signs of structural deterioration and potential chemical exposure during repacking operations. These conditions represented hazards that required systematic evaluation before they could develop into workplace accidents. Clause 6.1.2 of the international occupational health and

safety standard, ISO 45001:2018, explicitly mandates this approach, requiring for proactive hazard identification and systematic risk assessment to prevent occupational illnesses and acute injuries before they occur [4]. Previous research, in shuttlecock manufacturing demonstrated that the HIRARC methodology successfully reduced several high-risk level conditions such as respiratory hazard and mechanical, through the implementation of risk control [5]. Other research states, the HIRARC method can support electricity companies in identifying critical hazards, prioritizing preventive actions, and strengthening occupational safety management toward zero accident performance [6]. By applying the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method to PT X's warehouse operations, the research contributes practical validation of the effectiveness of HIRARC in reducing occupational risks within power plant warehouse operations.

Methodology

The research focused specifically on material handling and storage processes at PT. Paiton Operation and Maintenance Indonesia Warehouse operations. Data were collected from field observations combined with historical safety logs and structure questionnaire assessment. Following purposive sampling principles, the respondent was selected based on specific operational expertise [7]. In this research involved one respondent, works as the Warehouse Specialist, who was selected through purposive sampling for their extensive knowledge of warehouse operations, occupational safety, and incident history. The questionnaire evaluated daily work tasks, identified hazard and potential causes and documented existing risk control. The hazard identification phase examined both routine and non-routine activities across six warehouse operational zones: the main area warehouse, flammable oil area, cylinder cage, container pipe storage, capital storage and ash disposal zone. Each hazard was then evaluated using a standard risk analysis matrix. Risk is analyzed by combining likelihood and consequence scale to determine a risk level [8]. Likelihood was rated on a scale from 1 (Rare) to 5 (Certain) and consequence from 1 (Insignificant) to 5 (Catastrophic), shown in the table below.

Table 3 : Risk Matrix

Likelihood	Consequence				
	1 (Insignificant)	2 (Minor)	3 (Moderate)	4 (Major)	5 (Catastrophic)
5 (Certain)	High	High	Extreme	Extreme	Extreme
4 (Likely)	Medium	High	High	Extreme	Extreme
3 (Possible)	Low	Medium	High	Extreme	Extreme
2 (Unlikely)	Low	Low	Medium	High	Extreme
1 (Rare)	Low	Low	Medium	Medium	High

After define the risk level, the next step of research into the Risk Control phase. Risk control was formulated strictly aligning with the established occupational hierarchy of controls, prioritizing engineering mechanisms and administrative redesign over personal protective equipment. The final phase involved calculating the percentage in risk categorization to determine the theoretical improvement index generated by the proposed risk control.

Findings and Arguments

The hazard identification phase identified 23 hazards and 107 potential causes across warehouse and material handling activities. With the existing risk controls, the risk level concerns: 15 potential causes were rated as extreme risk (14,02%), 44 as high risk (41,02%), 41 as moderate risk (38,32%) and 7 as low risk (6,54%). Table 2 focuses on the three highest extreme risk level. It breaks down the potential causes at manual handling

and goods receiving activities and shows how the chosen mitigation risk controls can reduce the risk level.

Table 4 : Summary of Top 3 Extreme Risk

No.	Hazard	Potential Causes	Risk Level	Risk Control	Residual Risk
1	Spinal Strain & Muscle Injuries (Manual Handling)	Heavy lifting, poor posture, and repetitive pushing or pulling without mechanical aids.	Extreme	Administrative: Manual handling training, job rotation, safety posters.	High
			(L=5, C=4)	Personal Protective Equipment: Heavy-duty gloves, respiratory masks.	(L=3, C=3)
2	Ergonomic overload (Goods Receiving)	Manual offloading in confined truck beds and lifting heavy loads repeatedly.	Extreme	Engineering: Pallet jacks, hydraulic trolleys.	High
			(L=5, C=4)	Administrative: Ergonomic guidelines, job rotation, manual handling training.	(L=3, C=3)
3	Sharp Object Cuts & Lacerations (Manual Handling)	Handling damaged wooden pallets, protruding metal straps, or sharp container edges.	Extreme	Administrative: Pre-handling pallet inspections.	Moderate
			(L=4, C=4)	Personal Protective Equipment: Cut-resistant safety gloves.	(L=2, C=3)

The top three worst potential causes of hazards, all driven by manual handling and goods receiving. Spinal strain and ergonomic overload lead with the highest risk level (L=5, C=4), caused by unassisted heavy lifting in confined truck beds. Cuts and Laceration hazards rank at third position (L=4, C=4) from handling damaged pallets and sharp metal straps. For spinal strain and ergonomic overload, combining mechanical equipment such as pallet jacks, job rotation, manual handling training, and use cut-resistant gloves reduces both the likelihood and severity of injuries frequency and impact reducing cuts to moderate and ergonomic hazards to high. After the risk control recommendations consisting of engineering control, administrative control and personal protective equipment (PPE), the risk level percentages were reduced for the extreme risk level from 14,02% to 0%, reduce almost all warehouse hazards risk level into much safer low and moderate risk level. This is shown in the following graph

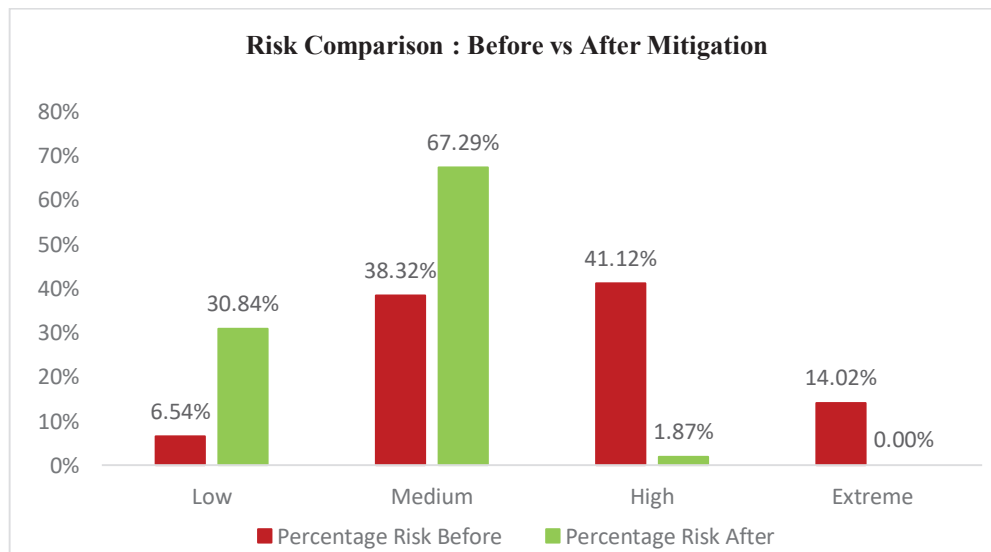


Fig. 7 Percentage of Risk Levels Before and After Implementing Recommended Controls

Conclusion

Evaluating PT. Paiton Operation and Maintenance Indonesia (POMI) Warehouse operations using The HIRARC Method, it was identified 23 hazards across 107 potential causes within 9 work activities in 6 operational zones. Initially, over half of all identified causes fell into critical categories, 14,02% extreme, 41,02% high, primarily driven by unassisted manual handling, ergonomic overload during truck offloading, and hazardous material storage. By considering recommended risk controls, combining the engineering controls use pallet jacks and hydraulic trolleys with administrative controls pre-use inspections, job rotation and use personal protective equipment cut resistant gloves, the residual risk improves significantly. Extreme risks are completely eliminated from 14,02% to 0%, high risk from 41,12% to 1,87% (leaving 2 residual ergonomic risks). Following the implementation of recommended risk control, most hazards in warehouse areas were reduced into manageable risk level. These results demonstrate that the HIRARC improves warehouse safety and supporting compliance with the principles of ISO 45001:2018. The research also confirms that HIRARC provides a practical framework for identifying hazards, assessing risks, and selecting recommended risk controls to reduce workplace accidents. To sustain these safety improvements, the company should adopt digital safety inspection apps and monitoring systems that enable real-time tracking on the warehouse area.

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Mobile Augmented Reality-Based App for Manufacturing Machine Guidance

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Abstract— Manufacturing workers often require continuous access to machine-related information even after completing initial training, especially if experienced operators or supervisors are not available to help them. Traditional approaches like printed documentation and oral directions lack interactivity and may be unavailable when needed during normal operation. In this paper we present an augmented reality-based manufacturing worker support system that provides on-demand machine guidance through a mobile application and web-based administration panel. The system allows workers to query machine information, safety instructions, instructional videos and AR-based visualisation through machine identification and enables administrators to manage and update training content from a central location. The system has been developed in an agile way and tested in the field involving real factory workers and administrators in a real manufacturing environment. Evaluation results revealed positive feedback related to usability and design and system functionality. The system we propose provides an interactive digital assistance approach for continuous worker learning, minimising the need for immediate human assistance and improving access to machine operation information within manufacturing environments.

Introduction

The manufacturing industry is increasingly adopting digital technologies to enhance productivity, operational efficiency and workforce competency. As manufacturing techniques become more automated and complex, workers need continuous access to correct machine information to do their jobs safely and effectively. Training usually happens during onboarding for employees, but they can still have issues with new equipment or troubleshooting problems, particularly when there are no experienced operators or supervisors around. Traditional support techniques such as printed manuals, verbal instructions and demonstrations at the workplace offer little interaction and are difficult to maintain when machine configurations, operating procedures or safety requirements change. These limitations point to the need for digital solutions that can provide instant, contextual and accessible guidance within the daily manufacturing operations.

Recent studies have explored the application of Augmented Reality (AR) in manufacturing environments to enhance human–machine interaction, industrial visualisation, and operator support. Zhang and Kwok [1] proposed an AR-based interaction interface for smart manufacturing, which provides a user-orientated approach to designing and customising physical objects using AR-based sketch interaction and communicating directly with machine tools for automated fabrication. Hahn et al. [2] used marker-based AR on smart glasses to support training in PCB assembly. In this case, the smart glasses visually guide users to identify the components and their location for installation in the production process. Chen et al. [3] proposed a fast AR visualisation toolkit for factory environments to assist the development and deployment of industrial AR applications. Other studies also showed the use of AR for machine monitoring, visualisation of equipment information and assisting human workers in flexible manufacturing environments [4, 5]. While these works show the potential of AR to improve industrial processes, current approaches focus on specific applications, e.g., training demonstrations, equipment monitoring, or process visualisation, and do not provide continuous

In a real production environment, workers can forget some specific operating procedures or may need immediate help when doing machine-related work. If you only have experienced people, you can call on for help, this can interrupt your workflow and create a reliance on human help. Thus, a need arises for a lightweight, accessible, mobile-based solution which provides on-demand machine knowledge and operational guidance to workers. In this paper, we propose an AR-based manufacturing worker support system composed of a mobile AR application and a web-based administration panel. The proposed system allows workers to identify the machine and see machine information, safety rules, video tutorials, and AR visualisation, while administrators can centrally manage and update digital content. The system is meant to support continuous worker learning, to decrease dependency on immediate human help and to improve accessibility to machine-related knowledge in manufacturing environments.

Methodology

This study employed a design-and-development approach to develop an integrated manufacturing training system that includes an AR application for workers and a web-based management system for administrators. The development process was divided into four stages: requirement analysis and system design, AR content development, system development, and system evaluation. Functional requirements were derived during the requirement analysis phase through discussion with interested parties and analysis of existing manufacturing training practices. The requirements led to the design of two related platforms. The mobile application was developed for the identification of machines using QR codes, AR visualisation, instructional videos and safety guidelines. The web-based system was developed for the administrator to manage users, machines and training materials.

The second stage was the development of AR content. This stage consisted of the creation of three-dimensional (3D) models of manufacturing machines and components using Blender; The models were optimised for mobile deployment and integrated into the AR environment to allow interactive visualisation and guidance for machine operation. In the system development phase, the mobile application was developed using Android Studio, implementing QR code recognition, ARCore for AR rendering, multimedia playback and cloud-based data synchronisation (using Google services). A web-based administration system was developed to manage training content centrally, machine data, and user accounts. Cloud infrastructure was also implemented to efficiently store and update both platforms.

The last stage was evaluation of the system via functional and field testing. Functional tests were conducted to verify the correctness and integration of system modules, such as QR code recognition, AR content display, multimedia access, and administrative functions. Then, the system was field-tested by factory workers and administrators in a real manufacturing environment to evaluate the usability, practicality and suitability of the system for supporting machine training activities. Analysis of feedback gathered from participants identified system effectiveness and areas for further improvement. The mobile AR application was developed to provide workers with on-demand machine assistance, as shown in Fig. 1. Machine identification gives workers access to operating procedures, instructional videos, and AR-based visualisation to help with machine operation without immediately relying on experienced personnel.

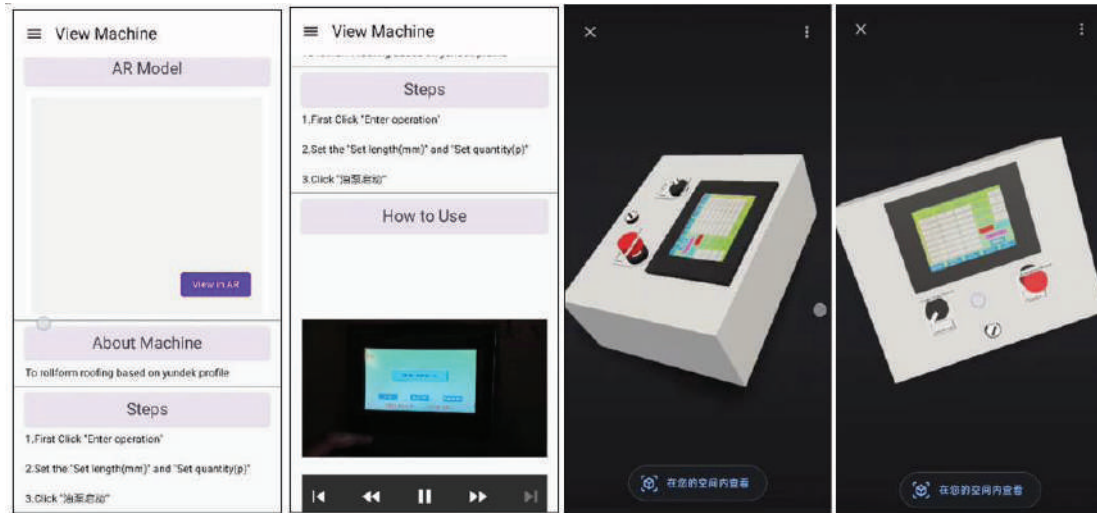


Fig. 1 Mobile Application Interface and AR Visualization for Machine Components

Results and Discussion

Field testing was conducted with eleven participants, consisting of ten selected factory workers and one factory manager, in a real manufacturing environment. The evaluation of the mobile AR application and the web-based administration panel was performed through the use of practical testing scenarios. The factory workers' evaluation was focused on the tasks of QR code-based machine identification, AR visualisation, instructional videos, and safety guidelines, and the factory manager's evaluation was focused on the administrative functions of the machine data, AR model, training content, and user management.

The results of the field tests summarised in Table 1 showed that the proposed system was positively accepted on all the evaluated criteria. Usability was rated the highest, with 80% of responses rated as "excellent", and indicated that the system was easy to operate on both platforms. The design and performance were rated positively, showing that the interface and system functions were efficient in supporting the training activities. In the AR model view, the ratings were equally split between 'excellent' and 'good', indicating that the AR feature was able to support the machine visualisation whilst also indicating that there is still room to improve the 3D assets. Overall Flow was rated "Average" in 10% of reviews, but these were mainly small navigation improvements rather than functional limitations. The results show that the proposed system provides a practical and interactive way of training in manufacturing.

Table 1: Field Testing Results

Criteria	Excellent	Good	Average	Poor	Key Insight
Performance	60%	40%	0%	0%	Generally responsive; minor delays with AR loading
Design	70%	30%	0%	0%	Visually appealing and intuitive interface
Usability	80%	20%	0%	0%	Highly user-friendly on both platforms
Overall Flow	50%	40%	10%	0%	Positive experience; slight navigation friction noted
AR Model View	50%	50%	0%	0%	Good visualization; optimization needed for speed
Video Tutorial	60%	40%	0%	0%	Clear and useful multimedia content delivery
Overall Project	30%	60%	10%	0%	System meets key requirements; refinements identified

User feedback indicated that some AR models experienced longer loading times due to large 3D asset sizes, highlighting the need for further optimisation of AR resources. Despite this limitation, the participants found the application useful to access machine information and

training materials. The administrators found it beneficial to have centralised management of content. The results show that the proposed system can effectively integrate QR code identification, AR visualisation, multimedia learning and web management to support interactive manufacturing training. However, limitations such as internet dependency, AR device compatibility and large multimedia file sizes may affect deployment in some environments. Finally, we suggest future work to optimise AR assets and increase the system's accessibility to support wider adoption.

Conclusion

We developed an AR-enabled mobile application for manufacturing machine guidance to provide continued support after traditional employee training. The system consists of a mobile AR application and web-based administration panel. Workers can get information about machines, operational instructions, safety instructions, and interactive AR visualisations without the immediate help of experienced personnel. The results of the field trial in a real manufacturing environment gave positive feedback regarding usability, design and system functionality. The results indicate that the proposed approach is suitable for supporting daily activities related to machines.

Future work can focus on improving the system in terms of accessibility, performance and scalability. Offline capabilities can be added to provide workers with essential machine information in low-connectivity areas. In addition, the loading performance. Furthermore, optimising the AR models and multimedia resources can enhance loading performance. Additionally, features such as multilingual support, real-time feedback from workers, and usage analytics could enhance the system. Such improvements could enhance the role of AR as a digital assistant for manufacturing workers and support more efficient and safer industrial operations.

Acknowledgement

This research received financial support from *i-CATS* University College.

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AI-Driven Assistive Tools for Supporting Readers with Learning Disability: A Systematic Review

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Abstract— This systematic review examines how AI-based assistive tools can support foundational readers with learning disabilities, especially learners with dyslexia. Following the PRISMA framework, 18 relevant studies published from 2022 to 2026 were reviewed to explore the types of AI tools available, their effectiveness, and the challenges associated with their use. The reviewed technologies can generally be grouped into intelligent tutoring systems, Large Language Model (LLM)-based assistants, and multimodal gamified applications. These tools provide various forms of support, including personalized reading activities and real-time emotion monitoring. Overall, the findings indicate that AI-assisted tools can help improve reading comprehension and fluency while also reducing anxiety by providing learners with supportive and non-judgmental feedback. Despite these benefits, several issues remain, particularly concerns related to data bias, unequal access to technology, and limited transparency of AI models, which may affect teachers' confidence in using them. Therefore, although AI has considerable potential to promote more inclusive learning, future development should focus on explainable AI, accessibility, and appropriate human oversight to ensure that technology complements rather than replaces the role of educators

Introduction

Neurodevelopmental disorders (NDDs), such as dyslexia, typically begin during the early stages of development and can continue to affect individuals throughout their lives. Dyslexia is one of the more common neurodevelopmental disorders and can make reading, writing, and understanding written information particularly challenging. These difficulties can occur even when an individual has average or above-average intellectual ability [1].

Among foundational readers, continued struggles with literacy may affect confidence, increase anxiety, and create difficulties in keeping up with academic demands [2]. Although traditional approaches, including phonics-based teaching and multisensory learning activities, are widely used to support learners with dyslexia, they may not always provide the level of individualization and flexibility that these learners require. Consequently, some learners continue to experience difficulties in developing literacy skills and participating fully in academic and social activities [3].

The growing use of artificial intelligence (AI) has introduced new possibilities for addressing some of these challenges. Technologies based on machine learning (ML), deep learning (DL), and large language models (LLMs) can support both identification of reading difficulties and the delivery of more personalized learning experiences [4]. AI-based tools can use technologies such as natural language processing (NLP), speech recognition, and computer vision to respond to different cognitive and language-related needs among learners with dyslexia [5]. One of their main advantages is their ability to adapt learning activities to individual learners. For instance, AI systems can adjust tasks and interventions according to difficulties in areas such as phonological awareness, word decoding, and reading fluency [6]. They can also make learning materials easier to process by simplifying complex text and providing immediate feedback, which may help reduce cognitive demands and encourage greater learner engagement [7].

This Systematic Literature Review (SLR) evaluates the integration of AI-driven assistive tools to enhance outcomes for foundational readers. The review is guided by three primary research questions:

- RQ1: What are the types and features of AI-based tools developed to support readers with learning disabilities?
- RQ2: What evidence exists regarding the effectiveness of AI tools in improving outcomes for readers with learning disability?
- RQ3: What are the main challenges, limitations and opportunities in implementing AI tools as for readers with learning disability support in educational settings?

Methodology

The PRISMA approach was used to advance the systematic review to promote transparency and methodological rigour. This systematic review had three important stages, which involves identification, screening, and eligibility. The literature search was conducted across major academic databases, including Scopus, ScienceDirect, Web of Science, and IEEE Xplore. Boolean search strings combined terms such as “Artificial Intelligence”, “Machine Learning”, “Learning Disability”, “Dyslexia” and “Assistive Tools”. The search initially produced 1903 results during the identification phase. During the initial filtering process, 877 records were automatically removed as they did not meet the preliminary inclusion criteria, including subjects not relevance to computer science or artificial intelligence, or publication outside the targeted timeframe of 2022-2026. 121 articles were managed to undergo another eligibility evaluation according to the set inclusion criteria:

1. Focused on AI-driven tools to support readers with learning disability;
2. Provided measurable outcomes such as diagnostic accuracy or reading improvement; and
3. Articles published in English between 2022 and 2026 with open access.

Exclusions were applied to grey literature, studies without human validation, and research not directly addressing AI-driven tools. Out of 121 articles that were considered, only 18 articles were included in this review after a strict eligibility review. To be able to include only high-quality articles in this Systematic Review, a quality appraisal process was done on each of the selected articles. The assessment instrument used was adapted from Abouzahra et al. [8].

Results and Discussion

Types and Features of AI-based Tools (RQ1)

The findings show that AI-driven assistive technologies for learners with dyslexia can be broadly grouped into several categories:

- Personalized learning and intelligent tutoring systems are designed to adapt learning materials according to each learner’s progress. For example, Intelligent Tutoring Systems (ITS) and LLM-based assistants such ChatGPT can adjust the difficulty and type of content as learners develop their reading skills [20]. Some systems also use behavioural data and knowledge graphs to identify specific phonological difficulties and provide more targeted reading activities [10].
- Multimodal and gamified applications take a different approach by combining interactive features with elements such as levels, rewards, and Augmented Reality (AR). Applications such as EasyLexia and ALEXZA use these features to make reading activities more engaging while providing multisensory learning support [26].
- In addition, many AI-based tools provide core accessibility features, including Text-to-Speech (TTS), Speech-to-Text (STT), real-time grammar checking, and adjustable text presentation, such as font size and spacing [13]. More advanced systems may also monitor learner’s emotional responses in real time and adjust the reading pace or feedback when signs of frustration are detected.

Table 1: Reviewed Studies Structured Summary

Reference	Author(s)	AI Tools Discussed	Outcome
[9]	Anjana Madhav Ram, Sara Saravi, Yanning Yang, Firat Batmaz, Parisa Derakhshan, Hossein Nevisi, Gary Storey	ChatGPT, Google Dialogflow, Grammarly, Goblin Tools, Text-to-Speech, concept-mapping	Dyslexic students face severe barriers in reading, writing, and planning. While GenAI tools offer high utility, they risk uncritical cognitive offloading and plagiarism. The proposed UDL-aligned AI Engagement Spectrum and student-facing AI Scaffold define clear boundaries and protect student authorship.
[10]	Jingqian Gu, Guanguan Zeng, Yan Li	Knowledge Graphs (KG), NLP syntax parsing, Weighted Scoring Model (WSM), Read&Write, Kurzweil 3000, Grammarly	Reading scores increased significantly from 54.2 to 73.6 over 16 weeks ($p < 0.01$), while the adaptive system reduced learning differences and anxiety.
[11]	Kaiyuan Tang, Kerui Chen, Shreya Gopi, Li Xie, Mark Quinlan, Youngjun Cho	GamifiedLM, Multi-agent LLM systems (gpt-4o, o3-mini, gpt-4o-mini), DALL-E-3, Generative UI, RAG	GamifiedLM reduced mental workload and frustration, cut distractions by 52%, and improved quiz scores compared with standard ChatGPT.
[12]	Pham Vu Minh Tu, Nguyen Xuan Nam, Do Thanh Huong, Viet-Huy Vuong	Multimodal CNN-LSTM Edge AI emotion classifier (facial + voice), Whisper ASR INT8, Adaptive Text-to-Speech (TTS), MDP controller	Adaptive Edge AI improved lesson completion, interaction, pronunciation, and phonics scores while using emotional adaptability to reduce student dropout.
[13]	Donatas Iliska, Daina Gudoniene	eXeLearning, Adobe Captivate, H5P, Xerte, Lectora, iSpring, Articulate Storyline, OCR text extraction, dyslexia-friendly fonts	Structured cues, step-by-step guidance, text highlighting, and task reviews are essential for dyslexic learners, with eXeLearning and Adobe Captivate being effective authoring tools.
[14]	Faezeh Shabanali Fami, Ali Akbar Arjmandnia, Hadi Moradisabzevar	MOBIN (M-CBCR) computer program with 24 cognitive games, K-means clustering in RapidMiner, Davies-Bouldin index	Experts validated the program highly, while K-means grouped tasks into three areas: executive functions, memory, and attention.
[15]	Inigo Lopez-Gazpio	Large Language Models (OpenAI's ChatGPT/GPT-4, Meta's Llama, Microsoft's Phi, Mistral)	LLMs can improve personalized and accessible learning for diverse students, but they also pose risks such as hallucinations, bias, and loss of learned knowledge.
[16]	J. Ignacio Mateo Trujillo, Ignacio Rodríguez-Rodríguez, Diego Castillo-Barnes, Andrés Ortiz, Auxiliadora Sánchez, Juan L. Luque	Adaptive sequential recommender system utilizing Matrix Factorization (SGD, SVD, ALS, NMF), Bayesian Knowledge Tracking (BKT), Spanish pseudoword generator, CP-KGC framework	The 3D matrix adapts phonetic difficulty to each child's performance, keeping learning at the right level and improving prediction of future reading difficulties.
[17]	Ka-Yan Fung, Tze Leung Rick Lui, Kuen-Fung Sin, Kwong-Chiu Fung, Huamin Qu, Shenghui Song, Lik-Hang Lee	Robot-Assisted Chinese Language Learning System (RACLS) utilizing 'Minibo Plus' humanoid robot (speech tracking, voice recording, multimodal feedback)	Humanoid robots increased motivation and engagement while reducing learning anxiety and supporting self-paced vocabulary learning.

[18]	Nesren Farhah, Muhammad Adnan, Ahmed Abdullah Alqarni, M. Irfan Uddin, Theyazn H. H. Aldhyani	Baseline Neural Network, CNN, Attention Model, LSTM, GRU, Transformers; Explainable AI (SHAP, LIME, PDP, ICE, global surrogate Decision Tree)	The Transformer model achieved the best student performance prediction, while K-means effectively grouped students based on their learning behaviors.
[2]	Sihang Zhao, Shoucong Carol Xiong, Bo Pang, Xiaoying Tang, Pinjia He	LARF (Let AI Read First, utilizing GPT-4 API) HTML-based GPT-4 text annotation with bold/highlighting, Bionic Reading, Kurzweil 3000	LARF significantly improved reading comprehension, focus, and patience, especially in severe dyslexia, while Bionic Reading showed no significant improvement.
[19]	Wenjing Pan, Xia Li, Xiaoyin Chen, Rui Xu	Readability classification models (Random Forest, SMO/SVM) incorporating 10 handcrafted 'textual form features' (similarity, overlap, length ratios), Coh-Metrix (108 semantic features), MUSS, ReWordify, BERT, RoBERTa, XLNet	Textual form features improved classification accuracy to 97.4%, while handcrafted linguistic features were more stable and interpretable than raw neural embeddings.
[20]	Ahmed Elragal, Ali Ismail Awad, Ingemar Andersson, Jörgen Nilsson	Conversational AI Bot (COFFEE), Google Dialogflow (GDF), ChatGPT, Python predictive models, Tableau, Canvas LMS, PostgreSQL	A GDF-based chatbot architecture was successfully developed as a reusable and adaptable template for inclusive education.
[21]	Gianluca Morciano, José Manuel Alcalde Llergo, Andrea Zingoni, Enrique Yeguas Bolívar, Juri Taborri, Giuseppe Calabrò	Collaborative-filtering recommendation models (user-based, item-based, weighted-hybrid), Pearson correlation, Euclidean distance, Cosine similarity, SVM, KNN, LR, RF	The hybrid recommendation model performed best, improving prediction accuracy and increasing dyslexic students' academic scores by nearly 1 point.
[22]	Jianxin Xiong, Hui Yin, Meisen Pan	Hybrid deep learning model (parallel CNNs for facial and speech extraction merged into LSTM layers), Reinforcement Learning (Learning Automata with reward/penalty operators), Fuzzy Logic	The CNN-LSTM model improved emotion recognition by 9.71%, while reinforcement learning personalized reading therapy texts.
[23]	Paloma Martínez, Alberto Ramos, Lourdes Moreno	Llama2 (7B and 70B models), QLoRA, PEFT, MUSS, ReWordify, Sentence Transformers (LaBSE)	Fine-tuning the smaller Llama2 7B model produced better Spanish Easy-to-Read content than zero-shot Llama2 70B, using a corpus of 1,941 aligned sentences.
[24]	Peng-Chan Chang, Rong-Ho Lin	Visual Prompt-Based Mobile Learning (VPML) system (Prompting, Learning, Evaluation subsystems with equation/variable/coefficient coloring)	VPML significantly improved students' algebra problem-solving and self-efficacy, with posttest scores averaging 77.32.
[25]	William Villegas-Ch, Joselin García-Ortiz, Santiago Sánchez-Viteri	CNN anomaly detector (speed, pen pressure, stroke alignment), SVM with RBF kernel, Random Forest (100 trees), Kalman Filter, Fourier Transform, PCA	The CNN model accurately detected writing anomalies, while real-time feedback reduced pen pressure and improved handwriting speed.

Evidence of Effectiveness (RQ2)

The evidence indicates that AI-driven assistive tools can provide meaningful benefits to learners, both in terms of academic performance and emotional well-being.

- Several studies reported noticeable improvements in reading comprehension and fluency following the use of AI-based learning systems. For example, one 16-week intervention reported an increase in the mean reading score from 54.2 to 73.6 [10]. In another study, adaptive learning systems achieved lesson completion rates that were approximately 30% higher than those of more conventional, static applications [12].
- AI tools may also help learners feel more confident and less anxious when completing reading activities. Immediate feedback allow learners to identify and correct mistakes without the fear of being judged, creating a more comfortable and supportive learning environment [10].
- AI-based adaptive systems provide continuous support based on each learner's needs. Rather than relying on a one-size-fits-all approach, these systems can adjust learning activities according to differences in learners' abilities and progress, helping address individual variations in reading development.

Challenges, Limitations and Opportunities (RQ3)

The use of AI to support learners with dyslexia still faces several challenges related to data, technology, education, and ethics.

- Data limitation and bias are one of the main challenges where there is limited availability of high-quality datasets that accurately represent learners with dyslexia. When AI models are trained using small or narrowly focused datasets, they may develop linguistic, demographics, or handwriting biases, which can affect their accuracy when applied to other groups or educational settings [27].
- Implementation challenge lies in adoption of AI tools as it depends on practical factors such as cost, access to suitable devices, internet connectivity, teachers' digital skills, and the computing resources required to run AI systems. These issues can further increase the digital divide, particularly in rural schools and other educational settings with limited resources.
- Many deep learning and LLM-based systems are difficult to understand because they provide recommendations without clearly explaining how those decisions were reached. Teachers may need to understand why certain learning materials were recommended, or whether an AI-generated recommendation is suitable for the learner. Without sufficient transparency, teachers may be less willing to trust the system. Therefore, Explainable AI, clear visual dashboards, and teacher involvement in the decision-making process are important for ensuring that AI support professional judgement rather than replacing it [4].
- Future opportunities of generative AI where it produces personalized explanations, reading materials, stories and interactive learning activities, while multimodal and Edge AI can offer more immediate support with reduced latency and potentially better privacy. Future systems should combine these capabilities with accessible interfaces, transparent analytics, and mechanisms that allow teachers or specialists to intervene when the AI is uncertain or unable to provide an appropriate recommendation [11], [12].

Review Constraints

This review has some limitations that should be considered when interpreting the findings. First, the literature search covered only four databases and included studies published in English between 2022 and 2026. As a result, relevant research from other databases or studies that use different terms to describe AI-based tools may not have been captured. Restricting the review to studies with accessible full texts may have also contributed to selection bias. Furthermore, the studies varied considerably in terms of participants' ages, languages, intervention periods, AI models, and outcome measures. These differences make it difficult to compare the findings directly and do not allow a formal meta-analysis to be conducted.

Conclusion and Recommendations

AI-driven tools have the potential to make a meaningful difference in supporting foundational readers with dyslexia, particularly by offering personalized learning experiences that may not always be possible in traditional classrooms. Evidence from existing studies suggests that tools such as intelligent tutoring systems and multimodal gamified applications can help improve reading performance while creating a more supportive environment where learners can receive feedback without feeling judged. At the same time, several challenges need to be addressed, including biased data, unequal access to digital resources, and the lack of transparency in some complex AI models, which can make it difficult for teachers to understand and trust their recommendations. Looking ahead, technologies such as Generative AI and Edge AI could further support inclusive education. However, their development should place greater emphasis on transparency, explainable results, accessibility, and appropriate human involvement so that AI works alongside educators rather than replacing them.

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Reliability-Driven Maintenance Scheduling with A Digital Twin, From Asset Criticality to Decision Optimisation

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Abstract— Unplanned failure is expensive, yet Digital Twin research still leaves the step from a risk number to a defensible maintenance date underspecified. This paper sets out a four-stage, reliability-driven Digital Twin for maintenance scheduling, with a single method fixed per stage and an explicit data product between stages. Asset criticality is settled by a Delphi panel and Analytic Hierarchy Process weighting, feeding a percentile-based Risk Priority Index. A BowTie hybrid of Fault Tree Analysis and Reliability Block Diagram logic then fixes the failure structure and the covariate set. Risk is estimated by a two-layer proportional hazards model with a cross-fitted residual correction, and that hazard becomes failure probability, downtime, cost and availability. A grid search over the preventive interval and a hazard threshold returns a Pareto set under an availability constraint. The twin is offline. It advises rather than controls. Validation using operational data is identified as a future step, with explicit discussion of scalability and modelling limitations.

Introduction

Maintenance costs money whether or not the equipment fails. An estimate of the annual cost of maintenance and poor maintenance for United States manufacturers was of the order of 222 billion dollars [1]. Two main approaches are currently in practice, and each has its own problems. Reactive repair is waiting for things to break, and that downtime is money. Time-based preventive maintenance replaces components on a fixed schedule, often wasting usable component life. Condition-based maintenance reduces this inefficiency by reacting to measured equipment condition, but it requires data availability, an appropriate model, and a decision rule [2]. So, in plant operations, the central question is not whether a component is degrading, but when intervention should happen and at what cost. Condition monitoring and prognostics are mature at the detection layer [3]. Digital Twin research extended them with a virtual counterpart that mirrors the asset and hosts its models [4]. Whether those systems are twins at all is another matter. A categorical review found many published Digital Twins are digital models or digital shadows, integration between physical and virtual asset left partial or manual [5]. For a maintenance engineer, the test is not fidelity. It is whether the twin changes a decision. Three weaknesses recur in Digital Twin work aimed at maintenance. One is the gap between deterministic simulation and stochastic failure, since twin models often return a point estimate of remaining useful life and say nothing about its uncertainty [6]. Another is the gap between risk and decision. Probabilistic outputs are produced, but rarely converted into the quantities a planner uses, such as failure probability inside a planning window, expected downtime, or cost per option [7], [8]. The third weakness is methodological. Studies pick their own criticality ranking, reliability tool, and risk model, so no workflow survives reuse across an asset base [9]. Digital Twin research has also grown fastest in production planning, where maintenance enters as a boundary condition rather than as the decision under study [10].

This paper answers with a four-stage, reliability-driven Digital Twin framework for maintenance scheduling, with one method fixed per stage. The full specification appears in a companion journal article by the authors [11], and what follows is the condensed argument for maintenance and reliability readers.

Proposed framework

An offline Digital Twin involves four analytical stages, as presented in Fig. 1 and evaluated by the decision rules in Table 1. Data products flow through these stages in a sequential manner. The priority vectors determine the limits for Stage 2, the minimal cut sets provide the covariates for Stage 3, and the hazard and survival curves are the optimisation focus for Stage 4. No feedback from the twin to the asset. The data transfer is only from the asset to the twin. The twin gives the recommendations, and the maintenance engineer gives the authorisation. An offline Digital Twin involves four analytical stages, as presented in Fig. 1 and evaluated by the decision rules in Table 1. Data products flow through these stages in a sequential manner. The priority vectors determine the limits for Stage 2, the minimal cut sets provide the covariates for Stage 3, and the hazard and survival curves are the optimisation focus for Stage 4. No feedback from the twin to the asset. The data transfer is only from the asset to the twin. The twin gives the recommendations, and the maintenance engineer gives the authorisation.

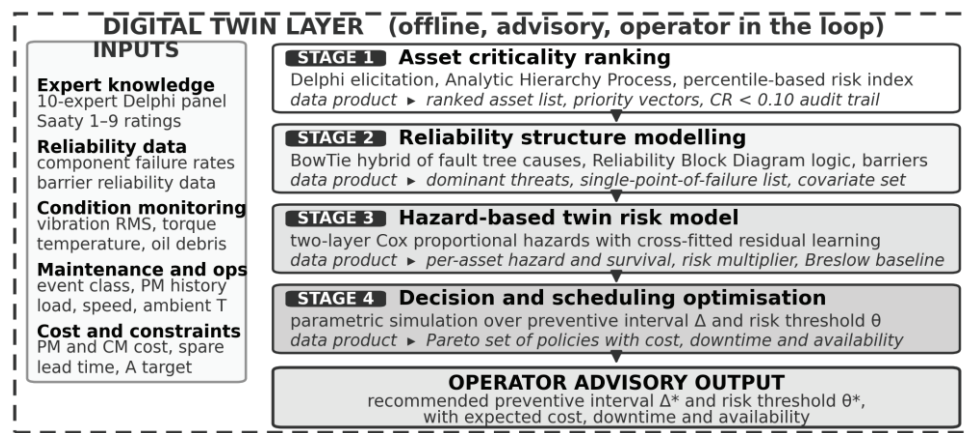


Fig. 8 Four-stage reliability-driven Digital Twin framework for maintenance scheduling

Table 1: Decision rule that must be satisfied before each stage passes its data product downstream.

Stage	Decision rule
1. Asset criticality ranking	Consistency Ratio below 0.10 on every pairwise matrix; ties broken on the highest severity rating
2. Reliability structure modelling	Single-point-of-failure rule on every basic event; barriers ranked by Risk Achievement Worth
3. Hazard-based twin risk model	Schoenfeld and martingale residual checks passed; residual target computed out of fold
4. Decision and scheduling optimisation	Availability constraint met; monotonicity and extreme-value checks passed on the simulation engine

Criticality ranking requires a combination of engineering judgement and quantifiable assessment, seldom achieved by a single method. Stage 1 uses the Delphi process with AHP weighting and a percentile-based risk index. A panel of ten experts evaluates candidate specifications, such as failure rate, downtime per failure, and replacement cost, against a predefined set of criteria [12]. No consensus is assumed; criteria must reach a Fleiss's kappa of at least 0.50 in three rounds of feedback, and highly correlated sub-criteria are discarded. Pairwise comparisons on Saaty's 1-9 scale [13] produce priority vectors. Severity, occurrence, and detection are measured on data-driven percentile scales. These vectors weight the Risk Priority Number, and the highest-ranking asset proceeds to Stage 2.

Stage 2 involves examining the failure modes of the top-ranked asset and the mechanisms that prevent such failures. Fault Tree Analysis is used to find the basic-event combinations that lead to the top event, in accordance with IEC 61025[14]. The components and barriers are combined using Reliability Block Diagram logic in series, in parallel or k-out-of-n redundancy,

according to BS EN 61078 [15]. The BowTie method combines these analyses and arranges barriers on both sides of the event sequence. This is an example of defence in depth. The sequence is broken by the presence of any effective barrier. The barrier metrics are assumed to be time-dependent probabilities, such as the probability of failure on demand. The top-event frequency is then calculated as a sum of all threat pathways.

Stage 3 produces the risk number that drives the schedule. Cox proportional hazards suits the job for three reasons. It is semi-parametric, it handles right-censored lifetimes without committing to a lifetime distribution, and it returns hazard ratios that an engineer can read [16], [17]. That last property is not cosmetic. A recommendation that cannot be explained will not be authorised. The model is fitted in two layers, a fleet layer on all units and a condition-monitoring layer on the smaller monitored subset using the fleet baseline as a fixed offset. The fleet layer holds population-level behaviour, so the second layer only has to explain what the monitored sensors add. A residual corrector, trained out of fold, absorbs the non-linear and interaction effects that a linear predictor cannot represent, and the final model refits both coefficient vectors jointly, as in Eqs. (1) and (2).

$$\begin{aligned} h_i(t | x_i) &= h_{0,F}(t) \exp(\beta^T x_i + \gamma z(x_i)) \\ S_i(t | x_i) &= \exp(-H_{0,F}(t) \eta_i), \quad \eta_i = \exp(\beta^T x_i + \gamma z(x_i)) \end{aligned} \quad (1) \quad (2)$$

Two assumption checks must pass before the fitted model is released. Schoenfeld residuals test whether the proportional-hazards assumption holds over time, and martingale residuals test whether a covariate enters the model in the wrong functional form. A covariate that fails either check is handled by either a stratified baseline or the residual corrector.

Stage 4 converts hazard into quantities a planner can act on. For a preventive interval and an analysis horizon, the failure probability, total cost, and availability follow from the Stage 3 survival function in Eqs. (3) and (4). C_{PM} and C_{CM} are the preventive and corrective action costs. The scheduling problem is written as Eq. (5), in which a hazard threshold triggers an early intervention and an availability target constrains the search. The first implementation searches a grid, the interval running from 30 to 365 days and the threshold from the 70th to the 95th percentile of the fleet hazard distribution. That leaves roughly 1000 to 10000 candidate policies. Each policy is then simulated. The trigger logic runs, stochastic failures are drawn from the survival curve, and cost, downtime and availability accumulate over the horizon. The result is a Pareto front of cost, availability and expected failures for the asset manager to choose the operating point that is consistent with the organisation's risk appetite.

$$\begin{aligned} P_{fail,i}(\Delta) &= 1 - \exp(-H_{0,F}(\Delta) \eta_i) \\ C(\Delta) &= C_{PM} (T / \Delta) + C_{CM} P_{fail}(\Delta), \quad A(\Delta) = 1 - P_{fail}(\Delta) MTTR / T \\ \min_{\Delta, \theta} C(\Delta, \theta) &\quad \text{subject to} \quad A(\Delta, \theta) \geq A_{target} \end{aligned} \quad (3) \quad (4) \quad (5)$$

The grid search is computationally cheap here, as the workload scales only with the grid resolution and the number of replications, since there is only one asset and two decision variables. This efficiency, however, is lost in fleet-wide optimisation. Shared crews, spare-part constraints and the presence of other assets link decisions and increase the search space exponentially, making complete enumeration impossible. The conventional method to tackle this complexity is via simulation optimisation methods [18]. Genetic algorithms and particle swarm optimisation, among other heuristic searches, have been applied to fleet-scale maintenance routing and scheduling [19]. Grid search is kept in the single-asset scenario as every candidate solution can be evaluated, allowing to validate metaheuristics as the framework is scaled.

Data and validation requirements

The framework needs five data blocks. Survival fields hold the asset identifier, the last-replacement and observation end dates, the time-to-event, and a binary event indicator. Condition-monitoring covariates follow ISO 17359 indicators, namely oil debris count, torque, temperature and vibration RMS [20]. Maintenance and operational covariates form two further blocks, covering event class, maintenance count, mean time to repair (MTTR), load, speed, ambient temperature and shift. Scheduling and economic variables supply spare lead time, crew availability, the two action costs, downtime cost per hour and the availability target. Lifetimes are right-censored, with censoring assumed non-informative given the covariates.

The current pilot assumes that maintenance returns assets to an as-good-as-new condition, which is only true if components are fully replaced. Most maintenance, however, leaves assets in a condition between new and as-bad-as-old [21]. There are two established approaches to this phenomenon. The first is the age-reduction model, which decreases the effective age of an asset following maintenance. The second is the quasi-renewal model that, as repairs accumulate, decreases the expected time between failures in a stepwise manner [22]. Both approaches only change the survival curve and have no effect on decision-making and optimisation. The main difficulty in implementing this approach is not theoretical, but the lack of data. The main difficulty in implementing this approach is not theoretical but practical, as estimating reduction factors requires extensive maintenance data for each asset, which the pilot currently lacks.

Three validation tracks are performed before deployment. Internal validation consists of simulating lifetimes from a known Cox model under covariate perturbations of 1 and 2 standard deviations, and comparing hazard and survival estimates to the ground truth using Kullback-Leibler divergence. Temporal validation is more stringent, in which the model is trained on years one to four of historical data and tested on year five, with discrimination assessed by Harrell's C-index, accuracy by the Brier score, and calibration by the expected calibration error. Sensitivity analysis perturbs the fitted coefficients by one standard error and the two action costs by 20%, then assesses whether the Pareto front and the recommended policy are robust.

Conclusion

This framework has three key properties that make it different from a general twin architecture. The first is method-problem fit, as the method is selected for the maintenance problem, not because it is new, for each stage. The second is traceability, because the priority vectors, cut sets and hazard curves are passed consistently between stages, rather than recomputed. The third property is auditability, which is quite useful, especially for maintenance teams, because there is a decision rule at each stage that can be reviewed (as opposed to an opaque score).

The framework is defined but not yet validated, as the empirical case study is still ongoing. Thus, the behaviour of the optimisation layer should be considered as designed, rather than empirically shown. Two limitations are identified, which are grid search on the fleet scale and the renewal assumption under repeated interventions. The next step will be to apply the framework to operational data and compare the proposed schedule to current practices in terms of costs, downtime and availability.

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INNOVATION & GLOBAL OPERATIONS



Evaluating the Contribution of Modern Petrol Vehicle Features to a Sustainable Automotive Market

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Abstract— This study examines how enhanced features of petrol-powered vehicles influence the creation of a sustainable automotive market in Malaysia. While the automotive sector transitions toward greener transportation, petrol-driven cars remain vital due to affordability and established infrastructure. This paper evaluates fuel efficiency and clean emission as independent variables, with integrated technology acting as a moderator. A quantitative survey was administered to 300 respondents across Putrajaya. Structural Equation Modeling via AMOS (SEM-AMOS) was utilized to evaluate model fitness and test interaction effects. The structural model demonstrated an excellent fit to the data where $\chi^2/df = 1.616$, CFI = 0.948, RMSEA = 0.045 and PClose = 0.772. The findings reveal that integration technology acts as a critical moderator that strengthens the effects of fuel efficiency and emission reductions on the sustainable automotive marketplace. The significant interaction effects prove that fuel efficiency and clean emissions alone are insufficient; their structural impact on market sustainability heavily depends on the sophistication of the vehicle's integrated technology systems. These results underscore petrol-engine innovations as a critical bridging solution toward a sustainable automotive future in Malaysia.

Introduction

Electric vehicles (EVs) are popular due to their advanced technology. However, petrol vehicles remain relevant due to their cost-effectiveness and improved performance [1]. Environmental concerns and stricter regulations have driven manufacturers to improve petrol-powered vehicles to achieve higher fuel efficiency and sustainability [2]. Modern petrol engine technologies integrate fuel economy, direct fuel injection, and turbocharging, including hybrid systems, to improve performance and reduce emissions [3]. This helps manufacturers meet consumer demand while complying with environmental regulations. Furthermore, the carbon footprint of petrol-powered vehicles is significantly reduced through improved emission controls such as particulate filters and catalytic converters [4]. From a market perspective, consumer preferences still favor petrol vehicles due to their cost-effectiveness and availability. Developing countries need sophisticated petrol-powered vehicles for sustainable transportation networks because they lack the infrastructure required for electric vehicles [5]. In this regard, industry and political players have joined forces in understanding the consumer aspects to make informed purchasing choices [6]. Therefore, this study examines how modern developments in petrol-powered cars are creating sustainable progress in the automotive industry. Petrol engines can remain popular by offering easy refueling, fast acceleration capabilities, and smooth handling systems. In fact, the world has seen advances in emission control systems as well as engine cooling and fuel injection technologies that have resulted in higher efficiency and better environmental outcomes [4].

The automotive industry is currently going through a phase of technological development where the Malaysian automotive sector strives to achieve the country's economic growth with sustainable targets. While electric vehicle become a new trend, the development of petrol engines can meet this aspiration by achieving higher fuel economy and equivalent performance capabilities [7]. Modern petrol engines have achieved a reduction in their carbon footprint through innovative technologies of direct fuel injection systems and turbocharging with variable valve timing [8]. This is in line with the international campaign for the reduction of

greenhouse gases. However, technological advances have not prevented conventional petrol engine vehicles from contributing to carbon emissions, air pollution and energy consumption [9]. The Malaysian automotive industry needs to regulate and identify sustainable and low-carbon automotive solutions for consumers and manufacturers. This requires a fixed or consistent regulatory framework [10].

Therefore, the objective of this study is to determine the extent to which integrated technology features moderate fuel efficiency and clean emissions to achieve sustainability of petrol engine vehicles in the automotive market. This study was conducted around Putrajaya which has good ecological practices. An assessment of the respondents' perspectives on improved petrol car technology innovation solutions can provide an insight into the competitiveness of sustainable strategies that benefit economies of the consumers.

Literature review

Modern petrol-powered vehicles have evolved into environmentally friendly vehicles with lower fuel consumption. Advanced engine powertrains offer higher levels of performance alongside enhanced smart features in turbocharging, direct fuel injection, stop-start systems and are equipped with safety and convenience technologies such as ADAS (Advanced Driver Assistance Systems) [11]. New cars use engine control systems that improve environmental performance and emit fewer pollutants [7]. Better quality lightweight vehicle parts and improved sequential gearbox operation increase user comfort, while better insulation, together with quieter engines, lead to better driving comfort. Real-time fuel monitoring and eco-driving modes give drivers full control over their vehicle's efficiency via their touchscreen interface.

Based on current developments, petrol-powered vehicles emphasize three important elements: improved fuel efficiency, emission reduction technology, and environmentally friendly hybrid integration technology. Strict regulations on automobile emissions have made fuel efficiency a priority [12]. Modern automotive engineers have now succeeded in designing highly fuel-efficient internal combustion engines (ICEs). It encourages the global to continue to force the reduction of harmful gases and promote clean environmental emissions [13]. The complex combination of systems improves the combustion process but uses less power and does not waste much energy). This makes driving a harmony between the environment and the functions of integrated technology that provide satisfaction to users [14]. The growing need for more environmentally friendly transportation is also driving the creation of hybrid vehicles in which petrol fuel is powered by environmentally friendly technology. This is a bridge between the internal combustion engine and the future electric car that reduces pollution without eliminating the petrol engine [12]. Hybrid support systems provide alternative fuels, advanced engines and intelligent control technologies to improve the environmental performance of petrol cars within an affordable price range.

Methodology

The study was conducted systematically and focused on its direction. In quantitative research, the data analyzed describes patterns, relationships, and effects between variables. It began with the definition of the problem and research objectives. Literature review identified relevant variables related to vehicle characteristics and sustainability in the automotive sector. Conceptual model helps explain the relationship between independent variables and dependent variable via moderator. This was translated into a survey questionnaire as the research instrument containing 20 questions with a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Simple random sampling was selected involving a sample size of 383 petrol vehicle drivers as respondents from a population of 110,600 people [15]. Data were collected face-to-face over a period of 2 months in the field such as shopping malls, recreational areas and restaurants to aid respondents' correct understanding of the study.

A total of 300 useable data were successfully collected (after rejecting 83 returned surveys that did not meet the purpose). In SPSS (version 26), Exploratory Factor Analysis (EFA) extracted 3 factors for the data. Structural Equation Model Analysis (SEM) was performed to test the research model using SPSS AMOS (version 23). The measurement model used Confirmatory Factor Analysis (CFA) to determine each indicator that provides a level of validity and reliability based on the threshold value of the goodness-of-fit criterion set. Common indicators used are the chi-square ratio divided by the degrees of freedom ($\chi^2/df < 5.0$), fit indices (CFI > 0.90, SRMR < 0.08 and RMSEA < 0.06). The structural model tests the research hypothesis by interpreting the path coefficient value and significance threshold value ($p < 0.05$) and the coefficient of determination value (R^2) to validate the model. The findings are then discussed and the conclusions drawn.

Results and discussions

KMO achieved is 0.928. This is enough to confirm that the data sample is sufficient and suitable for Factor Analysis. Principal Component Analysis and Varimax rotation have extracted 3 different factors. It contributes 52.5% of the total cumulative variance, an acceptable threshold for social science studies. Next, the Rotated Component Matrix in Table 1 shows that all variables have factor loadings higher than 0.40. This explains the large variance is within the statistical threshold to determine the correct group of variables

Table1: Factor analysis

Rotated Component Matrix			
	Component		
	1	2	3
Small engine	.766		
Catalytic converters	.633		
Direct fuel injection	.597		
lighter materials	.540		
Low-emission engines	.480		
Turbo engines	.479		
Filters		.759	
New engine technology		.749	
Cleaner emission standards		.576	
Cleaner combustion		.516	
Modern petrol engines		.500	
Regenerative braking			.729
Innovative engine designs			.599
Start-stop systems			.597
Hybrid systems			.555

Table 2: Goodness of fit results

Measure	Estimate	Threshold	Interpretation
CMIN	268.250	--	--
DF	166	--	--
CMIN/DF	1.616	Between 1 and 3	Excellent
CFI	0.948	>0.95	Acceptable
SRMR	0.045	<0.08	Excellent
RMSEA	0.045	<0.06	Excellent
PClose	0.772	>0.05	Excellent

Confirmatory factor analysis (CFA) was conducted on the structural model with moderation to assess the structural relationships among latent variables (N = 300). Model fit in Table 2 was assessed using standard psychometric indices, namely relative chi-square (χ^2/df), Comparative Fit Index (CFI), Root Cause Residual (SRMR), Root Cause Error of Approximation (RMSEA),

and p-value for Closeness of Fit (PClose). The structural model showed an excellent fit to the data: $\chi^2(166) = 268.250$, $p < .001$; $\chi^2/df = 1.616$; CFI = .948; SRMR = .045; RMSEA = .045 (95% confidence interval); and PClose = .772. The χ^2/df ratio is below the threshold value of 2.0, the CFI is above .90, and both the SRMR and RMSEA values are below the threshold of .05. That is, the approximation of the model to the empirical data is very good. This is confirmed by the non-significant PClose indicator ($p > .05$), where the approximation is ideal and consistent with the true population error. Therefore, the measurement model is stable, and the path coefficients for the mediation analysis can be interpreted with high confidence.

Conclusions and recommendations

To generalize, structural model analysis (AMOS SEM) showed that the interaction effect model had an excellent fit to the data: $\chi^2(166) = 268.250$, ($p < 0.001$); $\chi^2/df = 1.616$; CFI = 0.948; SRMR = 0.045; and RMSEA = 0.045 (PClose = 0.772). Based on these ideal population parameters, the main principle of the study establishes that integrated technology acts as a moderator of critical contingencies (boundary conditions) in the sustainable automotive market in Malaysia. Through the application of 95% bias-corrected confidence interval (CI) methods with 5,000 bootstrapping samples, this study confirms that the influence of fuel efficiency and net emissions on market sustainability is not static. This linear relationship is dynamically driven by the level of application of smart vehicle technology, in line with local consumer trends which are now largely influenced by the restructuring of domestic fuel subsidies [16, 17].

Although parameter stability is met, the interpretation of this moderating interaction effect has several methodological limitations (exceptions). The use of 5,000 bootstrapping samples successfully overcomes the multivariate non-normality problem that often occurs in the production of SEM interaction indicator products, especially if the latent sampling error range for the interaction is relatively ambiguous [18, 19]. The sample size ($N = 300$) limits the ability to detect small interaction effect sizes (f^2) if latent product errors are not controlled using orthogonalization methods [20]. The nature of integrated technologies as moderating effects requires further classification to distinguish whether they are synergistic or buffering to avoid misinterpretation of the interaction design [21].

Practically, the implications of this research contributes a new element to the theory of market sustainability by demonstrating the role of synergistic moderation which is robustly confirmed through non-parametric parameter testing (bootstrapping). Integrated technologies have been shown to act as a catalyst that doubles the strength of the relationship between engine green performance and long-term market acceptance [22]. In Malaysia, vehicle manufacturers can no longer market mechanical efficiency aspects in isolation. Green mechanical features must be synergized with artificial intelligence (AI) or advanced driver assistance systems (ADAS) to sustain the volume of the petrol market [23, 24]. Government agencies such as Malaysia Automotive Robotics & IoT Institute (MARii) can also use this moderation framework in assessing the Energy Efficient Vehicle (EEV) ecosystem.

As conclusions, sustainability of the petrol vehicle market in Malaysia is significantly determined by the moderating interaction effect between green performance and the level of integrated technology, as confirmed by the 95% robust error estimate bootstrapping (5,000 resamples). For future studies, the recommendations proposed include plotting two-way interaction graphs (simple slopes analysis) to visualize how the slope of the fuel efficiency relationship changes when integrated technology is at a high level (+1 SD) compared to a low level (-1 SD) [21]. In addition, the interaction model confirmed through bootstrapping can be retested using multi-group analysis (MGA) to see the impact of technology interactions post-implementation of the National Energy Transition Roadmap [25].

Acknowledgement

The authors would like to thank the Universiti Teknikal Malaysia Melaka (UTeM) and the Centre of Technopreneurship Development (C-TeD) for providing a research platform and continuous support in realizing this research work.

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Perceived Intelligence and AI-DSS Adoption in the Public Sector: A Systematic Review of UTAUT Extensions

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Abstract— Artificial Intelligence-powered Decision Support Systems (AI-DSS) are reshaping decision-making and efficiency in the public sector, yet adoption remains inconsistent. This study examines whether UTAUT adequately explains AI-DSS adoption in government contexts. A systematic review of 92 peer-reviewed studies (Scopus and Web of Science, 2020–2025), following PRISMA, shows UTAUT's core constructs remain influential but 73% of studies extended the model, most commonly with Trust (33.7%), Perceived Risk (20.7%), and Transparency (15.2%). None operationalized a construct capturing users' belief in an AI system's reasoning and learning capability. This paper proposes "Perceived Intelligence" (PI), a novel construct mediating Performance and Effort Expectancy on Behavioural Intention, giving researchers a testable framework and policymakers including those implementing Malaysia's MyDIGITAL blueprint as a diagnostic tool for building AI adoption trust in governance.

Introduction

The government's use of AI has been a paradigm shift in the public administration system that has provided enhanced services and data-driven policymaking [1], [2]. AI is seen as a major enabler for governments to be efficient, as reflected in major initiatives such as Malaysia's MyDIGITAL, the European Union (EU) Malaysia's MyDIGITAL, European Union (EU) AI Act, the United States' (US) Executive Order on Safe, Secure, and Trustworthy AI and China's AI Development Plan [3], [4]. As pointed out by [5], [6] and in different sectors such as health care, education and fraud detection [7] ministries can shift from reactive to predictive governance with AI-DSS.

This review addresses that theoretical gap by critically examining UTAUT's use in AI-DSS adoption in the public sector, identifying its weaknesses, and proposing a theoretical extension. Central to this review is 'Perceived Intelligence' as a critical mediating variable. These findings help fill this gap by formulating a more nuanced model and offering policymakers a practical blueprint for navigating digital government transformation

Review Method

This review followed PRISMA protocol [8], covering studies on UTAUT applications to AI adoption in public sector contexts published January 2020–December 2025. A systematic search in Scopus and Web of Science used: ("UTAUT" OR "Unified Theory of Acceptance and Use of Technology") AND ("AI" OR "artificial intelligence" OR "machine learning" OR "intelligent system*") AND ("public sector" OR "government" OR "governance" OR "public administration") AND ("adoption" OR "acceptance" OR "use"), limited to titles, abstracts, and keywords.

The selection strategy is shown in Figure 1. Inclusion criteria were peer-reviewed English-language articles (2020–2025) with an empirical or theoretical focus on UTAUT-based AI adoption in the public sector; consumer-technology studies, non-AI studies, and technical papers without behavioral aspects were excluded. Of 1,318 papers identified, 403 duplicates and 763 records were removed at screening, 152 underwent full-text review, and 92 studies were retained for analysis.

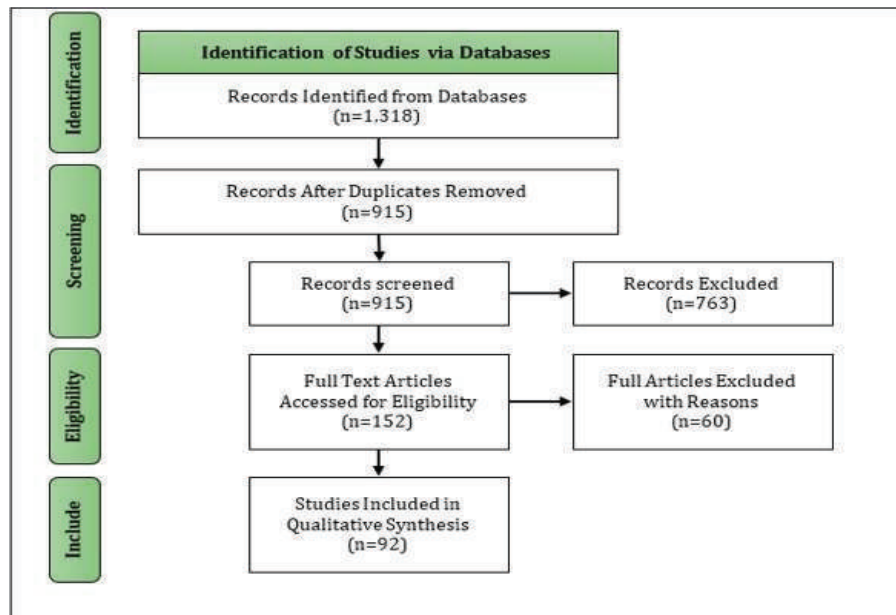


Fig. 1 PRISMA flow diagram of the study selection process

Results

Descriptive Analysis

Analysis revealed clear patterns in UTAUT construct use. Core constructs remained dominant: Behavioral Intention (100%), Performance Expectancy (96.7%), Facilitating Conditions (93.5%), Effort Expectancy (92.4%), and Social Influence (87.0%). Ity (15.2%). There was no study that formally tested Perceived Intelligence. Quantitative methods dominated (85%) with health care (24%) and e-government (22%) being the main areas of interest. Main types of technology are AI-DSS (38%) and predictive analytics (30.4%). Table 1 summarizes these patterns. Core UTAUT constructs remain widely used (>85% of studies), Trust/Perceived Risk/Transparency are the most common AI-specific extensions, and no study formally tested Perceived Intelligence to confirm the gap this paper addresses.

Table 1: Comprehensive summary of UTAUT applications in AI adoption studies (n=92)

Dimension	Key Result	Interpretation
Core UTAUT constructs	87.0%–100.0%	Behavioral Intention, Performance Expectancy, Facilitating Conditions, Effort Expectancy, and Social Influence remained widely used.
AI-specific extensions	15.2%–33.7%	Trust, Perceived Risk and Transparency/ The most frequent addition was explainability, which reflects trustworthiness, uncertainty and black-box concerns.
Methods and sectors	Quantitative: 85.0%; Healthcare: 24%; e-Government: 22%	Survey-based studies dominated, with healthcare and e-government receiving the greatest attention.
Technology type	AI-DSS: 38.0%; Predictive Analytics: 30.4%	Decision-support and predictive systems aligned most closely with public sector AI use cases.
Novel construct	Perceived Intelligence: 0.0%	No reviewed study formally tested Perceived Intelligence, confirming the theoretical gap addressed in this paper.

Research Gaps

This study aims to examine systematically the use of the UTAUT framework to understand AI adoption in the public sector, highlight its theoretical limitations, and introduce a new mediating construct called Perceived Intelligence. The proposed framework synthesizes insights from XAI, trust calibration theory and the public sector governance literature, to provide a more

holistic understanding of the dynamics of AI-DSS adoption. More recent scholarship has added constructs such as ‘Trust’ and ‘Transparency’ to AI-focused UTAUT models [9], [10], but often considers trust as monolithic. The antecedent of trust is users’ perception of AI’s cognitive capability. The antecedent of trust in public sector governance is under-theorized and not much research has been conducted [2]. The intersection of AI ethics, algorithmic transparency, and public sector governance remains underexplored in technology adoption research [11], [12].

Geographical and Temporal Distribution

On the continent scale, Asia takes up nearly half (48%) of the publications, whereas Europe and North America provide 22% and 18%, correspondingly. It should be noted that Oceania and Middle East demonstrate emerging but still relatively small activity, while Africa and South America stay significantly underrepresented, which is quite surprising because developing areas might face the hardest time adopting AI [13], [14].

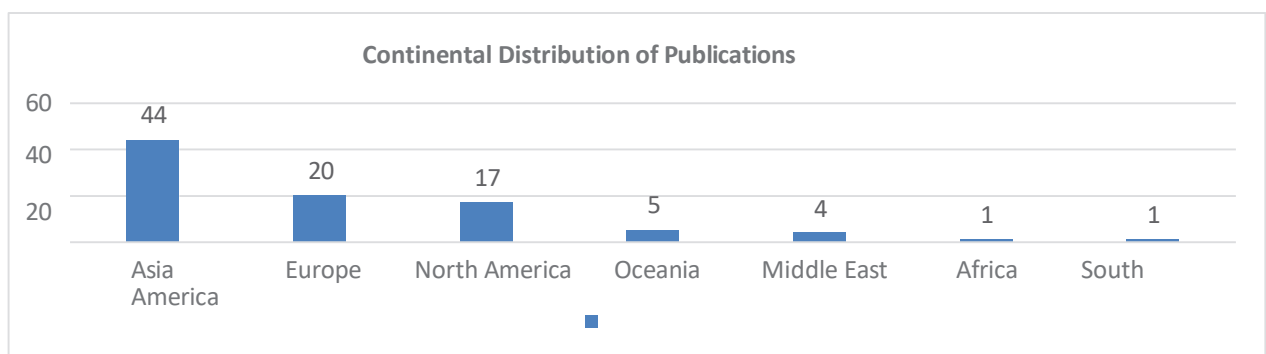


Fig. 2 Continental distribution of publications

Comparison with Previous UTAUT Extensions

Table 2 compares the proposed framework with other significant UTAUT extensions, demonstrating the novelty of integrating Perceived Intelligence as a mediating construct for public sector AI-DSS adoption.

Table 2. Comparison of proposed framework with previous UTAUT extensions

Study/Extension	Key Added Constructs	Focus	Methodology	Key Findings
Venkatesh et al. [15]	Hedonic Motivation, Price Value, Habit	Consumer technology	Quantitative SEM	Extended model explained 7% more variance
Gefen et al. [16]	Trust, Perceived Risk, Security	Mobile payment	Survey-based PLS	Trust strongest predictor of intention
Glikson and Woolley [9]	AI Self-Efficacy, Trust, Personal Innovativeness	AI-enabled healthcare	Conceptual review	Trust partially mediated effects
Shin [10]	Transparency, Explainability, Accountability	General AI adoption	Empirical study	Proposed 6-factor AI-specific model
Proposed	Perceived Intelligence (mediator)	Public sector AI-DSS	Systematic review	Mediating role between PE/EE and BI

Discussion

Key Findings and Theoretical Contributions

Core UTAUT constructs remain influential, but continuous necessity for extension with Trust, Perceived Risk, and Transparency proves the classic theory insufficient for AI adoption [17], [18]. A significant problem associated with antecedents of trust in relation to perception of AI’s cognitive ability emerges, supporting the proposed extension [19], [20]. Asian dominance and quantitative approach limitations indicate need for more diverse and

mixed-method research [21]. The theoretical contribution of this paper is threefold. First, it advances scholarly understanding of AI-specific adoption dynamics in public sector settings. Second, it puts forward Perceived Intelligence as a new mediating construct based on well-established theoretical foundations such as trust calibration theory [22] and the explainable AI literature [10]. Third, it offers a testable framework that can guide future empirical research on AI-DSS adoption in governance settings.

Proposed Extended UTAUT Model

Based on analysis, we propose an extended UTAUT model integrating Perceived Intelligence as a central mediating construct. Performance Expectancy and Effort Expectancy influence Perceived Intelligence, which shapes Behavioral Intention and Adoption. Social Influence and Facilitating Conditions retain direct links to Behavioral Intention, while Gender, Education, and Income moderate relationships [17].

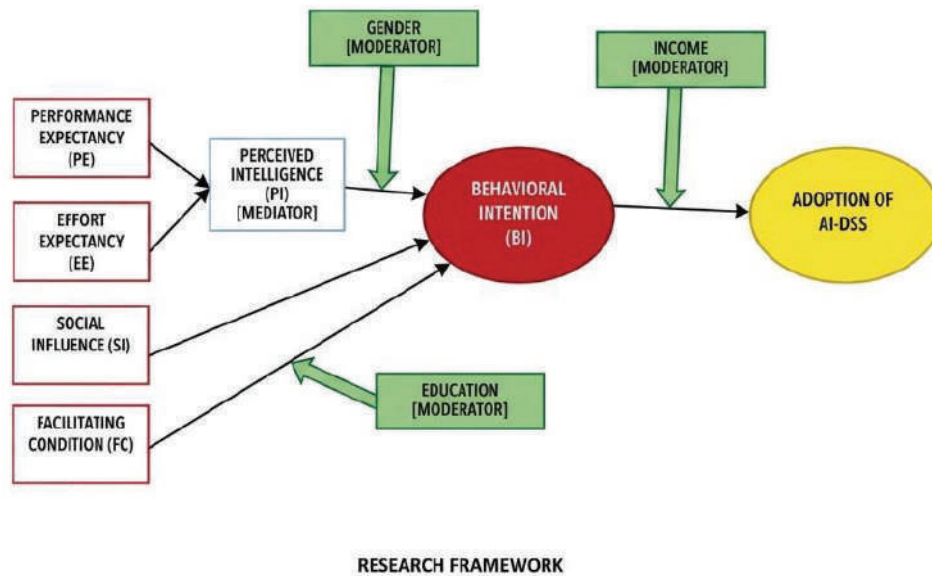


Fig. 3 The proposed extended UTAUT Model with perceived intelligence as a mediator

Note: Perceived Intelligence sits between Performance Expectancy, Effort Expectancy, and Behavioral Intention, while Social Influence and Facilitating Conditions retain direct roles.

Theoretical Foundations of Perceived Intelligence

The conceptualization of Perceived Intelligence draws on three theoretical streams. First, automation-bias research indicates that reliance behaviors are heavily shaped by perceived system capabilities [25], [26]. Second, the integrative model of organizational trust [27] holds that perceptions of ability are fundamental to trust formation, a principle extending to human-AI relationships. Third, explainable AI research shows that perceived system intelligence mediates the relationship between transparency and trust [10], [28]. This framing extends the broader technology-acceptance and innovation-diffusion traditions from which UTAUT itself was synthesized, including the extended technology acceptance model [23] and diffusion of innovations theory [24].

Hypothesized Structural Paths

Based on the theoretical foundations and construct definitions, we propose the following formal hypotheses for empirical testing. Table 3. Theoretical rationale and hypothesized directions for each relationship in the proposed framework.

Table 3. Hypothesized paths in the proposed framework

No	Relationship		Theoretical Rationale
H1	Performance Expectancy → Perceived Intelligence	Positive (+)	Users judge intelligence based on how useful and accurate the AI system is. AI-DSS improves decision with consistent users attribute to the system's reasoning ability.
H2	Effort Expectancy → Perceived Intelligence	Positive (+)	Ease of use affects users' attribution of adaptive, intelligent behavior Intuitive interfaces and clear explanations are a sign that the system "understands" what the user needs.
H3	Perceived Intelligence → Behavioral Intention	Positive (+)	The higher the perceived intelligence (reasoning, learning, contextual understanding), the more willing users are to adopt and continue using the AI-DSS.
H4	Performance Expectancy → Behavioral Intention	Positive (+)	Retained as a direct predictor as outlined in the original UTAUT specification. Users who perceive performance gains are more likely to intend adoption.
H5	Effort Expectancy → Behavioral Intention	Positive (+)	Retained as a direct predictor according to the original UTAUT specification. The ease of use of the system is a predictor for users' intention to adopt it.
H6	Social Influence → Behavioral Intention	Positive (+)	Retained as a direct predictor as outlined in the original UTAUT specification. Perceived pressure from supervisors and colleagues influences adoption intentions.
H7	Facilitating Conditions → Behavioral Intention	Positive (+)	Retained as a direct predictor as outlined in the original UTAUT specification. Adequate infrastructure and support enable adoption intentions.
H8	Behavioral Intention → Adoption	Positive (+)	Users who intentionally plan to use AI are more likely to translate their plans into actual system use.
H9	Perceived Intelligence mediates Performance Expectancy → Behavioral Intention	Positive (+), mediated	Performance Expectancy affects Behavioral Intention directly and indirectly through Perceived Intelligence. Users need to believe that the system is smart enough to provide performance gains reliably.
H10	Perceived Intelligence mediates Effort Expectancy → Behavioral Intention	Positive (+), mediated	Effort Expectancy is a predictor of Behavioral Intention directly and indirectly via Perceived Intelligence. Ease of use alone is insufficient; users must also perceive underlying intelligence.

Conclusion

In this review, the utilization of UTAUT as a theoretical model in analyzing AI adoption in the public sector will be critically examined. While reviewing 92 papers on this topic, one of the shortcomings of UTAUT in capturing trust arising from users' perceptions regarding the capabilities of AI was identified. As such, an extended version of UTAUT which integrates Perceived Intelligence as a mediator in the model is recommended. Finally, this review provides an insight into closing the gap between the technological capabilities of AI and its adoption in public governance through the lens of users' perception of the capabilities of AI systems.

Acknowledgement

The authors thank the Ministry of Higher Education (MOHE) Malaysia for sponsoring this work through the Fundamental Research Grant Scheme FRGS/1/2025/SS01/UTEM/02/1 and the Faculty of Technology Management and Technopreneurship, Universiti Teknikal Malaysia Melaka (UTeM), for their support.

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Consumer Adoption of Personalized Additive Manufacturing Products: Insights into Perceived Value and Adoption Barriers

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Abstract—Personalized additive manufacturing (AM) allows consumers to adapt product features according to their own needs and preferences, while also giving them a more active role in the design process. For users with limited design experience, AI-based guidance may reduce the difficulty of choosing and modifying product features. Even with these capabilities, personalized AM has not yet gained broad consumer acceptance. Cost, unclear benefits, and the perceived difficulty of customization may discourage potential users. The study examined how consumers evaluate personalized AM, with attention to perceived value, motivation, adoption barriers, preferred design support, and familiarity with the technology. Data for this study were collected through a quantitative cross-sectional survey involving 100 respondents. Descriptive statistics and multiple response analysis were used to summarize the main response patterns. Pearson’s chi-square test and Spearman’s rank-order correlation were then used to examine selected relationships. Functionality received the highest response (61%), followed by ease of personalization (43%) and innovation (31%). Designing a product based on personal preferences was the main motivation (59%), whereas high cost (66%) and process complexity (41%) were the main barriers. Many respondents selected AI-assisted customization (61%) and guided design features (51%), reflecting a preference for stronger support during design. Familiarity with AM was positively related to consumer interest, although the relationship was weak ($\rho = 0.272$, $p = 0.006$). These results show that technological capability alone may not be enough to encourage adoption. Consumers also need to recognize a clear benefit and feel able to manage the design process. These findings may help manufacturers improve personalization strategies while providing useful direction for future university–industry collaboration.

Introduction

Additive manufacturing (AM) supports the production of customized products without requiring the same tooling and standardization used in conventional mass production. This makes it possible to modify product form and function for individual users [1], [2].

Personalization gives consumers more control over selected product features and can involve them directly in design decisions [3], [4]. However, many users do not have advanced design knowledge. AI-assisted recommendations and guided interfaces may help them make suitable choices without managing the full technical process [5]. Participation is still more likely when the expected benefit is clear and the customization steps remain manageable [6], [7].

The availability of customization technology does not necessarily lead to consumer adoption. A personalized product may be attractive, but the additional price, effort, and uncertainty can reduce that interest [8], [9]. For this reason, adoption needs to be examined as a balance between the value consumers expect and the effort required from them. Research on product customization suggests that practical benefits and the quality of the customization experience often matter more than novelty alone [7]. This balance between expected value and required effort reflects the human-centered smart manufacturing perspective, where technology is assessed together with user needs, usability, and value creation [10]. Figure 1 illustrates how these factors are brought together in a consumer-oriented conceptual framework.

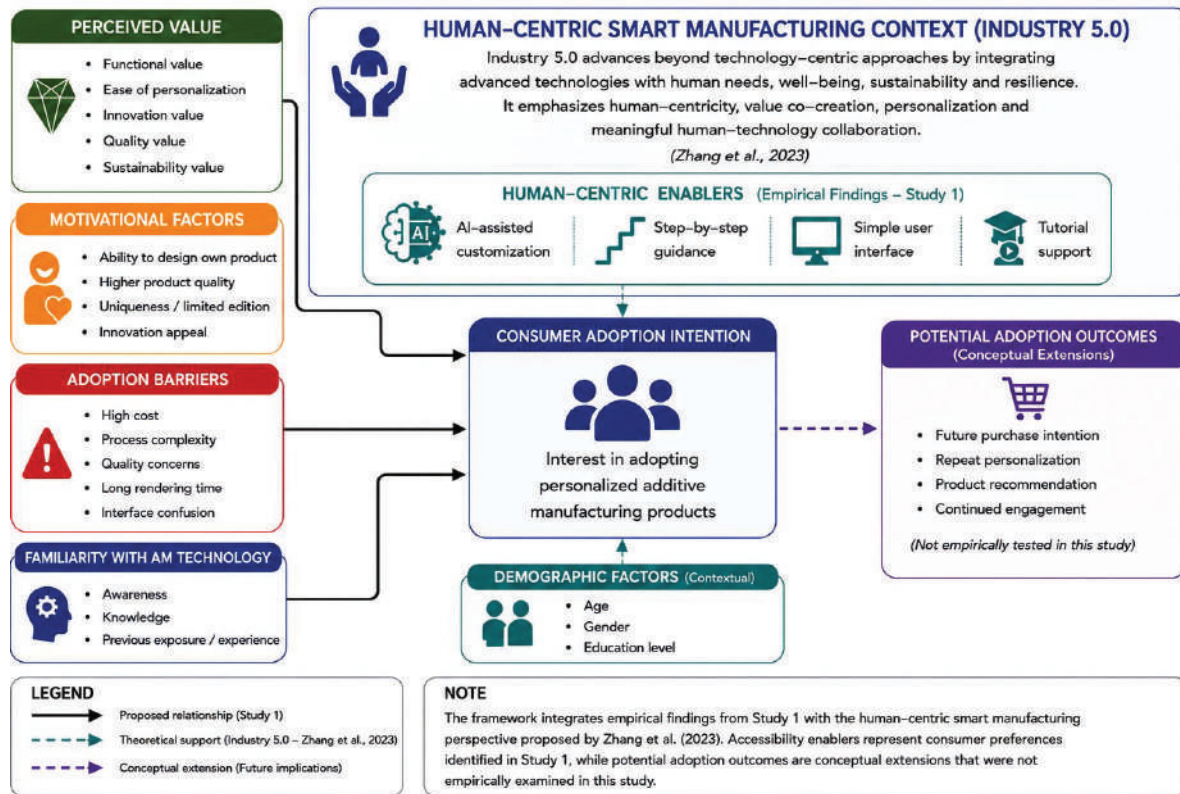


Figure 1. Proposed Consumer-Oriented Conceptual Framework for the Adoption of Personalized Additive Manufacturing Products. (Source: Developed by the authors through literature synthesis and informed by the empirical findings of Study 1.)

The framework links perceived value, motivation, adoption barriers, and familiarity with AM technology to consumers' intention to adopt personalized AM products. Demographic characteristics and accessibility support are included as contextual and enabling factors that may shape this intention. The potential adoption outcomes are presented as conceptual extensions for future research and were not empirically examined in the present study.

Methodology

A quantitative cross-sectional survey was used to examine consumers' perceptions of personalized additive manufacturing products. Participants were recruited through non-probability convenience sampling with voluntary self-selection. The questionnaire was shared through social media and online communities related to 3D printing and AM. Individuals with different levels of AM familiarity and experience were eligible to participate voluntarily, and all responses were treated confidentially. After incomplete or inconsistent responses were screened, 100 valid cases remained for analysis in IBM SPSS Statistics. Descriptive statistics and multiple response analysis were used to identify the most frequently selected responses. Pearson's chi-square test examined associations between demographic characteristics, familiarity, and consumer interest. Spearman's rank-order correlation assessed the strength and direction of the relationship between familiarity and interest. Statistical significance was set at $p < 0.05$.

Results and Discussion

The results show that respondents considered both the expected benefits of personalization and the effort required to obtain them. Respondents tended to value the practical benefits of personalization, but their interest was weaker when the process involved greater cost,

complexity, or uncertainty. Figure 2 groups the descriptive results into four dimensions: perceived value, motivation, adoption barriers, and accessibility preferences.

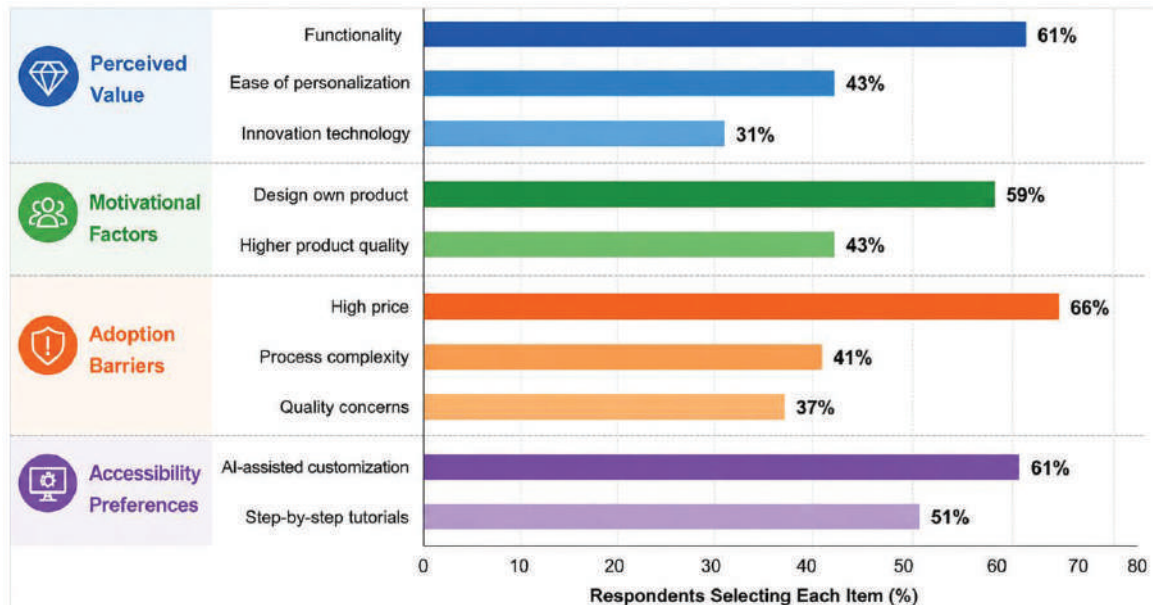


Figure 2. Summary of Key Consumer Adoption Dimensions
 Note: N = 100; multiple responses were allowed.

The survey responses indicate that consumers were more interested in personalized AM when the experience offers practical value and remains easy to navigate, while interest may decline when personalization involves additional cost, effort, or doubt about the product. Within the perceived value dimension, functionality was the most frequently selected value factor (61%), followed by ease of personalization (43%) and innovation (31%). This pattern indicates that respondents placed greater emphasis on product usefulness and a manageable design process than on novelty alone. Previous studies have also reported that personalized product value depends on both the final product and the quality of the customization experience [1], [6], [7]. The opportunity to design a product according to personal preferences was the strongest motivation (59%), followed by expectations of higher product quality (43%). This pattern suggests that respondents valued both the final product and their involvement in shaping it. This pattern is consistent with the role of co-creation, individual expression, and user participation in personalized product experiences [3], [4], [7].

Price was the most common barrier, selected by 66% of respondents. Process complexity (41%) and product-quality concerns (37%) were also reported. Interest in personalized AM may therefore weaken when consumers anticipate higher costs, greater effort, or uncertainty about the outcome. Similar value–effort concerns have been reported in studies of mass customization and 3D-printing adoption [6], [8], [9].

AI-assisted customization was selected by 61% of respondents, while 51% preferred step-by-step tutorials. These preferences show that respondents wanted more support during design. However, the study did not test the effectiveness of an operational AI platform. Guided recommendations and simplified interfaces may reduce the technical demands placed on non-designers [5], [6]. This type of support fits a human-centered manufacturing approach because it places user needs and abilities alongside production requirements [10]. To examine whether demographic characteristics and familiarity with AM technology were associated with consumer interest, Pearson’s chi-square test and Spearman’s rank-order correlation were conducted. The results are presented in Table 1.

Table 1. Summary of Inferential Statistical Results

Relationship	Test	Statistic	p-value	Decision
Gender × Interest	Chi-square	8.571	0.073	Not significant
Age × Interest	Chi-square	29.318	0.022	Significant
Familiarity × Interest	Chi-square	18.484	0.018	Significant
Familiarity ↔ Interest	Spearman	$\rho = 0.272$	0.006	Significant, weak positive

(Source: Authors' survey analysis (N = 100). Significance level: $p < 0.05$.)

Within the study sample, age group and familiarity with AM technology were significantly associated with consumer interest, whereas gender was not. Spearman's rank-order correlation also showed a significant but weak positive relationship between familiarity and interest ($\rho = 0.272$, $p = 0.006$). Although respondents who were more familiar with AM tended to report stronger interest, the small correlation indicates that familiarity explains only part of the response. Users may still hesitate when product value is unclear or the personalization process appears difficult to manage [1], [7], [9].

From an industry perspective, the results highlight four areas for improvement: price transparency, fewer customization steps, clearer information about product quality, and additional support during design. AI-based guidance may be useful, particularly for first-time users, but it should reduce rather than add to the complexity of the process. Earlier AM studies also report process complexity, limited knowledge, technological uncertainty, and implementation readiness as barriers to broader adoption [11], [12].

Future university–industry collaboration could divide responsibilities according to expertise. Universities could examine consumer needs and test interface usability, while industry partners could provide manufacturing knowledge, digital platforms, and real production settings. However, this collaborative pathway is presented as an implementation implication and was not directly examined in the current study.

Conclusion

Consumer interest in personalized AM was mainly associated with practical value and participation in design. Functionality received the highest response (61%), while designing a product according to personal preferences was the main motivation (59%). At the same time, high cost (66%) and process complexity (41%) reduced the appeal of personalization. Respondents also showed a preference for AI-assisted customization and guided design features, particularly where these tools could make the process easier for users with limited design experience. Familiarity with AM had a positive but weak relationship with consumer interest ($\rho = 0.272$, $p = 0.006$), showing that knowledge of the technology alone may not be enough to encourage adoption. Consumers are more likely to participate when the product offers a clear benefit and the design process does not require excessive technical effort. The next stage of this research will examine whether direct involvement in product design and production changes consumer perceptions, engagement, and willingness to adopt personalized AM products.

Acknowledgement

The authors would like to thank the Ministry of Higher Education of Malaysia and Universiti Teknikal Malaysia Melaka for funding this research through the Fundamental Research Grant Scheme (FRGS), no. FRGS/1/2024/SS02/UTEM/02/3.

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Axiomatic Design Framework for a Smart 3D-Printed Stingless Bee Hive with IoT Integrated Monitoring System

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Abstract — The rising demand for stingless bee (kelulut) products has driven the need for more efficient hive management systems to improve both colony welfare and honey yields. In Malaysia, traditional wooden hives often suffer from moisture buildup, pest infestations, structural decay, and unstable internal climates. Furthermore, while Internet of Things (IoT) monitoring systems exist, they are typically standalone setups rather than seamlessly integrated components of the hive architecture. This study introduces a smart, 3D-printed stingless bee hive developed using Axiomatic Design (AD) principles. By translating customer needs into precise functional requirements and design parameters, we systematically engineered a durable, modular, and easily monitorable hive structure. The prototype was fabricated using polylactic acid (PLA) via fused deposition modeling (FDM) and features a built-in IoT-enabled load cell for continuous monitoring. Field tests confirmed strong colony acceptance, robust structural integrity, and reliable remote data tracking. Ultimately, this integrated approach highlights the value of combining Axiomatic Design, additive manufacturing, and IoT for the future of precision beekeeping.

Introduction

Stingless beekeeping has emerged as an important agricultural activity in Malaysia, driven by growing demand for kelulut honey and its well-documented health and medicinal properties. Despite this commercial interest, the majority of beekeepers continue to rely on conventional wooden log hives, which are inherently vulnerable to moisture damage, fungal growth, pest infestation, and structural deterioration under Malaysia's tropical climate. Transitioning to modern, engineered hive designs is therefore essential—not only to mitigate these persistent risks, but also to enhance honey yield and support a more sustainable, productive beekeeping industry in Malaysia [1].

One of the central challenges in stingless beekeeping is colony loss and unproductive hives, which are frequently linked to poor habitat quality and the difficulty of monitoring colony health without physical intrusion. Conventional inspection requires physically opening the hive, which disrupts the internal microclimate, exposes bees to external stresses, and can trigger colony migration or dispersal. While recent work has demonstrated the value of both 3D-printed hive structures and IoT-based remote monitoring, these advances have largely proceeded on separate approach. Milovanovic et al. [2] developed a standalone IoT monitoring system using an ESP32 microcontroller with temperature, humidity, and weight sensors, enabling real-time, non-invasive tracking of colony health parameters. Ahmad Kamal et al. [3] took a complementary approach, implementing a MATLAB-based image processing pipeline with an ESP8266 module to monitor bee ingress and egress at the hive entrance as an indirect indicator of colony productivity. In both cases, however, the monitoring hardware remained an external attachment to an unmodified hive, rather than a deliberately integrated component of a purpose-built smart structure.

Addressing this gap calls for a holistic approach in which the physical hive and its monitoring architecture are co-designed from the outset. This study therefore demonstrates a systematic methodology for developing a smart, 3D-printed stingless bee hive that seamlessly integrates IoT monitoring capability, guided throughout by the AD framework.

Methodology

Axiomatic Design Framework

This study employs the AD framework to systematically structure the design process and improve overall development efficiency. The framework provides a rational and logical foundation for translating high-level design intent into actionable engineering specifications [4], and its applicability spans diverse fields including software engineering, manufacturing, healthcare services, and electronic commerce. The framework originates from the identification of Customer Needs (CNs) and proceeds through three hierarchically linked domains, as illustrated in Figure 1. In each adjacent domain pair, the left domain defines the desired outcomes, while the right domain specifies the designer's proposed means of achieving them. Functional Requirements (FRs) capture what the customer expects the system to accomplish. Design Parameters (DPs) define the physical or engineering decisions through which each FR is satisfied. Finally, process variables (PVs) govern how the system is realized based on the defined DPs.

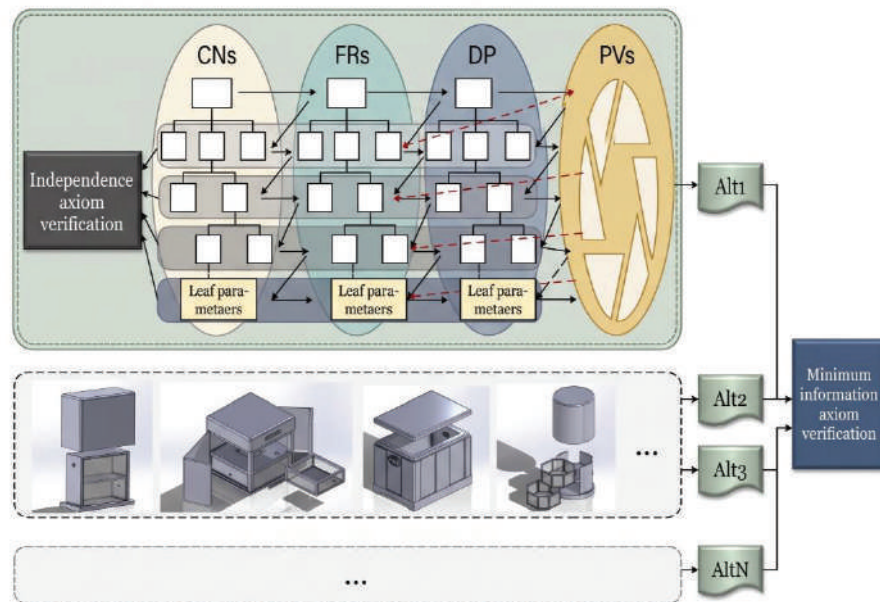


Fig. 9 AD Framework for Stingless Beehive Design

Drawing on the shortcomings of traditional wooden log hives, five Customer Needs were identified and systematically mapped to Functional Requirements and Design Parameters, as summarised in Table 1. The AD process rests on two governing principles: (1) the Independence Axiom, which requires that each FR remains functionally independent—a change to a single DP should satisfy only its paired FR without affecting others; and (2) the Information Axiom, which prescribes minimising the information content of the design. Based on these principles, the design matrix generated through domain mapping was verified to be independent rather than coupled. The CAD software was used to produce the initial hive designs, ensuring that each selected DP effectively addressed its corresponding FR

Table 1. Mapping of Customer Needs to Functional Requirements and Design Parameters

Customer Needs (CNs)	Functional Requirements (FRs)	Design Parameters (DPs)
Strong hive structure	Enhance structural strength	Fully 3D-printed PLA structure
Pest and moisture resistance	Reduce environmental damage	Modular non-porous enclosure
Easy/constant monitoring	Allow ongoing observation	IoT-enabled load cell system
User-friendly maintenance	Facilitate easier handling	Detachable assembly design
Colony well-being	Stable biological environment	Optimized internal compartment

Hive Development and IoT Monitoring System

To address the fundamental limitation of monitoring honey productivity without hive intrusion, a weight-based IoT approach was integrated directly into the hive structure. The finalised hive was fabricated using FDM 3D printing with PLA filament—a lightweight, durable, and environmentally benign alternative to traditional wooden logs. Transparent acrylic side panels were incorporated to permit non-invasive visual inspection of colony activity, eliminating the need to physically open the hive for routine observation. Then, a 5 kg load cell sensor, paired with an HX711 signal-conditioning amplifier, was mounted beneath the 3D-printed base to satisfy DP requirement. The sensor communicates with a NodeMCU ESP8266 microcontroller, which transmits weight data wirelessly to a cloud-based Blynk dashboard in near real time, as illustrated in the system block diagram in Figure 2. This architecture enables beekeepers to remotely track honey accumulation, foraging intensity, and colony growth trends via a smartphone application—ensuring zero physical disturbance to the colony.

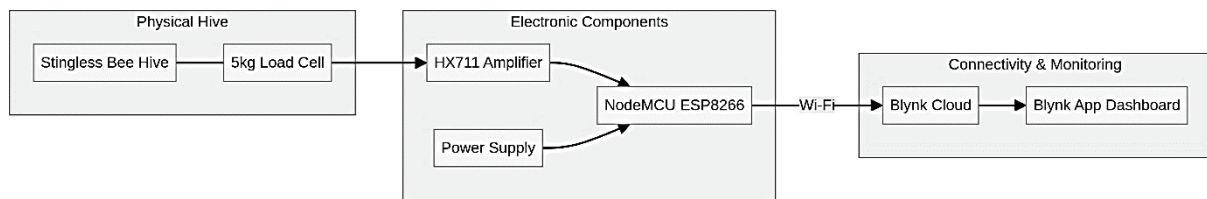


Fig. 2. Block diagram of the integrated IoT monitoring system

Results and Discussion

Fabricated Smart Hive

The AD methodology has effectively transformed the digital CAD model into a high-performing physical prototype, demonstrating its efficacy in practical applications. The detachable architecture heavily simplified assembly processes and routine maintenance while ensuring excellent structural rigidity. Furthermore, utilizing PLA for the 3D-printed components yielded a hive that is substantially lighter yet robust enough for field deployment. The use of non-porous materials in hive construction can minimize moisture retention, thereby lowering the chances of fungal growth and pest infestations, which are common issues in traditional wooden hives. However, using recycled plastic for beehives is not suggested. The unknown origin of the recycled polymers means they are not approved for food contact, which could contaminate and compromise the purity of the honey [5].

IoT Monitoring Performance and Hive Evaluation.

Field deployment of the smart hive confirmed reliable and continuous IoT performance throughout the evaluation period. Hive weight data were transmitted to the Blynk cloud dashboard at regular intervals, providing a near-real-time view of colony activity without physical intrusion. The load cell system captured gradual weight increases during active foraging hours—consistent with typical stingless bee foraging cycles—and stable overnight readings reflecting reduced activity and accurate baseline measurements. The built-in sensor demonstrated sufficient sensitivity to resolve incremental changes in honey accumulation and nest material deposition, allowing cumulative productivity trends to be tracked over days and weeks. The results agree with those reported by Rosli et al. [6] and Khairul Anuar et al. [7], who documented comparable load-cell weight fluctuations in Blynk- and Firebase-connected monitoring systems. These weight profiles, together with the field deployment images shown in Figure 3, demonstrate the practical utility of the system for continuous, remote hive management. By removing the need for frequent manual inspections, the IoT architecture significantly reduced colony stress, helped maintain stable internal conditions, and improved overall farm management efficiency [8]. Field observations further confirmed strong colony

acceptance of the 3D-printed structure; active nest construction was observed shortly after colony introduction, verifying the biological compatibility of PLA polymer with stingless bee behaviour. Compared with traditional wooden log hives, the prototype demonstrated clear advantages in structural robustness, ease of maintenance, and data-driven monitoring capability.

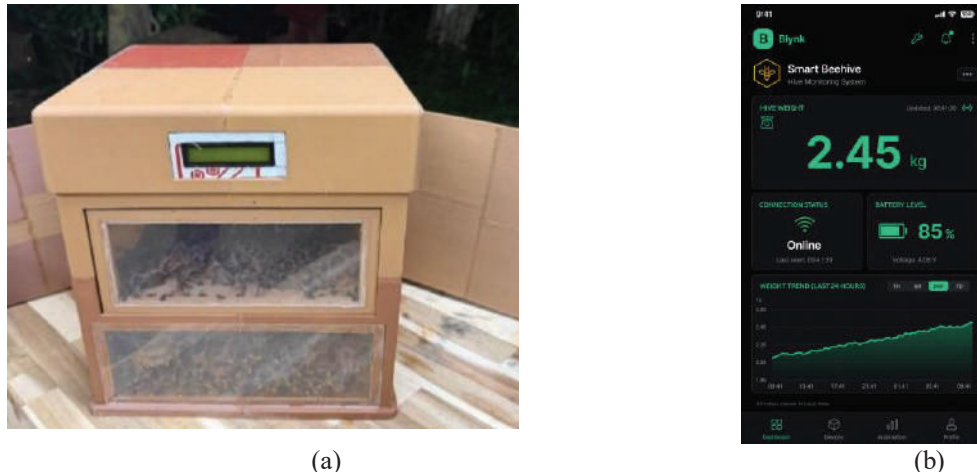


Fig. 3. (a) Deployed 3D-printed smart hive during field evaluation and (b) real-time weight monitoring data on the Blynk cloud dashboard

Conclusions

This study presents a successfully validated, smart 3D-printed stingless bee hive developed through the systematic application of the AD framework. By mapping Customer Needs through Functional Requirements to Design Parameters, the approach effectively addressed the core limitations of conventional wooden log hives. The resulting prototype—fabricated from PLA via FDM and equipped with an IoT-enabled real-time weight monitoring system—achieved a hive that is structurally robust, lightweight, and operationally user-friendly. Field deployment confirmed excellent colony acceptance, reliable IoT performance, and practical improvements in hive management. This work demonstrates the value of integrating structured design methodologies with additive manufacturing and IoT sensing, establishing a replicable model for the development of future precision beekeeping systems. For future work this study will explore comparative trials across stingless bee species and alternative materials would clarify optimal pairings for commercial meliponiculture.

Acknowledgement

The authors gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) for providing financial support that enabled this research. The institutional resources and funding made possible the experimental investigations, computational infrastructure development, and analytical work presented in this study.

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Digital Transformation, Trust and Customer Loyalty: Evidence from Abu Dhabi's Digital Economy

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Abstract—The rapid growth of Abu Dhabi's digital economy has transformed customer interactions with businesses and public services, making digital experience an important factor influencing customer satisfaction and loyalty. However, a positive digital experience may not be sufficient to sustain loyalty without customer trust in digital platforms. This study examines the mediating role of trust in the relationship between digital experience and customer loyalty in Abu Dhabi's digital economy. Drawing on Relationship Marketing Theory and the Technology Acceptance Model (TAM), the study proposes that digital experience positively influences customer trust, which in turn enhances customer loyalty. The study contributes to the understanding of customer behavior in digitally transformed environments and provides practical insights for organizations and policymakers seeking to strengthen trust and develop sustainable customer relationships in the UAE's digital marketplace.

Introduction

The global shift toward digital transformation is reshaping industries by integrating advanced digital technologies into business operations, customer interactions, and value delivery[1]. Digital transformation refers to the process of embedding digital tools and strategies into organizational processes, enabling businesses to enhance efficiency [2], foster innovation, and deliver superior customer experiences[2]. Abu Dhabi is at the forefront of the United Arab Emirates (UAE) digital transformation, aiming to increase the digital economy's contribution to the national GDP from 11.7% to over 20% within the next decade as shown in Fig. 1. This transformation is characterized by significant investments in AI, digital infrastructure, and customer-centric innovations. As businesses navigate this digital shift, establishing and maintaining customer trust becomes paramount, particularly in fostering loyalty and enhancing the overall customer experience. In Abu Dhabi, digital transformation is a key pillar of the UAE Vision 2030, which aims to position the region as a global leader in technological innovation and economic sustainability [3]. Government initiatives such as Smart Abu Dhabi, digital free zones, and advancements in artificial intelligence (AI), blockchain, and big data are transforming the region into a thriving digital ecosystem [4]. Businesses across sectors banking, retail, logistics, and public services are embracing these changes to meet the evolving expectations of a tech-savvy customer base. In this environment, businesses that focus solely on operational efficiency and personalization through digital transformation risk being outpaced by competitors who also prioritize building trust as a key differentiator. Trust, therefore, emerges as a critical mediator that determines whether customers choose to remain loyal to a particular business or explore alternatives [5]. Figure 1 shows the UAE initiative of increasing the contribution of digital economy to the GDP of the country. As the current contribution at low level.

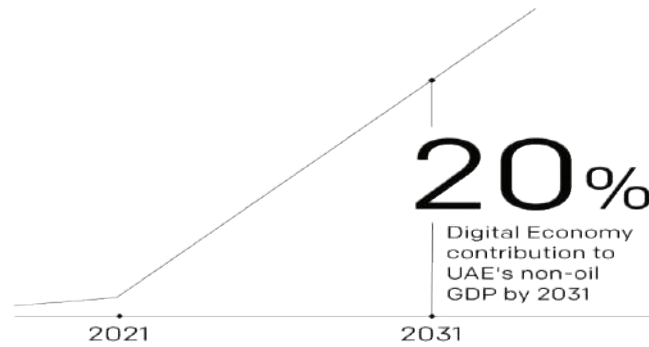


Fig. 10 Digital economy contribution to UAE non-oil GDP
 (Source: UAE Minister of State for Artificial Intelligence (MSAI)(2024))

Accordingly, this study seeks to investigate how digital transformation influences customer trust and customer loyalty among consumers using digital services in Abu Dhabi. The study contributes to digital transformation literature by developing and empirically testing a conceptual model applicable to emerging digital economies while providing practical implications for organizations seeking to improve customer retention through trusted digital services.

Literature Review

Digital transformation represents the integration of digital technologies into all areas of an organization's operations, resulting in fundamental changes to how businesses deliver value to customers and remain competitive in an evolving market [6]. It is more than just the adoption of new tools or platforms; it is a cultural and strategic shift that requires businesses to rethink their processes, customer interactions, and organizational structures. This study categorizes digital transformation across four interlinked factors Technological Enablement, Strategic Alignment, Organizational Readiness, and Trust-Oriented Infrastructure. Each of these dimensions plays a pivotal role in shaping the customer experience and loyalty within Abu Dhabi's digital economy.

Customer loyalty refers to the commitment of customers to consistently engage with a brand or business over time, driven by positive experiences, trust, and emotional connections [7]. Loyal customers are more likely to make repeat purchases, recommend the brand to others, and remain resilient to competitive alternatives [1]. In today's fast-paced digital economy, customer loyalty has evolved beyond mere repeat business; it now encompasses emotional engagement, advocacy, and long-term brand affinity. Customer trust refers to the confidence customers place in a business to fulfill its promises, act ethically, and safeguard their interests. It is a fundamental component of long-term customer relationships, serving as a bridge between satisfaction and loyalty [8]. In the digital economy, trust has become increasingly important as customers interact with businesses through technology-driven platforms and services. The reliance on digital tools for transactions, communication, and data sharing has heightened customer concerns about issues such as data privacy, security, and transparency [1]. Trust ensures that customers feel confident engaging with a business, even in a competitive and complex marketplace, as shown in Table. 1.

Table 1: Summary of Empirical Findings (Synthesis)

Font size	Regular
[10]	Trust mediates between customer value perceptions and loyalty intentions.
[9]	Digital touchpoints enhance CX, but trust is needed for long-term loyalty.
[6]	Ethical AI and transparent data use significantly improve trust scores in digital banks.

Studies have shown that while digital channels improve customer satisfaction, their effect on customer loyalty is mediated by trust [9]. Similarly, [6] demonstrated that ethical AI practices strengthen customer trust in digital banking, which in turn significantly enhances customer retention. This framework provides a strategic roadmap for enterprises in Abu Dhabi to transform customer engagement through trust-centered digital innovation, while promoting sustainability, inclusivity, and cultural alignment, as shown in Fig. 2.

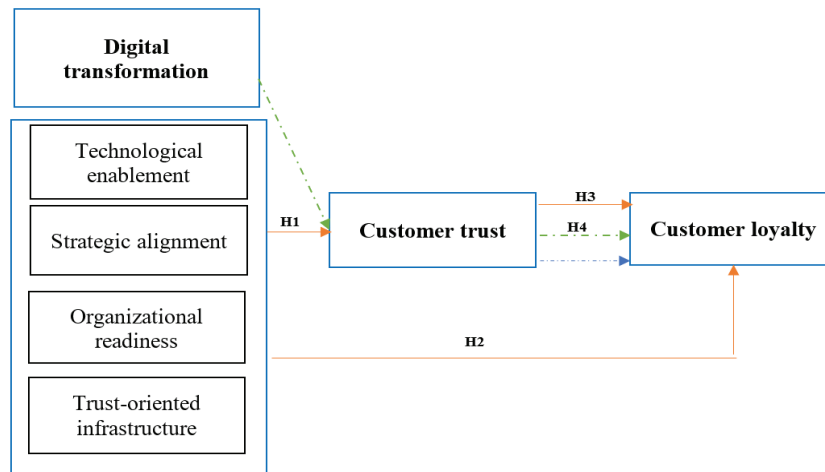


Fig. 2 Research Framework

Methodology

This study will adopt a quantitative research design to examine the impact of digital transformation strategies on long-term customer loyalty, with customer trust serving as a mediating variable. Primary data will be collected through a structured questionnaire distributed to customers using digital services in Abu Dhabi. A purposive sampling technique will be employed to select respondents with experience in digital platforms. Data will be analyzed using Structural Equation Modeling (SEM) to test the proposed relationships among digital transformation, customer trust, and customer loyalty. Ethical principles, including informed consent, confidentiality, and voluntary participation, will be maintained throughout the study.

Results and Discussion

Digital transformation is the main independent variable in the framework, consisting of four enablers: Technological Enablement, Strategic Alignment, Organizational Readiness, and Trust-Oriented Infrastructure [11]. These enablers focus on integrating technologies such as AI, blockchain, big data, and IoT into business operations to improve efficiency and enhance customer-centric services, while ensuring alignment with organizational strategy and readiness for implementation. Customer trust acts as the mediating variable, reflecting customers' confidence in a business's reliability, transparency, and ethical use of data [12]. It is especially important in digital environments where concerns about privacy and security are high, and it strengthens the link between customer experience and loyalty by encouraging repeated engagement. Customer loyalty is the dependent variable and represents customers' long-term commitment to a brand, shown through repeat purchases, advocacy, and emotional attachment [13]. Overall, the framework shows that digital transformation improves customer experience, which builds trust and ultimately leads to loyalty. However, loyalty depends not only on technology adoption but also on strong trust-building practices such as data governance, transparency, and ethical digital use.

Conclusions

The findings indicate that digital transformation does not directly lead to customer loyalty; rather, trust plays a key mediating role in this relationship. Organizations that invest in trust-building practices, including secure data management, ethical use of AI, transparent communication, and personalized services, are more likely to translate digital capabilities into long-term customer loyalty. Thus, trust serves as a critical bridge between digital service delivery and sustained customer commitment. The study therefore recommends that organizations prioritize trust-building strategies alongside digital transformation initiatives to strengthen customer loyalty and develop sustainable customer relationships.

Acknowledgement

The authors would like to thank Universiti Teknikal Malaysia Melaka UTeM for their direct and indirect contributions.

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Development of Framework for Enhancing Material Handling Performance in Plumbing Material Storage Systems by Using Lean Six Sigma

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Abstract— Efficient material handling is essential for ensuring effective inventory management and maintenance operations in building maintenance stores. However, the use of manual inventory management systems has led to inefficiencies, including waiting, motion and inventory waste. This study aimed to identify the current material handling issues, analyse the contributing factors and proposed a framework to enhance the material handling performance in the plumbing material storage system at the Building Maintenance Store, Facility Management Office, Universiti Teknikal Malaysia Melaka (UTeM). A qualitative research approach was adopted through site observation and semi-structured interviews. Lean Six Sigma (LSS) using the DMAIC methodology was applied to this study while the Fishbone Diagram and 5 Why Analysis were used to determine the root cause of the problems. Interview findings indicated that inventory management issues were identified by respondents, making it the most significant factor affecting material handling performance. Therefore, a framework integrating a chatbot, QR code technology and digital inventory database was proposed to improve inventory visibility, reduce material handling waste and support more efficient maintenance operations.

Introduction

Efficient material handling plays an important role in ensuring smooth inventory management and maintenance operations in building maintenance stores. Plumbing spare parts such as pipes, valves, fittings and sanitary components must be stored, identified and retrieved efficiently to support maintenance activities. An effective material handling system reduces searching time, minimises unnecessary movement and improves overall operational performance. However, many maintenance organisations still rely on manual inventory management systems, which often result in poor inventory visibility, inefficient material handling and delays in maintenance work.

Manual inventory practices contribute to several operational problems, including waiting, motion and inventory waste. Store personnel often spend excessive time locating required materials due to inadequate inventory records and the absence of a systematic tracking system. These inefficiencies reduce productivity, increase labour effort and may affect the quality of maintenance services. Therefore, improving material handling performance through a more systematic inventory management approach has become an important issue in building maintenance operations.

Lean Six Sigma (LSS) provides a structured methodology for identifying process inefficiencies and developing continuous improvement strategies. The DMAIC (Define, Measure, Analyse, Improve and Control) framework is widely used to identify root causes and implement effective improvement solutions. In this study, the Fishbone Diagram and 5 Why Analysis were employed to determine the factors contributing to poor material handling performance and to identify the primary root cause.

Therefore, this study aimed to identify the current material handling issues, analyse the contributing factors and propose a framework to enhance material handling performance in the plumbing material storage system at the Building Maintenance Store, Facility Management Office, Universiti Teknikal Malaysia Melaka (UTeM). The proposed framework integrates a

chatbot, QR code technology and a digital inventory database to improve inventory visibility, reduce material handling waste and support more efficient maintenance operations.’

Methodology

A qualitative research approach was adopted to investigate the material handling performance of the plumbing material storage system at the Building Maintenance Store, Facility Management Office, Universiti Teknikal Malaysia Melaka (UTeM). Site observation and semi-structured interviews were conducted to identify the current issues of material handling practices. Figure 1 below illustrates the DMAIC framework adopted in this study.

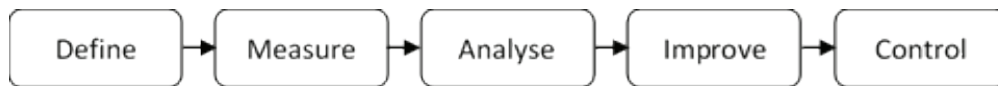


Fig. 11 DMAIC framework

The Lean Six Sigma (LSS) methodology based on the DMAIC (Define, Measure, Analyse, Improve, and Control) framework was employed as the main problem-solving approach [1]. During the Define phase, the existing material handling process, research objectives and project scope were identified. In the Measure phase, qualitative data were collected through site observations and semi-structured interviews. Qualitative research aims to understand the situation in the storage, people experiences and the reasons behind a particular issue [2]. The Analyse phase applied the Fishbone Diagram (Ishikawa Diagram) and 5 Why Analysis to determine the root causes of the identified problems. The Fishbone Diagram analysis was used to identify the potential problem with the root cause and focused on four main categories, namely Man, Method, Material, and Machine (4M) [3]. The findings obtained from these tools were used to identify the primary factor contributing to poor material handling performance. In the Improve phase, a framework integrating a chatbot, QR code technology and a digital inventory database was proposed to improve inventory visibility, reduce material handling waste, and enhance the efficiency of material retrieval and inventory management. Finally, the Control phase incorporated the Plan–Do–Check–Act (PDCA) cycle to support the continuous improvement of the proposed framework [4].

Results and Discussion

The current material handling process at the Building Maintenance Store consisted of receiving material request, checking inventory availability, issuing materials, updating inventory records and delivering the requested plumbing materials to the maintenance team. Besides that, site observation and interviews indicated that most inventory activities were performed manually using inventory record forms. As a result, store personnel experienced difficulties in locating materials, updating stock records and verifying inventory availability. These issues increased the material retrieval time and reduced the overall efficiency of maintenance operations.

Semi-structured interviews were conducted with the Store Department and Plumbing Maintenance Team to identify the current material handling issues in the plumbing material storage system. The findings revealed that the inventory management system was the most frequently highlighted issue with (100%) of respondents identifying it as a major concern. This was followed by storage layout (71.4%), communication (57.1%) and transportation and equipment (42.9%). These findings indicate that the inventory management system was the primary issue affecting material handling performance. Therefore, further analysis using the Fishbone Diagram and 5 Why Analysis was conducted to identify the root cause.

The qualitative findings identified three major lean wastes affecting the material handling process, namely waiting, motion and inventory. These findings were consistent with the lean

principles which emphasis the elimination of non-value added (NVA) activities to improve operational efficiency [5]. Table 1 shows the waste identification from the site observations.

Table 1: Waste identification

No	Wastes	Situation
1.	Waiting	Waiting occurs when plumbing maintenance staff need to wait for store personnel for checking the availability of item due manual inventory checking.
2.	Motion	Motion waste happens when staff spend extra time searching for specific plumbing items on the rack.
3.	Inventory	Inventory waste occurs when manual stock updates result in inaccurate inventory records and uncertainty regarding item availability

The Fishbone Diagram and 5 Why Analysis were used to identify the root cause of material handling issues. The analysis considered four categories namely Man, Method, Material and Machine (4M). The analysis indicated several contributing factors including the lack of a systematic inventory recording process, difficulty in locating materials, insufficient inventory and inefficient material retrieval activities. Subsequently, the 5 Why Analysis was conducted to determine the underlying root cause of the identified problems. The analysis revealed that the inventory management system issues were the primary root cause affecting material handling performance. Manual inventory recording reduced inventory visibility, prolonged material searching time and contributed to wastes which is waiting, motion and inventory. Similar studies have reported that an effective inventory management system is essential for improving inventory control and operational efficiency [6].

Table 2: Why analysis

Problem	Inefficient Material Handling
Why 1	Why was material handling inefficient? Because there was no inventory tracking system.
Why 2	Why was there no inventory tracking system? Because there was no barcode scanning system.
Why 3	Why was there no barcode scanning system? Because the store did not have a computerized inventory management system.
Why 4	Why did the store not have a computerized inventory management system? Because the inventory records were updated manually.
Why 5	Why were inventory records updated manually? Because the store still relied on a manual inventory management system instead of a digital inventory system,
Root Cause	Reliance on Manual Inventory Management System

Based on the identified root cause, a framework consisting of a chatbot, QR code technology and digital inventory database was proposed to improve material handling performance. The chatbot facilitates communication between the maintenance team and store personnel while the QR code and digital inventory database improve the material identification and inventory management. The proposed framework is expected to reduce the waiting, motion and inventory waste.

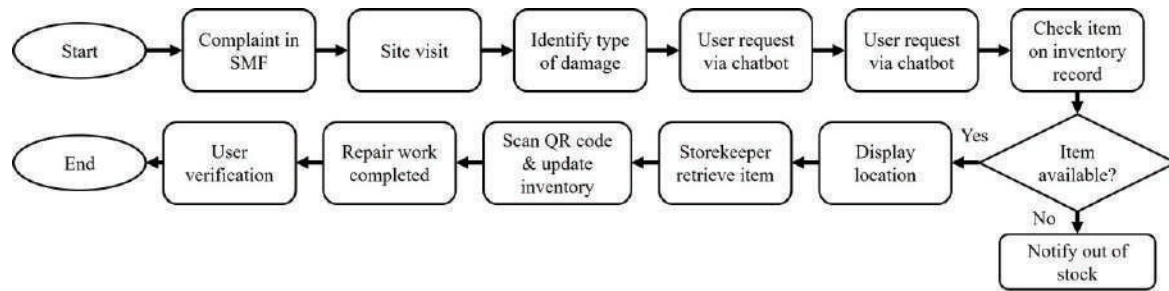


Fig. 2 Proposed framework

The proposed framework is expected to improve the stock verification, material retrieval, inventory accuracy and overall inventory management through the integration of a chatbot, QR code technology and digital inventory database. Similar studies have been reported which showed the digital inventory systems will improve inventory visibility, reduce search time [7], support more systematic inventory management and improve management accuracy [8]. Besides that, this digital inventory system also can automatically stock recording and monitoring process [9].

Conclusions

This study identifies the material handling issues in the plumbing material storage system at the Building Maintenance Store, UTeM. The findings showed that the manual inventory management system was the main root cause of waiting, motion and inventory waste. A framework integrating a chatbot, QR code technology and a digital inventory database was proposed to improve material handling performance. However, further studies may validate the proposed framework through practical implementation.

Acknowledgement

The authors gratefully acknowledge the Office of Facility Management, UTeM, for facilitating site access and providing valuable assistance throughout this study.

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Development of Conceptual Lenticular Disc Blade Design for Household LDPE Plastic Bag Shredder using HOQ

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Abstract— Flexible low-density polyethylene (LDPE) has a high elongation and low strength, making it challenging to shred at home. Inadequate cutting efficiency and inefficient shredding of carrier bags and thin film packaging are the results of conventional blades material wrapping and film deflection. This paper is goal is to create the Conceptual Lenticular Disc Blade Design for a home LDPE shredder using the House of Quality (HOQ) approach. 270 respondents in Batam City, Indonesia, were given questionnaires to complete in order to determine user needs and operational difficulties in home plastic shredding. The most important design parameters were found to be blade edge radius (15.08 %), cutting angle (13.11 %), and material toughness (11.65 %) after the data was methodically analyzed. A conceptual single-blade design with a lenticular disc profile, compound cutting edge radii of R34 and R33 mm, an outer disc radius of R38 mm, an inner bore radius of R8 mm, and a rotor stator clearance reference of 7 mm was then created using SolidWorks. In the final design, the edge radius denotes blade sharpness, the lenticular profile determines the effective cutting angle, and the clearance reference enables controlled LDPE cutting. The prioritized HOQ parameters are converted into geometrical features that are clearly visible. Thus, the main result of this study is a user oriented Conceptual Lenticular Disc Blade Design that provides a thorough geometrical basis for subsequent Finite Element Analysis (FEA) evaluation and optimization. In order to enhance shredding performance when designing lenticular blades, the paper demonstrates how the HOQ approach can be applied.

Introduction

Household plastic waste, particularly flexible LDPE in the form of carrier bags, thin films, and wrappers, has become a growing environmental concern in Indonesian cities that are rapidly becoming urbanized, such as Batam [1]. Mechanical shredding is a crucial pre-processing stage for plastic recycling. However, because LDPE's yield strength is only 9–12 MPa and its elongation at break exceeds 400 %, it is inherently difficult to shred. Instead of producing clean fracture, conventional blades result in rotor wrapping and elastic film deflection [2], [3]. Blade geometries meant for rigid plastics like PET and HDPE are therefore unsuitable for LDPE bags without deliberate geometric modification [4]. Previous blade design studies have examined variables like cutting angle and edge radius independently in the absence of an integrated user requirement framework for flexible LDPE processing [4], [5].

The House of Quality (HOQ) method offers a methodical way to convert household user requirements into technical parameters that are prioritized [6]. Blade edge radius (15.08 %), cutting angle (13.11 %), and material toughness (11.65 %) were found to be the three highest priority parameters in a previous study [7] that used Quality Function Deployment (QFD)-House of Quality (HOQ) on data from 270 Batam City respondents. In order to provide an explicit geometrical foundation for future FEA evaluation and optimization of household LDPE shredding performance, the current paper converts these HOQ priorities into a full parametric Computer Aided Design (CAD) geometry of a conceptual lenticular disc blade.

Methodology

A sequential design approach was used in this investigation. Initially, questionnaires were given to 270 household respondents in Batam City, Indonesia, in order to gather user

requirements. Blade edge radius, cutting angle, and material toughness were identified as the top three priorities when the HOQ method was used to convert user requirements into technical blade parameters [7]. After that, these parameters were directly mapped to the geometric characteristics of a SolidWorks model of a single lenticular disc blade.

Because the intersection of its two curved surfaces results in a progressive slicing action along the cutting height, the lenticular disc profile was chosen to reduce the elastic deflection of LDPE film prior to fracture initiation [5]. The compound cutting edge geometry corresponds to the edge radius of HOQ Rank 1. The effective cutting angle is governed by the lenticular curvature (HOQ Rank 2). HOQ Rank 5 is addressed by the rotor-stator clearance of 7 mm, which is computed as housing working depth minus shaft height minus outer blade radius ($85 - 40 - 38 = 7$ mm), as illustrated in Fig. 1.

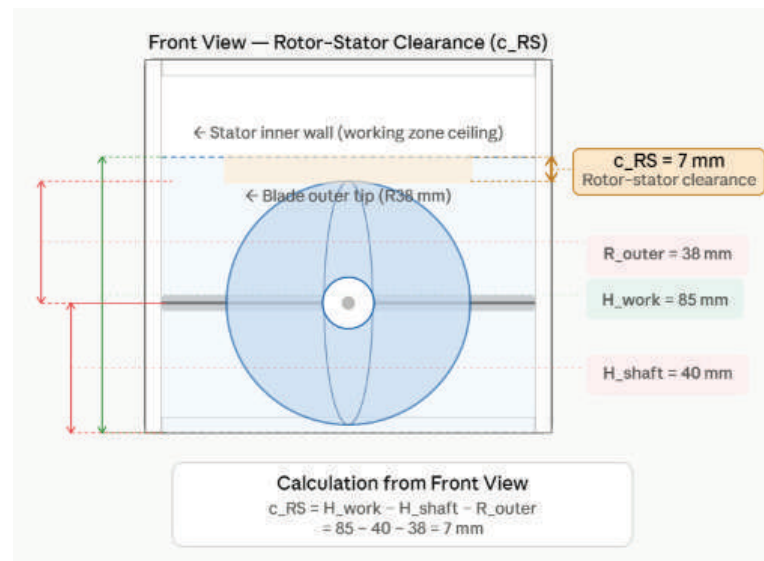


Fig. 1 Rotor–stator clearance [8]

Results and Discussion

The study's main output is a thorough conceptual single lenticular disc blade geometry made in SolidWorks. Figure 2 displays the proposed blade's engineering drawing along with its important measurements. The top three HOQ parameters are directly encoded in the blade geometry as explicit geometrical features.

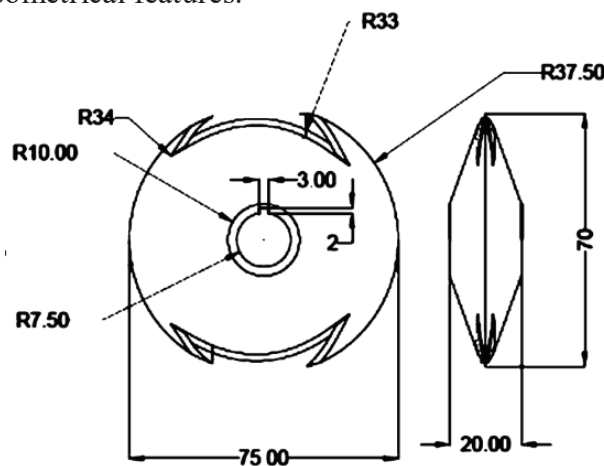


Fig. 2 Engineering drawing of conceptual lenticular disc blade design

The lenticular disc blade design attains complete traceability from specific blade dimensions to household user requirements. The compound cutting-edge geometry uses a

primary radius of R34 mm to concentrate contact stress at the blade tip for LDPE film fracture initiation for HOQ Rank 1 (blade edge radius, 15.08 %) and a relief radius of R33 mm to prevent severe edge damage under cyclic loading [5], [9]. The design of shredder blades for flexible film materials is in line with this dual radius geometry. The cutting envelope inside the 245 mm housing is defined by the outer disc radius of R38 mm and the disc span of 75 mm, giving home LDPE carrier bags enough cutting surface area.

The lenticular disc profile was selected for HOQ Rank 2 (cutting angle, 13.11 %) because the curved surface intersection creates a progressive shear action along the 70 mm cutting height, reducing LDPE film deflection prior to fracture [3]. Unlike flat or V-profile blades, which apply direct compression to materials with elongation at break greater than 400 %, the lenticular geometry guides the LDPE film into a controlled cut [2]. Uncut LDPE film cannot escape the cutting zone during shredding thanks to the rotor stator clearance of 7 mm, which addresses HOQ Rank 5 (10.63 %).

In flexible LDPE film, a primary radius of R34 mm concentrates contact stress at the blade tip to cause fracture, whereas a relief radius of R33 mm stops significant edge chipping under repeated loading [5]. The first and most crucial HOQ parameter, the blade edge radius (15.08 %), is implemented using this compound cutting-edge geometry. LDPE bags are less likely to deflect and wrap around the blade when the second HOQ parameter, the cutting angle (13.11 %), is incorporated into the lenticular disc profile. This produces a progressive shear action instead of direct compression [3]. During operation, the rotor-stator clearance of 7 mm (HOQ Rank 5, 10.63 %) keeps unprocessed LDPE film from escaping the cutting zone and prevents metal-to-metal contact. Table 1 provides a summary of the entire blade geometry.

Table 1. The conceptual lenticular disc blade is key geometric parameters

No.	Parameter	Symbol	Value	Unit	HOQ Priority
1	Outer disc radius	R_outer	38	mm	—
2	Cutting-edge radius (primary)	r_edge	34	mm	Rank 1 (15.08%)
3	Cutting-edge relief radius	r_relief	33	mm	Rank 1 (15.08%)
4	The radius of the bore in the inner hub	R_bore	8	mm	—
5	Outside radius of the hub	R_hub	10	mm	—
6	Inner fillet radius	R_fillet	7	mm	—
7	Overall disc span	W_disc	75	mm	Rank 2 (13.11%)
8	Cutting the height of the profile	H_cut	70	mm	—
9	Rotor–stator clearance (calc.)	c_RS	7	mm	Rank 5 (10.63%)

Table 2 illustrates how each user requirement from the QFD analysis is implemented as an explicit blade design feature by mapping the HOQ parameter to geometry. Unlike trial and error blade development, each lenticular disc blade geometrical decision is backed by a measurable user priority [6, 7]. The HOQ-based design approach is main contribution is this traceability.

The lenticular disc blade geometry directly and traceably links explicit blade dimensions and HOQ ranked household user requirements, as shown in Tables 1 and 2. Table 1 is compound edge radii (R2+R1 mm) and disc outer radius (R38 mm) define the cutting zone. Table 2 provides full traceability from user requirements to blade design by confirming that every HOQ ranked parameter corresponds to an explicit geometric feature.

Table 2. The conceptual lenticular disc blade's HOQ parameter-to-geometry mapping

Rank	HOQ Parameter	Geometric Feature	Design Rationale for LDPE
H3 (1st)	Blade edge radius (15.08%)	Compound edge: R34 mm primary + R33 mm relief	Relief prevents chipping under cyclic loading; sharp tip initiates LDPE fracture [5]
H1 (2nd)	Cutting angle (13.11%)	Lenticular disc profile and curvature	The deflection of LDPE films before fracture is reduced by progressive shear action [3, 4]
H12 (3rd)	Material toughness (11.65%)	Material selection for blades (S45C/SKD-11)	found to be a crucial factor; material comparison is saved for the FEA stage
H15 (5th)	Rotor–stator clearance (10.63%)	Based on housing geometry, c_RS = 7 mm	prevents metal-to-metal contact and keeps the LDPE film in the cutting zone [9]

The disc outer radius (R38 mm) and compound edge radii (R34 mm+R33 mm) define the cutting zone, and the 7 mm clearance controls LDPE engagement. The final result is an easy to use parametric CAD blade geometry that can be utilized as the geometrical input for additional FEA simulation and cutting performance optimization for LDPE plastic bags used in homes.

Conclusions

This study used the House of Quality (HOQ) method to develop a conceptual lenticular disc blade design for a household LDPE plastic bag shredder. Three key outcomes were delivered: (i) HOQ analysis of 270 Batam City respondents identified blade edge radius (15.08 %), cutting angle (13.11 %), and material toughness (11.65 %) as the dominant design parameters; (ii) these priorities were translated into a complete single-blade parametric CAD geometry compound cutting edge radii R34mm and R33 mm, outer radius R38 mm, inner bore R8 mm, and rotor stator clearance 7 mm modelled in SolidWorks; and (iii) the geometry constitutes a fully traceable, user oriented basis for subsequent FEA evaluation and optimisation of household LDPE shredding performance.

Acknowledgement: The authors express their gratitude to UTeM, Politeknik Negeri Batam, and the 270 Batam City QFD-HOQ participants.

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Analysis of the Productivity of Mechanical and Industrial Engineering Study Programs Using the Data Envelopment Analysis (DEA) Method

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Abstract— This study aims to measure the technical efficiency of five study programs in the Department of Mechanical and Industrial Engineering (DTMI) at Universitas Negeri Malang. Using the non-parametric Data Envelopment Analysis (DEA) method with the Constant Returns to Scale (CRS) model, this research evaluates the ratio of four input variables to four output variables. The computational results indicate that four study programs achieved absolute efficiency (100%), while the Bachelor of Industrial Engineering was identified as inefficient (93.3%) and operated at the Increasing Return to Scale (IRS) phase. Optimizing publication outputs and graduation rates is recommended through a benchmarking strategy.

Introduction

Higher education institutions are required to continuously optimize the Three Pillars of Higher Education (education, research, and community service)[1], [2]. Although external quality assurance systems (such as BAN-PT or LAM Teknik accreditation) can represent macro-level academic quality standards, these instruments often do not provide explicit quantitative metrics regarding the efficiency level of resource utilization relative to specific outputs or the input-output ratio[3], [4]. Therefore, this study aims to precisely evaluate the technical productivity efficiency level in five study programs under the DTMI, Faculty of Engineering, Universitas Negeri Malang, for the 2023 academic year.

Previous literature reviews indicate that Data Envelopment Analysis (DEA)—a non-parametric linear programming technique initially formulated by Charnes, Cooper, and Rhodes (1978)—is a highly robust instrument for dissecting the productivity of Decision-Making Units (DMUs) [5]. Unlike linear regression, DEA does not require a priori weight estimation for each variable. In the context of higher education, productivity is defined as the equilibrium between inputs (human resources, funds) and outputs (graduates, scientific publications), and its measurement has been globally validated, such as universities in China [6], Spanish [7] and other universities [8]. Methodologically, this study applies DEA with the Constant Returns to Scale (CRS) assumption through both input-oriented and output-oriented approaches. Measurements were conducted using DEA Frontier and MaxDEA software[9], [10].

The Research Methodology

This research design utilizes a quantitative analytical approach. The evaluation objects (DMUs) consist of five study programs: Bachelor of Mechanical Engineering Education, Bachelor of Automotive Engineering Education, Bachelor of Mechanical Engineering, Bachelor of Industrial Engineering, and Master of Mechanical Engineering. Data was extracted from internal institutional databases, SINTA, and PDDikti for the year 2023.

The evaluation model is built upon an architecture of two variable groups:

- A. Input Variables: (1) Number of Lecturers, (2) Lecturer-Student Ratio, (3) Number of Funded Researches, and (4) Number of Funded Community Services.
- B. Output Variables: (1) Number of Graduates, (2) Graduates with GPA >3.5, (3) Research Publications, and (4) Community Service Publications.

The linear programming resolution was processed using DEA Frontier software (as a Microsoft Excel add-in module) to simulate the input-oriented approach, and MaxDEA to calculate output-oriented parameters within the bounds of the CRS assumption. Slack value

and target setting analyses were applied to formulate continuous improvement proposals for the inefficient DMU.

Result and Discussion

The performance matrix computation indicates that four out of five study programs successfully achieved an absolute efficiency coefficient (1.00 or 100%). The Bachelor of Industrial Engineering is the only entity that has not operated optimally. A summary of the efficiency results is presented in Table 1.

Table 1: Study Program Relative Efficiency Scores (CRS Model)

DMU Code	Study Program	Efficiency Score	Status
DMU 1	Bachelor of Mechanical Engineering Education	1	Efficient
DMU 2	Bachelor of Automotive Engineering Education	1	Efficient
DMU 3	Bachelor of Mechanical Engineering	1	Efficient
DMU 4	Bachelor of Industrial Engineering	0.933	Inefficient
DMU 5	Master of Mechanical Engineering	1	Efficient

The return to scale analysis proves that the Bachelor of Industrial Engineering (DMU 4) is in the Increasing Return to Scale (IRS) phase. The IRS characteristic confirms the existence of latent capacity where a proportional addition to input factors will trigger a multiplied escalation of output.

The efficiency of DMU 4 (Bachelor of Industrial Engineering) was first evaluated using the input-oriented Constant Returns to Scale (CRS) model in DEA Frontier. In the DEA framework, the relative efficiency of each DMU is evaluated by comparing its combination of inputs and outputs with the best-performing DMUs that form the efficiency frontier. A score of 1 indicates that a DMU is located on the efficiency frontier, whereas a score below 1 indicates relative inefficiency. Based on the DEA Frontier calculation, DMU 4 obtained an efficiency score of 0.933 (93.3%), while the other four study programs achieved a score of 1.00. Thus, DMU 4 was identified as relatively inefficient under the CRS model, indicating that its current combination of inputs and outputs had not reached the benchmark efficiency frontier.

Following the CRS efficiency assessment, the Return to Scale (RTS) result generated by DEA Frontier was examined to determine the scale condition of DMU 4. The DEA Frontier results explicitly classified DMU 4 as having an IRS condition. Therefore, the IRS status was not inferred directly from the 0.933 efficiency score; rather, it was obtained from the separate Return to Scale output accompanying the DEA calculation. The IRS condition indicates that DMU 4 has potential to increase its output at a proportionally greater rate through an improvement or expansion of its operating scale. This interpretation is consistent with the subsequent DEA target analysis, which recommends increasing graduates from 46 to approximately 58, research publications from 26 to approximately 28, and community-service publications from 5 to approximately 9. The DEA Frontier results also identify S1 Mechanical Engineering Education and S1 Mechanical Engineering as benchmark programs with reference contributions of 25.4% and 52.6%, respectively.

Through slack-based target setting computation, the inefficiency of DMU 4 is predominantly caused by an output achievement deficit. The improvement targets mandate:

- A. An increase in graduation volume from 46 to a minimum of 58 students.
- B. An escalation of research publication output from 26 to 28 documents.
- C. An increase in community service publications from 5 to 9 outputs.

To realize these targets, DMU 4 management must conduct proportional benchmarking against superior reference DMUs, namely the Bachelor of Mechanical Engineering (56% reference weight) and the Bachelor of Mechanical Engineering Education (27% reference weight).

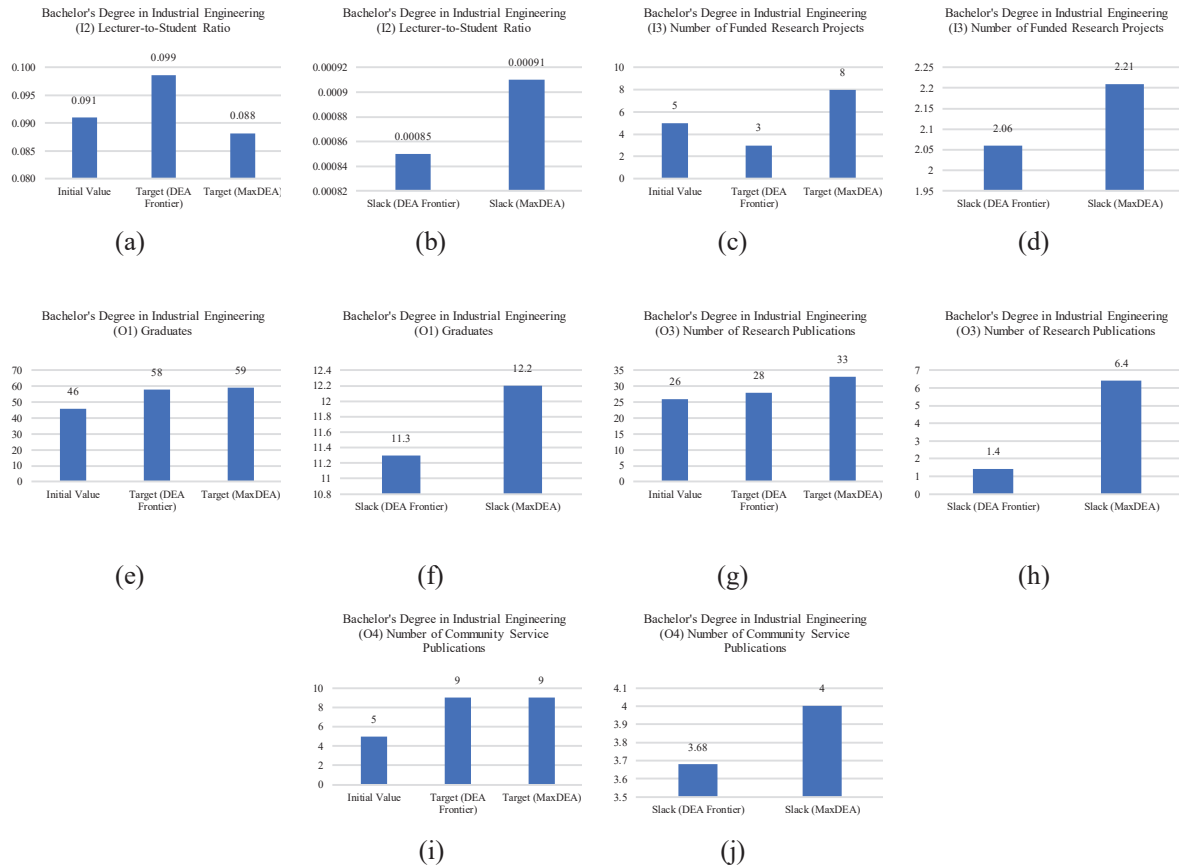


Fig. 1 (a)-(j) Comparison of DEA Frontier vs. MaxDEA

The comparison of the initial value, DEA Frontier, and MaxDEA demonstrates that the inefficiency of the Bachelor of Industrial Engineering program is consistently attributed to a deficit in the achievement of output variables relative to their initial values. Both computational models establish aligned escalation targets for the student graduation volume, specifically increasing it from 46 to a range of 58 to 59 graduates, alongside an increment in community service publications to 9 outputs. However, a discrepancy exists in the projections for the funded research input, as the first calculation reduces the target to approximately three research projects, whereas the MaxDEA model increases it to roughly eight. This discussion emphasizes that to minimize slack values and achieve optimal efficiency, the study program must prioritize robust strategies to stimulate academic outputs rather than focusing on the reduction of instructional resources.

Conclusions

Based on the computations and analysis of the findings above, several conclusions can be drawn as follows:

1. The Data Envelopment Analysis approach has proven precise in mapping academic productivity [6], [7], [8]. As many as 80% of the study programs within the DTMI of Universitas Negeri Malang are able to capitalize resources (inputs) into academic achievements (outputs) at maximum efficiency (100%).

2. An efficiency anomaly occurred in the Bachelor of Industrial Engineering study program, which stalled at 93.3%. The main problem lies in the program's inability to maximize research and community service publication outputs, as well as aggregate student graduation rates, compared to the volume of available resources.
3. Theoretically, this study validates the application of the Increasing Return to Scale (IRS) principle in a developing engineering study program ecosystem. Practically, these measurement results can be implemented as an empirical data foundation for the dean's office and department management in restructuring the allocation of teaching workloads and grant funding.
4. The priority restructuring is not focused on reducing inputs (such as reducing the number of lecturers), but rather on output stimulation strategies. It is recommended that the Bachelor of Industrial Engineering adopt the governance mechanisms (especially graduation acceleration and scientific publication mentoring) from the Bachelor of Mechanical Engineering and the Bachelor of Mechanical Engineering Education through a structured benchmarking method.

Acknowledgement

The authors gratefully acknowledge the financial and technical support provided by Department of Mechanical and Industrial Engineering, Universitas Negeri Malang throughout this research.

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Hybrid Differential Evolution with Insertion-Based Local Search for Flowshop Scheduling Optimization Using D-Optimal Parameter Configuration

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Abstract— The flowshop production system is widely implemented in manufacturing industries and Micro, Small, and Medium Enterprises (MSMEs), where effective job sequencing is essential for minimizing production completion time. The Differential Evolution (DE) metaheuristic algorithm is popularly used due to its strong performance in solving flowshop scheduling problems. However, DE's effectiveness depends heavily on its parameter configuration, and the algorithm is prone to premature convergence. These limitations indicate the need for a systematic parameter configuration strategy and an effective local improvement mechanism. This study aims to enhance DE's performance in minimizing makespan for flowshop scheduling by incorporating a local search procedure while utilizing the D-optimal design method for efficient parameter tuning. The proposed method was evaluated using secondary data from three benchmark cases: 5 jobs and 6 machines; 4 jobs and 6 machines; and 12 jobs and 3 machines. Experimental results demonstrate that the hybrid DE-local search algorithm yields more efficient scheduling and superior makespan values in two out of the three cases compared to previous studies, while maintaining identical performance in the remaining case. The experimental results show that the proposed DE–Local Search approach reduced computational time by 39.57% and 89.42% in two benchmark cases, respectively. Future research should investigate the robustness of this algorithm in large-scale flowshop scheduling problems with a higher number of jobs and machines.

Introduction

The flowshop scheduling problem (FSP) has been extensively investigated due to its significant economic implications and diverse industrial applications across manufacturing sectors and Micro, Small, and Medium Enterprises (MSMEs) [1]. In a typical flowshop system, a set of n jobs must be processed sequentially through m machines in the exact same technological order [2], requiring an exploration of $n!$ possible permutations [2]. Consequently, when the number of machines exceeds three ($m > 3$), the FSP becomes a highly complex combinatorial optimization challenge classified as an NP-hard problem [3], making exact mathematical approaches computationally prohibitive for larger instances [4]. The primary objective in FSP literature is commonly the minimization of makespan (C_{max}), which directly maximizes overall production efficiency and equipment utilization [1, 5].

To address the computational limitations of exact methods, metaheuristic approaches have become the dominant solution paradigm. Various algorithms, such as Particle Swarm Optimization [5], Genetic Algorithms [6], and Simulated Annealing [7], have demonstrated remarkable capabilities in finding near-optimal solutions within reasonable execution times. Rather than merely demonstrating their ability to obtain near-optimal solutions, these approaches exhibit different exploration–exploitation characteristics. For example, GA provides broad exploration through evolutionary operators but requires careful configuration of its genetic operators [6], while PSO can converge rapidly but may suffer from reduced population diversity when particles become concentrated around promising regions [5]. SA provides a mechanism for escaping local optima through probabilistic acceptance of inferior solutions, although its effectiveness is influenced by its cooling strategy and computational requirements [7]. These differences indicate that metaheuristic performance is strongly dependent on the search mechanism and its configuration, motivating the consideration of DE as an alternative population-based approach.

Among these, the Differential Evolution (DE) algorithm stands out due to its simple structure, ease of implementation, and fast convergence [8, 9]. However, a critical drawback

of DE is that its search efficiency depends heavily on its control parameters, namely population size (NP), maximum iterations ($MaxIt$), mutation factor (F), and crossover rate (Cr) [10]. Traditional parameter tuning approaches, such as full factorial designs, suffer from exponential experimental growth [11], whereas adaptive parameter methods often fail to simultaneously calibrate all four critical inputs [12]. Adaptive and self-adaptive DE variants have been developed to reduce the dependency on fixed parameter values by dynamically modifying parameters such as F and Cr during the evolutionary process [12]. These approaches can improve the robustness of DE because parameter values are adjusted according to the search progress rather than being fixed throughout the optimization. Nevertheless, adaptive mechanisms generally depend on predefined adaptation rules, success-history information, or problem-specific strategies. Consequently, they do not necessarily provide a systematic experimental assessment of the joint effects of NP , $MaxIt$, F , and Cr . In this context, adaptive parameter control and experimental parameter configuration address different aspects of the DE parameter problem: adaptive methods modify parameters during the search, whereas experimental design identifies an effective parameter configuration prior to the optimization process. Furthermore, standard DE is highly susceptible to premature convergence, frequently trapping the algorithm in local optima during complex combinatorial searches [10, 13].

To address this limitation, hybrid metaheuristic approaches have incorporated local search procedures to strengthen the exploitation capability of population-based algorithms. In flowshop scheduling, insertion-based local search is particularly suitable because it improves a permutation by relocating a job to another position in the sequence while preserving schedule feasibility. Previous hybrid approaches have shown that local search can refine promising solutions generated by evolutionary algorithms. However, this strategy primarily addresses solution-level exploitation and does not directly resolve the algorithm-level problem of selecting an effective configuration of DE control parameters. Therefore, two distinct but related limitations remain. First, the effectiveness of DE depends on how its control parameters are configured, while existing adaptive and self-adaptive mechanisms do not necessarily provide a statistically systematic calibration of all four parameters considered in this study. Second, even with an appropriate parameter configuration, DE may still experience insufficient exploitation and premature convergence. These observations suggest that parameter configuration and solution refinement should be considered as complementary levels of the optimization process. D-optimal design can address the former by efficiently identifying an informative combination of DE parameters, whereas insertion-based local search can address the latter by refining promising solutions generated during the evolutionary search.

To overcome these dual challenges, this paper presents a novel hybrid approach that significantly enhances the DE algorithm for flowshop scheduling optimization. Instead, this study proposes a systematic two-level optimization framework in which D-optimal experimental design is used for algorithm-level parameter configuration, while insertion-based local search is employed for solution-level refinement. The scientific rationale of this framework is that the two techniques address different sources of performance limitation in DE: D-optimal design determines how the DE search process should be configured, whereas local search improves how promising solutions are subsequently exploited. The scope of this study encompasses two major contributions, beginning with the implementation of a D-optimal design framework for the systematic, efficient, and statistically accurate calibration of all four DE parameters, effectively replacing conventional trial-and-error or heavy factorial designs [14]. Furthermore, it introduces the integration of an insert local search procedure into the DE framework to enhance the algorithm's exploitation capabilities, thereby preventing premature convergence and refining the overall solution quality [13].

Although D-optimal experimental design and local search have individually been investigated in optimization research, their combination in this study is not claimed as novel

merely because two existing techniques are integrated. Instead, the contribution lies in examining their complementary roles at two different levels of the DE framework—statistical algorithm configuration and solution-level refinement—and evaluating whether this interaction can improve the performance of DE for combinatorial FSP. This perspective distinguishes the proposed framework from studies that focus solely on adaptive parameter control or solely on hybrid local-search mechanisms.

The proposed methodology was rigorously evaluated using secondary benchmark datasets representing small-to-medium manufacturing configurations, specifically: 5 jobs with 6 machines, 4 jobs with 6 machines, and 12 jobs with 3 machines. The primary performance indicator is the minimization of the total makespan.

Experimental results demonstrate that the proposed hybrid DE-local search algorithm, powered by D-optimal parameter configurations, delivers superior performance. The proposed method achieved lower makespan values in two out of the three benchmark cases compared to previous literature, while successfully matching the optimal bound in the remaining instance. This underscores the robust synergy between D-optimal statistical design and hybrid local search strategies in elevating metaheuristic performance for combinatorial optimization.

Methodology

The proposed hybrid metaheuristic algorithm integrates standard Differential Evolution (DE) with an insert local search procedure to optimize the flowshop scheduling problem (FSP) with the objective of minimizing makespan (C_{max}). The algorithm executes sequentially through:

- (1) initialization of candidate solutions, $x_{i,j,0} = lb_j + rand_j(0,1)(ub_j - lb_j)$,
 - (2) makespan-based fitness evaluation, C_{max}
 - (3) mutation governed by scaling factor F , $v_{i,j,0} = xr_{0,g} + F(xr_{1,g} - xr_{2,g})$,
 - (4) crossover controlled by rate Cr ,
- $$u_{i,g} = u_{i,j,g} = \begin{cases} v_{i,j,g}, & \text{jika } rand(0,1) \leq Cr \text{ atau } j = j_{rand} \\ x_{i,j,g}, & \text{untuk yang lain} \end{cases}$$
- (5) exploitation enhancement via insert local search on trial vectors, and
 - (6) greedy selection.

The procedure is summarized in Figure 1. To overcome the high sensitivity of DE to its operational parameters without the computational burden of a full-factorial design ($3^4=81$ runs), a D-optimal design based on the Box-Behnken framework was developed using Minitab. This statistical approach systematically minimized the configuration into 16 optimal experimental runs across specified boundaries: Population Size ($NP \in [20,100]$), Iterations ($MaxIt \in [500,1000]$), $F \in [0.4,1.0]$, and $Cr \in [0.5,0.9]$. The hybrid algorithm was implemented in MATLAB and validated using secondary benchmark datasets from prior literature, consisting of three FSP instances (5 jobs $\times$ 6 machines, 4 jobs $\times$ 6 machines, and 12 jobs $\times$ 3 machines). Each configuration was replicated 10 times (totaling 480 independent computational runs) to evaluate and benchmark the resulting makespan against Branch and Bound and Moth-Flame Optimization methods.

The Findings and Arguments

The D-optimal design framework successfully minimized experimental complexity from $3^4 = 81$ combinations to 16 significant runs, reducing computation time without losing essential data. Across all three flowshop scheduling cases, variations among these 16 settings did not alter the final makespan, though they heavily impacted execution speed. The optimal parameter configuration yielding the fastest CPU time was identified as: $NP = 20$, $MaxIt = 500$, $F =$

0.7, and $Cr = 0.7$. The finding that the 16 parameter configurations produced identical final makespan values but different CPU times indicates that parameter configuration primarily affected the convergence efficiency of DE rather than the final solution quality for the evaluated benchmark instances. An appropriate combination of population size, iteration limit, mutation factor, and crossover rate may allow the algorithm to reach a high-quality solution with fewer computational efforts. Therefore, the benefit of D-optimal parameter calibration in this study is not only the reduction of experimental runs, but also the identification of a configuration that provides more efficient convergence.

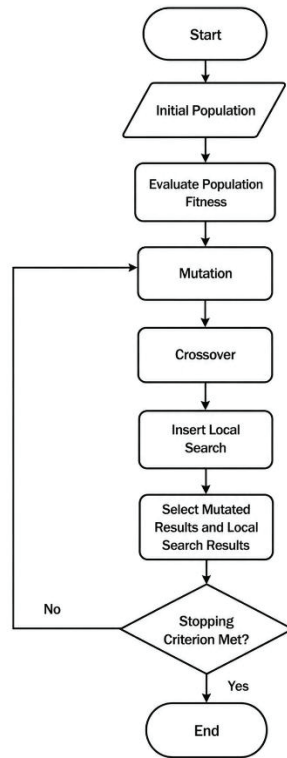


Fig 1: the method procedure

Table 1: Performance results

No	Source Literature	Literature Best	Pure DE Best	Hybrid DE+LS Best	Pure DE CPU (s)	Hybrid DE+LS CPU (s)
1	Mazda & Kurniawati (2020)	12,954.46 s	12,954.46 s	12,954.46 s	62.042	37.493
2	Nuriza & Oktiarso (2020)	639,580.00 s	638,920.00 s	638,920.00 s	33.840	37.398
3	Amallynda & Hutama (2021)	6,530.00 min	6,520.00 min	6,520.00 min	352.344	37.293

Benchmarking results in Table 1 demonstrate that the proposed hybrid DE + Local Search (LS) algorithm delivers robust performance. For Case 1, the hybrid method successfully matched the optimal bound found by the exact Branch and Bound algorithm while achieving a 39.5% reduction in CPU time compared to pure DE. This improvement can be attributed to the complementary roles of DE and insertion-based local search. DE provides global exploration by generating diverse candidate permutations, whereas the insertion local search intensifies the search around promising solutions by relocating individual jobs to alternative positions. In a permutation-based FSP, such a relocation can directly modify the sequence-dependent completion times and machine idle times. Consequently, the local search can refine promising

solutions without requiring DE to continue performing extensive global exploration, which may explain the lower computational time observed for the hybrid approach. For Case 2 and Case 3, the hybrid DE+LS outperformed existing literature methods (Branch and Bound and Moth-Flame Optimization) by finding superior, smaller makespan values. Regarding computational efficiency, the hybrid approach proved highly effective in larger problem dimensions, compressing Case 3's CPU time from 352.344 seconds to just 37.293 seconds.

Several limitations should be considered when interpreting these findings. First, the evaluation was conducted using only three relatively small benchmark instances, limiting the ability to generalize the results to large-scale flowshop scheduling problems. Second, the experimental evaluation considered a limited number of benchmark configurations and focused only on makespan minimization. Third, CPU-time comparisons may be affected by differences in hardware, software implementation, and computational settings when compared with previously reported literature results. Therefore, the observed computational advantage should be interpreted within the experimental environment of this study.

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Development of a Manufacturing Decision Framework for Patient-Specific Transtibial Prosthetic Socket Fabrication Using Alternative Additive Manufacturing Technologies

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Abstract—There is a need for additive manufacturing technologies that able to deliver reliable performance, manufacturing flexibility and cost efficiency to address the growing demand for patient-specific prosthetic devices. However, selection of the most appropriate technology is difficult, as several engineering and manufacturing factors need to be considered simultaneously. The study proposes Manufacturing Decision Framework (MDF) to select additive manufacturing technologies for patient-specific transtibial prosthetic sockets. The study compares two technologies, Selective Laser Sintering (SLS) and Stereolithography (SLA). The framework is a combination of finite element analysis (FEA), comparative manufacturing analysis and a weighted decision matrix considering variables of structural performance, production efficiency, cost efficiency, surface finish, accessibility of the machine, manufacturing flexibility, material efficiency and production of a single part. The FEA results were compared with experimental compression data, and the average discrepancy was 14.31% for SLS and 29.74% for SLA. SLA was superior in aspects such as surface finish, machine accessibility, manufacturing flexibility, single-part production, and cost-effectiveness, whereas SLS excelled in production efficiency and material efficiency. The weighted decision matrix showed a better overall score for SLA 86.5% than for SLS 80.5%. The estimated manufacturing cost reduced from RM1,902.79 per socket for SLS to RM222.98 for SLA which is 88.3% reduction for customized single-part production. Results show a large potential for cost-effective, customizable, low-volume manufacturing of prosthetic sockets by SLA. The proposed MDF provides a systematic engineering approach to technology selection and enables more readily accessible patient-specific prosthetic fabrication.

Introduction

Additive manufacturing (AM) has emerged as an effective approach for fabricating patient-specific prosthetic devices because it enables the production of complex geometries with high dimensional accuracy and rapid customization. The transtibial prosthetic socket is the key component of lower-limb prostheses that directly impact structural performance, user comfort and rehabilitation. Therefore, selecting appropriate manufacturing technology is critical to ensure both product quality and manufacturing efficiency (Paul et al., 2026; Üstündağ & Kır, 2025). Among polymer-based additive manufacturing technologies, Selective Laser Sintering (SLS) and Stereolithography (SLA) are widely employed for customized prosthetic fabrication. SLS is preferred for manufacturing durable functional components with excellent mechanical properties, whereas SLA offers superior surface quality, high printing resolution and lower equipment investment for customized production (Üstündağ & Kır, 2025; Ahmad et al., 2023). However, each technology has its own advantages and limitations in terms of manufacturing capability, operational accessibility and production cost, and the choice of technology is therefore dependent on specific manufacturing requirements.

The mechanical performance of various AM technologies has been researched, but there is a lack of studies proposing a systematic approach for selecting the most suitable

manufacturing process considering engineering and operational considerations. The present work proposes a MDF for patient-specific transtibial prosthetic socket fabrication that incorporates structural performance, manufacturing efficiency, production cost, operational accessibility and production suitability. A comparative case study using SLS and SLA is presented to validate the framework and provide practical guidance for evidence-based technology selection in the manufacturing of customized prosthetics.

Methodology

An MDF was created to facilitate the selection of appropriate additive manufacturing technologies for the manufacture of patient-specific transtibial prosthetic sockets. The framework considers five engineering criteria as outlined in Table 1: structural performance, manufacturing efficiency, production cost, operational accessibility and production suitability. The proposed framework was validated by using the Rapid Advance Future (RAF) transtibial prosthetic socket as a case study. An identical CAD model was printed using SLS with PA12 powder and SLA with Siraya Tech Blu Tough Resin. Finite element analysis was used to evaluate structural performance, and printing time, post-processing requirements, material consumption, and production cost were used to evaluate manufacturing performance. The results of the assessment were integrated in the proposed framework for the evidence-based selection of additive manufacturing technologies based on different production requirements.

Table 1: Engineering criteria used in the Manufacturing Decision Framework.

Evaluation Criterion	Assessment Parameter
Structural performance	Factor of safety, stress distribution
Manufacturing efficiency	Printing time, post-processing
Production cost	Material and processing cost
Operational accessibility	Machine availability, ease of operation
Production suitability	Low-volume or batch production

Results and Discussion

The results are presented in three stages, FEA validation, comparative performance assessment and manufacturing technology selection. Figure 1 shows the comparison of experimental compression test results and finite element analysis (FEA) predictions of SLS material PA12 and SLA material Siraya Tech Blu Tough Resin under applied loads ranging from 200 N to 2600 N. Both technologies exhibited a similar linear response which suggests consistent structural behaviour. However, the FEA SLS model was more consistent with the experimental results with an average deviation of 14.31% compared with 29.74% for SLA. The higher accuracy of SLS is attributed to the improved mechanical properties and isotropic behaviour of PA12 powder, whereas the SLA resin is more vulnerable to brittleness and process-induced variations. These results show that SLS yields more reliable structural predictions for the design of prosthetic sockets specific to individual patients (Paul et al., 2026; Üstündağ & Kır, 2025).

Figure 2 illustrates the comparative performance of SLS and SLA based on the proposed Manufacturing Decision Framework. SLS showed higher scores in structural performance, batch production capability and material efficiency, suggesting its suitability for durable, patient-specific prosthetic socket fabrication. Conversely, SLA outperformed SLS in single-part production, surface finish, cost-effectiveness, machine accessibility and manufacturing flexibility, making it more suitable for rapid prototyping and customised low-volume production. The results suggest that the choice of additive manufacturing technology depends on application requirements rather than on a single performance criterion, consistent with

previous studies on manufacturing decision-making and additive manufacturing technology selection (Ahmad et al., 2023).

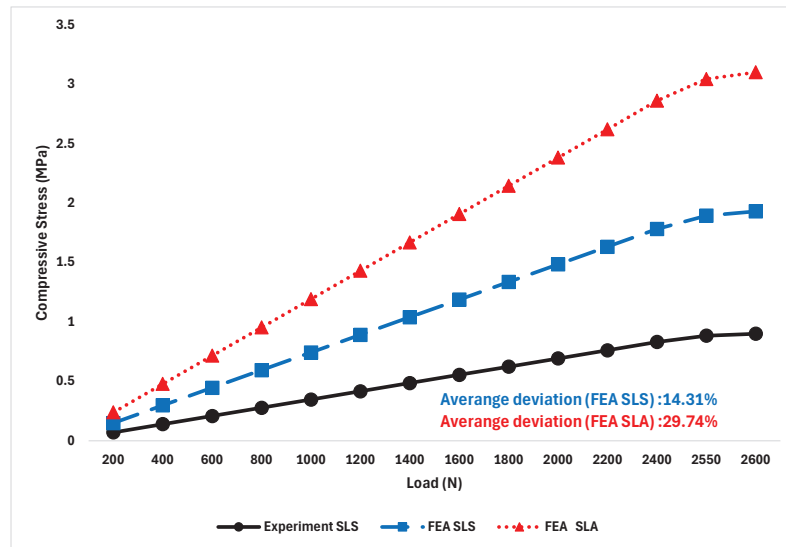


Fig. 12 Comparison of experimental compression test and finite element analysis results for SLS and SLA prosthetic sockets under different applied loads.



Fig. 2 Comparative performance of SLS and SLA based on the proposed Manufacturing Decision Framework.

Table 2 presents the weighted decision matrix developed using the proposed manufacturing decision framework. Based on the validated FEA results and comparative performance assessment presented in Figure 2, SLA achieved a higher overall score of 4.33/5.00, compared with 4.03/5.00 for SLS. SLA demonstrated advantages in surface finish, machine accessibility, single-part production, manufacturing flexibility, and cost efficiency, whereas SLS performed better in production efficiency and material efficiency. The estimated manufacturing cost was reduced from RM1,902.79 for SLS to RM222.98 for SLA, representing an 88.3% reduction for customized single-part fabrication. These results indicate that SLS remains advantageous for functional and batch production of prosthetic sockets, while SLA shows greater potential for affordable, customized, and low-volume prosthetic socket production (Miedzińska, Gieleta, & Popławski, 2020).

Table 2: Manufacturing decision matrix for the selection of additive manufacturing technology using the proposed Manufacturing Decision Framework.

Evaluation Criterion	Weight	SLS	SLA
Structural Performance	20%	4.5	5
Factor of Safety	15%	4	4.5
Production Efficiency	15%	5	2.5
Cost Efficiency	10%	3.5	4.5
Surface Finish	10%	4	5
Machine Accessibility	10%	3	4.5
Manufacturing Flexibility	10%	4	4.5
Material Efficiency	5%	4.5	3.5
Single-Part Production	5%	2	5
Overall Score	100%	80.5	86.5

Results and Discussion

This study developed a Manufacturing Decision Framework (MDF) to assist in the selection of additive manufacturing technologies for the fabrication of patient-specific transtibial prosthetic sockets. The framework was evaluated using finite element analysis, comparative manufacturing assessment and a weighted decision matrix. The advantages of SLS in production efficiency and material utilisation make it suitable for functional and batch production. However, SLA scored higher in overall decision and had more advantages for customised and low-volume manufacturing, especially in the aspects of structural performance, surface finish, machine accessibility, manufacturing flexibility, single-part production, and cost efficiency. The estimated cost of manufacturing was reduced from RM1,902.79 per socket for SLS to RM222.98 per socket for SLA. This is 88.3% reduction in the production cost for single part fabrication. The results suggest that SLA could be a promising low-cost alternative to produce customised prosthetic sockets. The proposed MDF provides a systematic engineering framework to select the technology, reducing the reliance on trial-and-error and helping develop more affordable and accessible patient-specific prosthetic solutions.

Acknowledgement

The authors would like to express their sincere appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for providing the facilities and technical support that made this research possible.

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Development of an Intelligent Wireless Rear Warning System for Food Delivery Motorcycles to Enhance Rider Visibility and Road Safety

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Abstract—The emergence of specialist food delivery services has led to more motorbikes being equipped with delivery boxes attached to the back, often obscuring the original brake lights and indicators, which diminishes the visibility of the rider and increases the risk of rear-end collisions, especially in low-light conditions. Although supplemental rear lighting systems have been developed to improve motorcycle visibility, most of the existing designs are based on wired systems that require significant modifications to the motorcycle system and hence limit their applicability for detachable delivery boxes. To solve the problem, this study proposed an advanced wireless rear alert system with an additional third brake light and turn signal in a removable delivery box utilizing Arduino Nano microcontroller and NRF24L01 wireless communication modules. The prototype was experimentally tested in daylight, at night with street lighting and at night without street lighting at observation ranges of 10 m, 25 m and 50 m. The proposed system demonstrated similar visibility scores to the conventional lighting system during daytime, with scores of 10, 7 and 5 at 10 m, 25 m and 50 m distances, respectively. In the night scenes with street lighting, the proposed approach obtained visibility scores of 8, 7 and 6, whereas the conventional system obtained 7, 4 and 1. In the conditions of the same evening without any street lighting, the proposed scheme counted 7, 6, and 5, while the conventional method achieved 6, 5, and 3. The highest improvement was observed 50 m below the street lighting, where the visibility score changed from 1 to 6. The results show that the proposed wireless rear warning system significantly improves the visibility of motorcyclists and provides a practical, inexpensive and quickly installed solution to improve the safety of food delivery motorcycles.

Introduction

The online food delivery business has grown rapidly, resulting in a significant increase in the use of motorcycles for last-mile transportation in Malaysia. Motorcycles are popular because they are economical, fuel-efficient and can easily manoeuvre in congested city traffic. But the growth of food delivery motorcycles has also created questions about rider safety. Difficult working conditions such as strict delivery deadlines, long working hours and heavy traffic mean that delivery riders are more likely to be involved in road traffic accidents. These occupational demands often lead to risky riding behaviour, with food delivery riders being one of the most vulnerable road users (Nguyen-Phuoc et al., 2022; Khan & Velaga, 2025).

Previous studies have shown that food delivery riders are at higher risk of crashes than conventional motorcyclists due to speeding, traffic violations and distractions from mobile applications for navigation and order management. Such behaviour reduces the capacity of riders to respond safely to changing traffic situations, especially in congested urban areas. The recommended solutions have been educational programmes and stricter traffic enforcement, but there are limited engineering-based solutions for safety (Pervez et al., 2025; Qian et al., 2024). Another safety concern is the use of rear-mounted delivery boxes that partially cover the motorcycle's original brake light and turn signal. The warning signals may be less visible, which slows down the reaction time of the drivers behind you, especially at night or in bad

lighting conditions, which increases the chance of a rear-end collision. The research aims to develop an intelligent wireless rear warning system by incorporating an extra third brake light and turn signal into a food delivery box. The systems communicate with each other using an Arduino Nano microcontroller and an NRF24L01 wireless communication module. The prototype was experimentally tested in different lighting and distance of observation conditions to evaluate its effectiveness in improving a rider's visibility. The system offers a cost-effective and practical solution to enhance the conspicuity of motorcycles and improve road safety for food delivery riders.

Methodology

The intelligent wireless rear warning system was developed through wireless concept, as illustrated in Figure 1a. First, the safety issues associated with food delivery motorcycles were identified, focusing on the reduced visibility of brake lights and turn signals caused by rear-mounted delivery boxes. Based on the identified requirements, a wireless lighting system was designed using Arduino Nano microcontrollers and NRF24L01 transceivers to transmit braking and turning signals from the motorcycle to an additional LED third brake light and turn signal installed on the delivery box. The prototype was then fabricated, assembled, and programmed before being integrated with the motorcycle as shown in Figure 1b. Functional testing was conducted to verify wireless communication reliability and signal synchronization. Finally, the prototype was experimentally evaluated under daylight, nighttime with street lighting, and nighttime without street lighting at observation distances of 10 m, 25 m, and 50 m. The visibility performance of the proposed system was compared with the conventional motorcycle rear lighting system to assess its effectiveness in enhancing rider visibility and improving road safety.

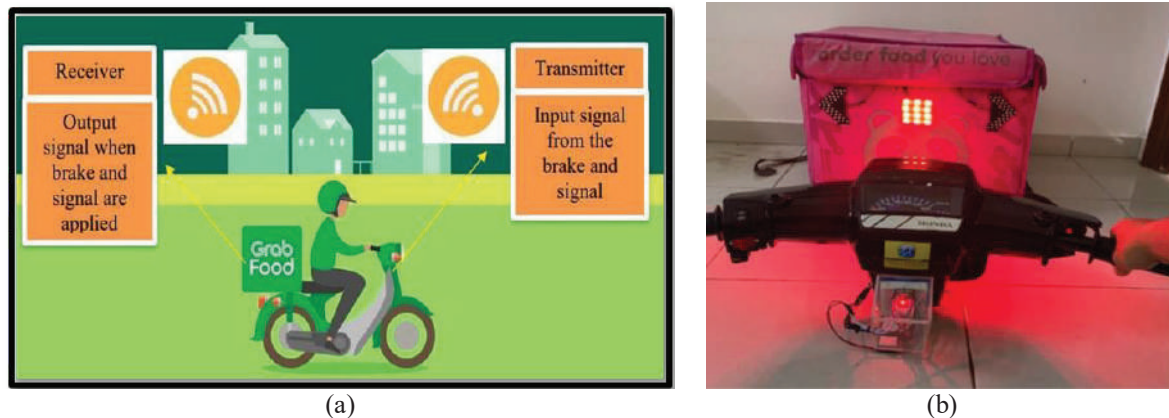


Fig. 1a Development concept of wireless rear warning system for a food delivery motorcycle. Fig. 1b Final prototype

Result and Discussion

The visibility performance of the proposed intelligent wireless rear warning system and the conventional motorcycle rear lighting system under three lighting conditions at observation distances of 10 m, 25 m, and 50 m is shown in Figure 2. In general, visibility was found to decrease with increasing distance of observation. The natural illumination decreased the effect of the additional rear warning system because the two systems had the same visibility scores of 10, 7, and 5 at 10 m, 25 m, and 50 m in the daylight.

The proposed system showed better performance at nighttime. Visibility scores for the proposed system were 8, 7, and 6 with street lighting compared with benchmark scores of 7, 4, and 1 at 10 m, 25 m, and 50 m, respectively. The proposed system also had better visibility scores of 7, 6, and 5 under nighttime conditions without street lighting, while the benchmark

scored 6, 5, and 3. The biggest gain was at 50 m with street lighting, where the proposed system achieved five visibility points more than the benchmark. This meant that the additional third brake light mounted on the delivery box could be seen more clearly at a greater distance, increasing the recognition of braking and turning intentions.

This is probably because the extra LED warning lights are higher up and thus less obstructed by the delivery box and more visible from the back. Similar results were found by Qian et al. (2024), who found improved visibility as an important factor in reducing risky riding situations. Pervez et al. (2025) also identified rider conspicuity as a key factor influencing the involvement of food delivery riders in crashes. Nguyen-Phuoc et al. (2022) proposed engineering solutions to support behavioral safety measures. Moreover, Mokhtar et al. (2023) mentioned that enhancing the visibility of the motorbike is an effective way to reduce road traffic accidents in Malaysia. Therefore, the proposed wireless rear warning system is a practical and low-cost solution to improve the rider visibility and the road safety in the nighttime operation.

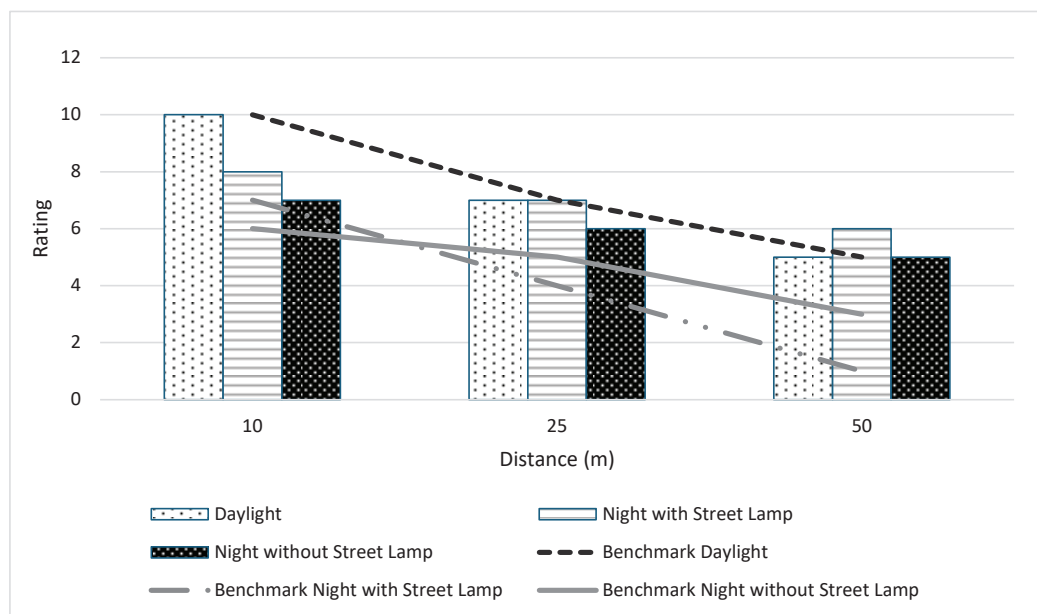


Fig. 2 Comparison of visibility ratings for the proposed system and benchmark under daylight and nighttime conditions.

Conclusion

This study recommended the design, development, and experimental evaluation of an intelligent wireless rear warning system for enhancing the visibility and safety of food delivery motorcycles. The proposed system integrates an additional third brake light and turn signal into a removable delivery box by using Arduino Nano microcontrollers and NRF24L01 wireless communication modules, thereby eliminating complex wiring and ensuring reliable real-time signal transmission. The experimental results indicate that the system achieved the same visibility as the conventional motorcycle lighting system in daylight and significantly improved visibility in nighttime conditions. The highest improvement was found at an observation distance of 50 m, where the proposed system consistently outperformed the benchmark system, indicating its effectiveness in improving rider conspicuity at longer distances. The new high position of the extra LED warning lights also allowed a better identification of braking and turning intentions and therefore increased the available reaction time for the drivers behind. The results indicate that the integration of intelligent wireless communication and an enhanced rear lighting system is a practical engineering solution to address the visibility issues of food delivery motorcycles. In addition to improving rider safety, the proposed design provides a feasible, low-cost, easy-to-retrofit solution that can be used in commercial deployment without

modification of the motorcycle's original electrical system. Future research should be directed to long-term field validation under real traffic conditions, weather-resistance evaluation, and integration of Internet of Things (IoT) technologies for supporting next-generation intelligent transportation and connected motorcycle safety systems.

Acknowledgement

The authors would like to express their sincere appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for providing the facilities, resources, and technical support that contributed to the successful completion of this research.

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Financial Literacy and Income Sustainability in Rural Cooperatives: A Critical Review of Empowerment Models

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Abstract— Rural cooperatives support financial inclusion, enterprise development and rural livelihoods, yet financial education does not consistently translate into sustainable income. This structured critical review examined empowerment models linking financial literacy with income sustainability in rural cooperatives. Scopus-indexed, English-language journal articles published from January 2016 to July 2026 were systematically searched, screened, appraised and thematically synthesised. Thirty-eight peer-reviewed studies met the inclusion criteria. Four models emerged: financial-access, governance-mediated, capability-inclusion and credit-linked performance. Evidence showed that financial capability produced stronger outcomes when supported by accountable governance, credit access, market linkages and opportunities for productive application. Cross-sectional designs, self-reported measures and inconsistent outcome definitions constrained evidence of sustained income effects. The review-derived framework positions financial capability as the individual foundation, cooperative governance as the institutional enabler, financial and market access as the opportunity mechanism and income resilience as the long-term outcome. Future longitudinal, comparative and multisource studies should directly test these relationships across cooperative types and diverse rural contexts.

Introduction

Rural cooperatives strengthen enterprise, financial inclusion, market participation and livelihoods. Their contribution to income sustainability depends on members translating financial knowledge into saving, borrowing, investment and enterprise decisions. Income sustainability includes income stability, revenue diversification, enterprise continuity and recovery from shocks. Rural evidence links financial literacy with banking, microfinance and digital financial services [1]. Microfinance studies indicate that governance influences how financial capability contributes to institutional sustainability [2]. These findings provide indirect evidence for cooperative settings.

Financial access alone does not ensure durable empowerment. Rural studies associate financial literacy and inclusion with socioeconomic participation [3]. Cooperative evidence shows that credit access supports farmers' financial performance when combined with financial knowledge, awareness and responsible attitudes [4]. Agricultural cooperatives promote empowerment through economic opportunities, participatory governance and leadership, although outcomes vary across members and market settings [5]. Existing research rarely integrates literacy, governance, credit, markets and enterprise support within one explanatory structure. Accordingly, this review aims to identify and synthesise empowerment models linking financial literacy with income sustainability in rural cooperatives, and to develop a framework explaining how financial capability, cooperative governance, financial access and market access contribute to sustained income resilience.

Methodology

This study adopted a structured critical review supported by systematic search, screening, quality appraisal and thematic synthesis. SPAR-4-SLR structured search, selection and synthesis decisions [6]. PRISMA 2020 guided reporting of identification, screening, eligibility and inclusion [7].

The Scopus database was searched for English-language, peer-reviewed journal articles published from January 2016 to July 2026. Searches examined titles, abstracts and keywords

through Boolean operators, phrase searching and wildcards. Terms combined “financial litera*,” “financial capabilit*,” “financial behavior,” cooperativ*, rural*, farmer*, “financial inclus*,” “income sustainab*,” “livelihood resilien*,” “economic empower*” and “enterprise perform*.” Multiple overlapping search combinations were merged, explaining duplicate records. The final search occurred in July 2026. Eligible studies examined financial literacy or capability within rural cooperatives, agricultural cooperatives, credit cooperatives or closely related rural-finance institutions and reported income, livelihood, enterprise or empowerment outcomes. Studies lacking rural relevance, financial-capability components, institutional evidence or usable outcomes were excluded. Scopus identified 1,364 records. Removing eight duplicates left 1,356 titles and abstracts. Two reviewers excluded 1,262 records and assessed 94 full texts. Fifty-six articles were excluded for insufficient rural-cooperative relevance (n = 19), absent income, livelihood or empowerment outcomes (n = 17), absent financial-literacy components (n = 12) or inadequate empirical evidence (n = 8). Thirty-eight articles entered synthesis. An audit trail retained search outputs, dates, screening decisions and exclusion reasons.

Two reviewers completed screening and quality appraisal, resolving disagreements through discussion. QuADS appraised each article across 13 methodological and reporting criteria [8]. Item-level QuADS profiles informed evidence weighting without excluding studies solely on the basis of quality. An extraction matrix recorded context, cooperative type, participants, methods, literacy dimensions, mechanisms, outcomes and limitations. Collaborative reflexive thematic analysis supported coding and theme refinement [9]. Synthesis compared convergence, disagreement, methodological variation and transfer limitations while distinguishing direct cooperative evidence from adjacent rural-finance evidence across countries, cooperative types, designs and member groups.

Findings & Discussion

The thematic synthesis generated four empowerment models through coding and comparison of recurring mechanisms across the included studies. Extracted evidence on financial knowledge, access, governance, participation, credit and livelihood outcomes was grouped into codes, refined into themes and consolidated into four analytical models. Table 1 presents representative evidence patterns and critical interpretations from the broader synthesis. The financial-access model linked literacy with banking, microfinance and digital-finance participation [1], although evidence came from rural populations rather than cooperatives. The governance-mediated model grouped accountability, transparent decision-making and participation as institutional mechanisms supporting the contribution of literacy to rural microfinance sustainability [2].

Table 1: Critical Thematic Synthesis of Rural Cooperative Empowerment Models

Empowerment model	Evidence pattern	Critical interpretation
Financial access	Adjacent rural evidence linked financial literacy with banking, microfinance and digital-finance participation [1].	Financial access did not establish sustained cooperative income.
Governance-mediated	Adjacent microfinance evidence linked governance with financial literacy and institutional sustainability [2].	Cooperative governance structures require direct empirical testing.
Capability-inclusion	Rural evidence associated financial literacy and inclusion with socioeconomic empowerment [3].	Improved participation and financial confidence did not confirm stable income.
Credit-linked performance	Direct cooperative evidence linked credit access, financial literacy and participation with financial performance and empowerment [4], [5].	Outcomes varied across gender, institutional capacity, cooperative type and market conditions.

Source: Authors’ synthesis

The capability-inclusion model combined financial knowledge, inclusion, decision-making and socioeconomic empowerment [3]. These outcomes reflected improved participation and confidence, but did not establish sustained income. The credit-linked performance model drew on direct cooperative evidence showing that credit access produced stronger financial outcomes when supported by financial knowledge, awareness and responsible attitudes [4]. Agricultural cooperative evidence linked empowerment with economic opportunity, participatory governance and leadership [5]. Outcomes nevertheless varied across gender, institutional capacity, cooperative type and market conditions.

Across the four models, evidence converged around a common pathway: financial capability alone was insufficient for sustained income outcomes. Governance operated as an institutional enabler, while financial and market access provided opportunities for members to apply capability productively. Table 2 therefore positions the Review-Derived Integrated Income Sustainability Framework as an integrative synthesis rather than an empirically validated causal model. Financial capability represents the individual-level foundation, cooperative governance the institutional enabler, financial and market access the opportunity mechanism and income resilience the long-term outcome.

Table 2: Review-Derived Integrated Income Sustainability Framework

Framework Component	Analytical Position	Institutional Function	Proposed Assessment Indicators
Financial capability	Individual-level foundation	Applied financial literacy, coaching and financial decision-making	Budgeting, savings, debt management and record keeping
Cooperative governance	Institutional enabler	Transparency, accountability and member participation	Participation, repayment performance and member trust
Financial and market access	Opportunity mechanism	Credit, digital finance and market linkages	Productive credit use, sales performance and revenue diversity
Income resilience	Long-term outcome	Sustained livelihood and enterprise capacity	Income stability, enterprise continuity, savings buffers and shock recovery

Source: Authors' synthesis

This positioning extends evaluation beyond training participation. Cooperatives should assess behavioural change through budgeting, saving, borrowing, investment and record keeping, together with credit use, revenue diversity, enterprise continuity and shock recovery. Longitudinal, multisource assessment using member interviews, financial statements and repayment data would better distinguish temporary literacy gains from sustained behavioural improvement and resilient livelihoods.

Conclusion

This review positions financial literacy as a foundation for income sustainability in rural cooperatives. Sustainable outcomes depend on its interaction with accountable governance, financial and market access and enterprise opportunities. The review-derived framework integrates financial capability as the individual-level foundation, cooperative governance as the institutional enabler, financial and market access as the opportunity mechanism, and income resilience as the long-term outcome. Cooperatives should assess behavioural change, credit use, revenue diversity, enterprise continuity and shock recovery rather than training participation alone. Evidence remains constrained by cross-sectional designs, self-reported outcomes, uneven coverage and inconsistent definitions. Future longitudinal, comparative and

multisource studies should test these relationships across agricultural, credit and multipurpose cooperatives, while examining whether financial capability produces behavioural improvement and livelihood resilience.

Acknowledgement

The authors acknowledge City Graduate School, City University Malaysia and National Cooperative Movement (ANGKASA) Sarawak, for academic guidance and research access. Appreciation is extended to the Faculty of Electrical Engineering Technology and the Socio-Technical Competencies for Community Empowerment Research Group, Universiti Teknikal Malaysia Melaka, for institutional and research support.

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From Emotional Engineering to Game Theory: A Conceptual Framework for Packaging Design Strategy Development

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Abstract— Emotional engineering provides detailed evidence on consumer responses to individual packaging elements; however, effective packaging product development requires the integration of these elements into comprehensive design configurations. This paper proposes a conceptual framework that links emotional engineering, statistical evidence, packaging design strategy development, and game theory decision-making. The framework defines the packaging design domain, measures emotional response (Y1) and purchase likelihood (Y2), validates measurement instruments, evaluates decision-relevant alternatives, forms candidate packaging strategies, develops their utility structures, and applies the Nash bargaining concept for decision-making. Design alternatives are retained based on mean performance, statistical comparability, association between Y1 and Y2, predictive relevance, and sensitivity evaluation. Retained designs are recombined across shape, handle, cap, and label to generate sets of candidate packaging strategies. Each packaging strategy is characterised by emotional-response and purchase-likelihood utilities. The Nash bargaining model provides a conceptual rule for identifying the most balanced design strategy that maximises joint gains in emotional response and purchase likelihood, each above their respective minimum acceptable levels.

Introduction

Packaging not only contains and protects a product but also functions as a system of visual, ergonomic, and informational cues. Bottle shape, handle features, dispensing mechanisms and label communication may jointly affect emotional responses, perceived quality and purchase-related decisions [1-5]. Kansei engineering provides a systematic approach for translating consumers' psychological sentiments into measurable product design information [1-3]. Nevertheless, an isolated preferred shape, handle, cap, or label may not constitute a good package design; these elements have to work together as part of a packaging strategy that attracts consumers' attention and accommodates affective trade-offs.

Emotional design studies commonly identify influential design elements, predict relationships, or rank alternatives [2-3], yet the transition from Kansei-derived emotional evidence to the final selection of balanced and stable design strategies remains limited. Contrary to conventional multi-objective methods such as Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Pareto optimisation, which rely on predefined preferences, reference points, or dominance rules, Nash bargaining determines a balanced strategy by maximising the joint proportional gains in both objectives above their minimum acceptable levels [6]. The primary contribution of this research is the integration of validated Kansei measurements, statistical screening of design alternatives, formation of comprehensive packaging configurations, acceptance thresholds, and Nash-product optimisation within one decision-making framework.

This paper develops a conceptual methodological framework. The framework has three objectives: (1) to establish procedures for validating emotional-response and purchase-likelihood measurement; (2) to define criteria for translating design element-level evidence into packaging strategies; and (3) to formulate a conceptual Nash-product decision model for future empirical application.

Proposed Framework and Validation Procedure

Figure 1 illustrates the process of developing emotional-engineering and game-theoretic framework for packaging design strategy. The first three stages define the packaging design

domain, measure emotional response (Y1) and purchase likelihood (Y2), and validate instrument measurement. In empirical application, each participant would evaluate five bottle shapes (S1-S5), four handles (H1-H4), four caps (C1-C4) and four labels (L1-L4), resulting in an initial factorial space of $5 \times 4 \times 4 \times 4 = 320$ feasible design configurations. Emotional response (Y1) will be measured from seven-point semantic-differential Kansei dimensions, and purchase likelihood (Y2) will range from 1 (totally unwilling) to 7 (totally willing). Exploratory factor analysis and internal consistency assessment would be applied for construct validity and measurement reliability [7-8]. Stage 4 evaluates design alternatives using established procedures for dependent observations. Because each respondent would evaluate all alternatives, repeated-measures ANOVA will be applied together with assumption assessment, corrected pairwise comparison and effect-size interpretation. Besides, repeated-measures correlations and mixed-effect regression will be used to examine the relationships among Y1, Y2 and Kansei attributes [9-11].

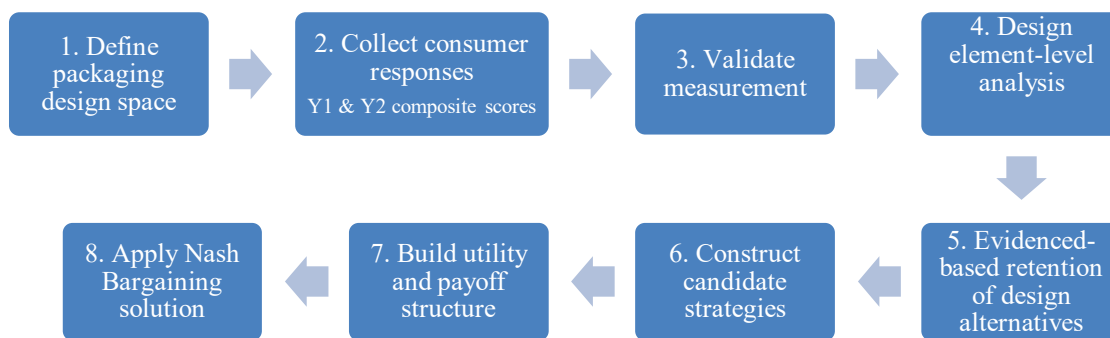


Fig. 1 Emotional-engineering and game-theoretic framework development process

The fifth and sixth stages translate design-level statistical evidence into packaging strategy alternatives. A design level will be retained primarily according to Y1 and/or Y2 mean performance and adjusted pairwise comparisons. Partial eta-squared was used to assess the overall magnitude of differentiation within each packaging element. Repeated-measures correlation, mixed-effect regression and sensitivity evidence are referred for supporting retention decisions [6],[12]. Table 1 explains the proposed selection criteria of design alternatives.

Table 1: Proposed criteria for retaining packaging-design alternatives

Evidence	Recommended retention criterion
Emotional response (Y1)	Retain a design with a leading Y1 mean or no significant difference from the leading alternative. Assess partial eta-squared values (effect size) as evidence of overall differentiation.
Purchase likelihood (Y2)	Retain a design with a leading Y2 mean or no significant difference from the leading alternative. Assess partial eta-squared values (effect size) as evidence of overall differentiation.
Y1–Y2 relationship	Retain a design that indicates a meaningful positive association between emotional response Y1 and purchase likelihood Y2.
Predictive evidence	Retain a design whose Kansei attributes show meaningful predictive relevance to purchase likelihood in a mixed-effects model.
Sensitivity analysis	Retain a comparable or strategically distinctive alternative for subsequent comparison.

Low statistically performed and non-distinctive designs are excluded, which will reduce the original design space of 320 configurations to a smaller feasible set. Retained designs will be recombined across shape, handle, cap and label to form candidate packaging strategies. The final stages involved assigning utility and payoff structure to each packaging strategy. Finally, the Nash Bargaining solution will be applied to determine a packaging strategy that provides the most balanced trade-off between the emotional-response utility Y1 and the purchase-likelihood utility Y2 within a cooperative bargaining framework.

Conceptual Game-Theoretic Decision Model

The proposed model applies the Nash bargaining principle as a two-objective decision rule without representing human players, whereby emotional response and purchase likelihood are treated as two interrelated objectives that require balancing during strategy selection. The selected packaging strategies are represented as S , as shown in Equation 1. Each strategy combines one retained shape, handle, cap and label and is assigned two proposed utility measures: $U_1(s)$ for emotional response and $U_2(s)$ for purchase likelihood (Equation 2). For each strategy s , $U_1(s)$ is calculated as the equal-weighted mean of the emotional-response means for its selected shape, handle, cap and label. These element-level means are calculated from their respective Kansei dimensions, with higher values consistently showing more favourable responses. $U_2(s)$ is the regression-predicted purchase-likelihood score based on $U_1(s)$ and the dummy-coded design levels. Both utilities are expressed on the same 1–7 scale. The validated Y1 and Y2 estimates will be converted into strategy-level payoff values $U_1(s_i)$ and $U_2(s_i)$ for the subsequent game-theoretic process. Based on the Nash bargaining concept, the model will be able to identify the optimal packaging strategy as a cooperative trade-off that maximises the balanced gains in both objectives [13-14].

$$S = \{s_i\}_{i=1}^N ; s_i = (S_j, H_k, C_m, L_n) \quad (1)$$

where s_i represents an individual strategy with a feasible combination of packaging elements, S_j, H_k, C_m , and L_n represents candidate shape, handle, cap, and label alternatives, respectively. N is the number of candidate packaging strategies generated from stage 6 (Figure 1).

Each strategy is represented by the payoff values, U :

$$U(s_i) = [U_1(s_i), U_2(s_i)], \quad i=1, \dots, N \quad (2)$$

where $U_1(s_i)$ represents emotional-response utility and $U_2(s_i)$ represents purchase-likelihood utility.

To define the feasible bargaining space, minimum acceptable utility level of d_1 for emotional response and d_2 for purchase likelihood should be applied [15]. Both d_1 and d_2 are fixed at 4.00 as the neutral midpoint of both seven-point scales. The individually rational feasible set is defined as Equation 3.

$$F = \{s \in S : U_1(s) \geq d_1, U_2(s) \geq d_2\} \quad (3)$$

where F is strategies meeting the minimum acceptable utility requirements

The Nash Bargaining Solution will be developed conceptually as per Equation 4. The best-balanced packaging strategy is selected from the Nash product that maximises joint gains in

levels. This model shows a structured transition from evidence in emotional engineering to game-theoretic packaging decision-making.

$$s^* = \arg \max_{s \in F} [U_1(s) - d_1] [U_2(s) - d_2] \quad (4)$$

where s^* is the candidate strategy that maximises the product of utility gains above the disagreement point $\arg \max$ is the value of s that produces the maximum result, $s \in F$ restricts the optimisation to strategies that meet both neutral utility requirements

Conclusion

This paper developed a conceptual framework to transform evidence from emotional engineering into feasible packaging strategies and a game theory-based decision model. The development process includes validating the measurement of emotional response and purchase likelihood, translating design element-level evidence into decision-relevant design alternatives to support the formation of packaging strategies, and formulating a conceptual game-theoretic decision model to identify best-balanced design. This systematic process can prevent premature interpretation of the preferred element-level design as an optimal packaging configuration. Emotional response and purchase likelihood are presented as utilities in the game-theoretic model. Nash product maximises both joint gains in emotional response and purchase likelihood above their respective minimum acceptable levels. Future studies should construct and validate the model using observed Y1 and Y2 values, conduct sensitivity analysis using alternative values of d_1 and d_2 , assess robustness of the strategy across consumer segments and practical design constraints.

Acknowledgement

This study is supported by Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan, Universiti Teknikal Malaysia Melaka. The authors gratefully acknowledge everyone who contributed suggestions and comments.

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Work-Life Balance, Employee Development, and Job Satisfaction as Predictors of Organizational Performance in Malaysia's National Registration Department

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Abstract— This study examines work-life balance, employee development, and job satisfaction as predictors of organizational performance among employees of Malaysia's National Registration Department (JPN), where sustained service quality depends on workforce capability and well-being. A quantitative cross-sectional correlational design was employed. Using proportionate stratified random sampling, 364 valid responses were obtained from 499 counter and back-office employees. Data were collected through a structured 20-item questionnaire using a five-point Likert scale and analysed through descriptive statistics, Cronbach's alpha, Pearson correlation, and multiple regression. All constructs recorded high mean scores, with organizational performance ranking highest ($M = 4.290$), followed by Job Satisfaction ($M = 4.051$), Employee Development ($M = 3.996$), and work-life balance ($M = 3.977$). Reliability coefficients ranged from 0.894 to 0.946, indicating strong internal consistency. All predictors were positively associated with organizational performance. Job satisfaction showed the strongest bivariate relationship ($r = 0.634$), while employee development emerged as the strongest independent predictor ($\beta = 0.304$), followed by job satisfaction ($\beta = 0.302$) and Work-Life Balance ($\beta = 0.167$). The model explained 47.9% of performance variance. The findings highlight the importance of targeted development, supportive working conditions, employee satisfaction, and effective workload management in strengthening JPN's overall organizational performance and public-service delivery.

Introduction

Malaysia's National Registration Department (JPN), safeguards national identity records and provides civil registration, citizenship, and public registration services. These responsibilities require accuracy, integrity, compliance, digital capability, and timely delivery. Public-sector performance depends on employee behaviour, management, and human resource practices [1]. Evidence associates Work-Life Balance with stronger Job Satisfaction and employee performance [2]. Employee Development strengthens competence, organisational commitment, and work performance [3], while meta-analytic evidence confirms a positive association between Job Satisfaction and job performance [4]. Guided by Job Demands-Resources theory, Employee Development and organisational support for Work-Life Balance are conceptualised as job resources that enhance capability, well-being, and the capacity to manage demands. Job Satisfaction represents a work-related attitude potentially associated with stronger perceived Organizational Performance [5].

Despite attention to employee-related determinants of performance, limited evidence explains the combined contribution of these factors within Malaysia's public registration services. This gap is important because JPN employees work under strict service standards while managing sensitive data, digital systems, and public expectations. This study examines Work-Life Balance, Employee Development, and Job Satisfaction as predictors of perceived Organizational Performance among JPN employees. By establishing their relative contributions, the study extends employee-performance research to a Malaysian public-sector context and offers practical evidence to inform workforce development, support, employee well-being, and service-performance strategies within JPN.

Methodology

This study employed a quantitative cross-sectional correlational design to examine Work-Life Balance, Employee Development, and Job Satisfaction as predictors of perceived Organizational Performance among National Registration Department employees at one time point in Malaysia.

The study population comprised 499 JPN employees, including 262 counter personnel and 237 back-office personnel. Proportionate stratified random sampling was applied by category to represent both strata [6]. Based on the population proportions, the initial targets were 191 counter personnel and 173 back-office personnel. Sample adequacy was evaluated against the population size and inferential analyses [7]. Following data collection and screening, the final achieved sample comprised 364 respondents: 189 counter personnel (51.9%) and 175 back-office personnel (48.1%). The small difference between the targeted and achieved distributions did not materially affect proportional representation.

Data were collected through JPN communication channels using a 20-item questionnaire. Work-Life Balance, Employee Development, Organizational Performance, and Job Satisfaction were each measured using five items on a five-point Likert scale ranging from 1, strongly disagree, to 5, strongly agree. Ishikawa Domain Mapping translated the research objectives into four questionnaire domains, with five items assigned to each construct. After statistical analysis, SWOT Analysis organised the findings into strengths, weaknesses, opportunities, and threats to support recommendations for JPN. Both frameworks functioned as instrument-development and interpretive tools rather than statistical techniques.

Data screening assessed completeness, duplicate records, response consistency, and coding accuracy. Construct scores were calculated as the mean of their respective items. Descriptive analysis included frequencies, percentages, means, standard deviations, and construct rankings. Cronbach's alpha assessed internal consistency [8]. Pearson correlation examined the strength and direction of relationships, while multiple regression estimated each predictor's independent association with perceived Organizational Performance [9]. Statistical significance was set at $p < .05$. Regression assumptions were evaluated using residual diagnostics, the Ramsey RESET test, the Breusch-Pagan test, and variance inflation factors. HC3 robust standard errors were applied following the detection of heteroscedasticity. Anonymity, voluntary participation, standardised procedures, and the exclusion of personal identifiers reduced potential common method bias, although no statistical test was conducted [10]. Given the cross-sectional design, the results indicate association and prediction rather than causality.

Findings & Discussion

The descriptive results showed high perceived levels across all four constructs. Organizational Performance recorded the highest mean score at 4.290, followed by Job Satisfaction at 4.051, Employee Development at 3.996, and Work-Life Balance at 3.977. Standard deviations ranged from 0.693 to 0.776, reflecting moderate variation in employee responses. All Cronbach's alpha coefficients exceeded 0.80, confirming strong internal consistency. Organizational Performance recorded the highest reliability coefficient at 0.946, while Work-Life Balance recorded the lowest at 0.894.

The correlation analysis showed significant positive relationships between all predictors and Organizational Performance. Job Satisfaction recorded the strongest correlation, $r = 0.634$, followed by Employee Development, $r = 0.620$, and Work-Life Balance, $r = 0.593$. All relationships were significant at $p < .001$. The regression model was statistically significant, $F(3,360) = 110.296$, $p < .001$, explaining 47.9% of the variance in perceived Organizational Performance, with an adjusted $R^2 = 0.475$. Linearity was supported, $p = .978$, and VIF values of 2.067–2.660 indicated no serious multicollinearity. As residual non-normality and

heteroscedasticity were detected, HC3 robust standard errors were applied. Employee Development was the strongest predictor, $\beta = 0.304$, $p < .001$, followed by Job Satisfaction, $\beta = 0.302$, $p < .001$. Work-Life Balance also remained significant, $\beta = 0.167$, $p = 0.028$. Thus, all predictors were independently associated with stronger perceived Organizational Performance.

Table 1: Descriptive Statistics and Reliability of the Research Constructs

Construct	Items	Mean	Standard Deviation	Rank	Interpretation	Cronbach's Alpha
Organizational Performance	5	4.290	0.693	1	High	0.946
Job Satisfaction	5	4.051	0.767	2	High	0.938
Employee Development	5	3.996	0.732	3	High	0.934
Work-Life Balance	5	3.977	0.776	4	High	0.894

Table 2: Correlation and Multiple Regression Results for Organizational Performance

Predictor	Pearson r	Correlation p-value	Standardized Beta	t-value	Regression p-value	Regression Result
Work-Life Balance	0.593	< .001	0.167	2.199	.028	Significant
Employee Development	0.620	< .001	0.304	3.841	< .001	Significant
Job Satisfaction	0.634	< .001	0.302	3.754	< .001	Significant

Note. N = 364; $R^2 = .479$; adjusted $R^2 = .475$; $F(3,360) = 110.296$, $p < .001$. Regression t-values and p-values are based on HC3 robust standard errors.

Overall, employee development was the strongest unique predictor, while job satisfaction showed the strongest bivariate association. Work-life balance remained significant but contributed less strongly. SWOT highlighted strong performance and job satisfaction, lower work-life balance, development opportunities, and workload-related threats.

Conclusions

The findings indicate that Work-Life Balance, Employee Development, and Job Satisfaction were positively associated with perceived Organizational Performance within Malaysia's National Registration Department. Employee Development was the strongest predictor, while Job Satisfaction showed the strongest bivariate association. Work-Life Balance remained significant, although its contribution was smaller. The results are consistent with Job Demands-Resources theory, positioning Employee Development and organisational support for Work-Life Balance as job resources, while Job Satisfaction represents a positive work-related attitude. Nevertheless, the cross-sectional design does not establish causality, and self-reported data may introduce common method bias. JPN should prioritise role-specific training, digital capability, career development, supervisory support, and workload management. Future studies should employ longitudinal designs, objective performance indicators, and comparisons across public-sector organisations.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia, for academic guidance and JPN for its cooperation and research access. Appreciation is also extended to FTKE and the SoTeCH Research Group, UTeM, for institutional support.

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Current EV Policy Effectiveness and Consumer Adoption Intention: Evidence from Malaysia

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Abstract - Electric vehicles (EVs) are becoming an effective means to reduce greenhouse gas emissions and increase sustainable transportation. The Malaysian government has adopted various EV policies and financial incentives, but the EV adoption rate remains low compared with its neighbouring countries. While previous studies have mainly concentrated on the determinants of behavior and technology-based adoption of EVs, relatively little research has focused on the efficacy of existing EV policies and incentives in shaping consumers' attitudes toward EV adoption. The study, using the Theory of Planned Behavior (TPB), investigated how current EV Policy Effectiveness and EV incentives influence intention of customers in Malaysia to adopt EVs. IBM SPSS Statistics software was used for reliability and multiple regression analyses. A quantitative, cross-sectional study was conducted with 120 respondents from Malaysia. The results of this study indicated that Current EV Policy Effectiveness positively and significantly affected the adoption intention of EVs ($\beta = 0.264$, $p = 0.023$), while there was no significant effect for EV Incentives ($\beta = -0.151$, $p = 0.188$). The findings stated that the clarity, consistency, and long-term credibility of EV policy may be more important in improving consumer adoption intention than incentive mechanisms, particularly. The study is one of the few studies to examine consumer confidence in the EV environment in Malaysia through the lens of policy-related external factors, making it an important addition to the TPB literature, while offering practical suggestions for making policy more effective for policymakers. Findings will help to develop evidence-based solution strategies for achieving the National Energy Transition Roadmap (NETR) proposed in Malaysia and transitioning towards sustainable mobility.

Introduction

Transportation consumes about 25% of global energy-related carbon dioxide (CO₂) emissions and transitioning to sustainable mobility is a global priority (International Energy Agency, 2025). Electric vehicles (EVs) are among the most promising technologies for low-carbon transportation and have garnered significant attention from governments across the globe through the introduction of fiscal incentives, regulatory policies, and infrastructure development programmes to speed up consumer uptake. While these measures have been implemented, adoption of EVs has been uneven across countries, reflecting the effectiveness of government interventions as much as the availability of policies and incentives: the perception of relevance, availability, consistency, and long-term reliability of incentives is important.

Malaysia has rolled out several national programs and fiscal measures to advocate for transitioning to E-mobility, including the National Energy Transition Roadmap (NETR) and Low Carbon Mobility Blueprint (LCMB). The adoption of EVs is still relatively low, though, and this matters for gauging consumer perceptions of the success of current measures to increase EV uptake and if incentives are enough to build the uptake of EVs.

Past studies have largely centered on behavioural, technological, financial, and infrastructural factors affecting EV uptake, with relatively little research on consumer perceptions of the effectiveness of existing EV policy and the EV incentives in Malaysia. This study examines two institutional factors by following the Theory of Planned Behavior (TPB), which are external factors determining consumers' EV Adoption Intention. In particular, the study examines the impact of the effectiveness of existing EV policies and the availability of EV incentives on consumers' EV adoption intentions. The conceptual framework proposed in

this study suggests that Current EV Policy Effectiveness and EV Incentives are positively related to EV Adoption Intention, as shown in Figure 1.

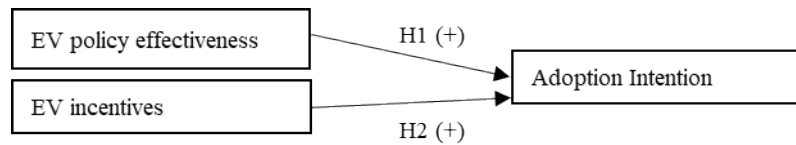


Fig. 13 Proposed Research Framework

Literature Review and Hypotheses Development

The shift from conventional to electric vehicles (EVs) has been well recognised as a driver of Government policy. It is important not only to have incentives or regulations in place, but also to have consumers' perception of the policy's clarity, consistency, long-term access, and reliability. Accordingly, some previous research indicates that government policies that provide financial certainty, raise consumer confidence, and enhance EV purchase intention are effective (Xue et al., 2023; Chatterjee et al., 2024). Yet, results from the more developed EV markets show that increased uptake of EVs is not necessarily correlated with the number of policy instruments; successful policy instruments vary based on the consumer type, geographic location, and EV market maturity (Zhao et al., 2024).

Theory of Planned Behaviour (TPB) is a theory that states that attitudes, together with subjective norms and perceived behavioural control, affect behavioural intention. The effectiveness of current government policies is an external institutional factor that can strengthen pro-EV attitudes and consumer confidence in EVs. Likewise, EV incentives can lower the perceived cost of EVs and enhance consumers' perceived EV ownership capabilities. Incentives' influence, however, can vary depending on what individuals think about the availability, sufficient length, sufficiency, and applicability of incentives. Therefore, the influence that the policy and incentives have on EV adoption intention is theoretically expected to vary across the context of the consumers and markets (Chatterjee et al., 2024; Yu et al., 2025).

Although more studies have been made available on EV adoption, three such gaps cannot be ignored. First, existing research generally has concentrated on behavioural, technological, and environmental factors, and consumers' perceptions of the effectiveness of existing EV policies have been relatively under-researched. Second, incentives have been talked about a lot as moderating or contextual variables, and their own effect on the adoption intention has been under-researched. Finally, although the efforts of both the National Energy Transition Roadmap (NETR) and the Low Carbon Mobility Blueprint (LCMB) are underway, there is limited empirical research conducted in the Malaysian context. This study is designed to examine the direct effects of CEPE and EV Incentives on EV users' intentions to purchase EVs in Malaysia to overcome the above-mentioned gaps. The following hypotheses are therefore proposed:

Hypothesis 1 (H1): Current EV policy effectiveness has a positive influence on consumers' intention to adopt electric vehicles.

Hypothesis 2 (H2): EV incentives have a positive influence on consumers' intention to adopt electric vehicles.

Methodology

The current study conducted a quantitative cross-sectional survey, which investigates the effect of current EV policy effectiveness and EV incentives on adoption intention among consumers in Malaysia. The target population was Malaysian consumers who are aware of and interested

in EV technology, aged 18 or older. 120 responses have been applied, using purposive sampling. Respondents are diverse in terms of gender, age, education, income, and employment history, thus representing a broad spectrum of Malaysian consumers in terms of EV adoption. Both online and offline survey administration were used to collect data. Items of the structured questionnaire were adapted from previous studies on EV adoption, government policy and incentives, and consumer behavioural intention to be used as the research instrument. Current EV Policy Effectiveness: 4 items, EV Incentives: 5 items, EV Adoption Intention: 5 items and the questions were based on a 5-point Likert scale (1 represents strongly disagree, and 5 represents strongly agree). The questionnaire was piloted and discussed with experts before the data collection to make it clear and suitable. The data gathered were analysed using SPSS statistics software (IBM SPSS Statistics 20). Demographic data of the respondents were presented by descriptive analysis, while the measurement items were internally consistent and tested through analysis of reliability where Cronbach's alpha was applied. Then, to analyze the impact of Current EV Policy Effectiveness and EV Incentives on EV Adoption Intention, the current study applied Multiple Regression Analysis. Consists of firstm the standardised coefficients (β), followed by the t-statistics and p-values to assess statistical significance, and the coefficient of determination (R^2) for assessing the explanatory power of the regression model.

Discussion and Findings

120 valid responses were analysed, which comprised 54.2% female ($n = 65$) and 45.8% male respondents ($n = 55$). In terms of age, the largest proportion were between the ages of 35–44 (31.7%, $n = 38$), followed by those aged 45–54 (30.0%, $n = 36$), then 25–34 (23.3%, $n = 28$). The educational level of the respondents was as follows; 42.5% ($n = 51$) had obtained a Master's degree. Continued with 22.5% ($n = 27$) with a Bachelor's degree. The respondents also had diverse income groups and employment statuses which also brought diversity to the sample of the study.

Table 1. Summary of Reliability and Multiple Regression Results

Construct/Hypothesized Relationship	Cronbach's Alpha	Standardized β	t	p	Decision
EV Policy Effectiveness → Adoption Intention	0.780	0.264	2.312	0.023	Supported
EV Incentives → Adoption Intention	0.849	-0.151	-1.325	0.188	Not supported
EV Adoption Intention	0.918				

Model statistics: $R^2 = 0.044$; Adjusted $R^2 = 0.027$; $N = 120$.

Based on the analysis of reliability, the Current EV Policy Effectiveness, EV Incentives, and EV Adoption Intention constructs show Cronbach's Alpha of 0.780, 0.849, and 0.918, respectively, showing a good internal consistency. The multiple regression analysis results showed that Current EV Policy Effectiveness was statistically significant in influencing EV Adoption Intention, while EV Incentives was not. The model accounted for 4.4% of the variance in EV Adoption Intention ($R^2 = 0.044$, Adjusted $R^2 = 0.027$), which is relatively small.

Current EV Policy Effectiveness has a positive and significant effect on customers' intention to buy an electric vehicle ($\beta = 0.264$, $t = 2.312$, $p = 0.023$), thus supporting H1. The results suggest that transparency and consistency in government policies, along with reliability, could boost EV market uptake by mitigating uncertainty about ownership and investments in EVs. The findings align with Chatterjee et al. (2024), who stated that the attitude and perceived behavioural control of EV adoption of consumers is enhanced by stronger government policy, and with Zhao et al. (2024), who pointed out that it is the design of government policy that matters and not just the number of policy incentives. That implies that the consumer could be

more concerned with the effectiveness and stability of the overall EV policy environment when deciding if they should adopt an EV in the future.

H2 was not supported, as EV Incentives had a non-significant negative effect on intention to adopt electric vehicle ($\beta = -0.151$, $t = -1.325$, $p = 0.188$). The present findings indicate that financial incentives (tax exemptions, purchase-related incentives, charging support, etc.) can lower the financial burden of owning an EV, but may not be enough to boost consumers' adoption intention. A potential explanation is that consumers might also consider other factors beyond monetary ones when deciding to buy an EV, including the consistency, availability, and predictability of the policy context over time. According to Mpoi et al. (2023) and Yu et al. (2025), this discovery is relevant to previous studies that have pointed to the same positive results towards the incentives given by the government on adoption of EV.

Results have generally supported the proposed model to a certain degree. Current EV Policy Effectiveness could be said as a strong predictor of intention to adopt EVs, while EV Incentives were found to have no significant direct effect. Policymakers should thus focus more on making EV policies clearer, consistent, accessible, and credible rather than on financial incentives as the primary tool from a practical perspective. The relatively low level of explanation of the model also suggests that EV adoption intention may not only be affected by other behavioural, economic, technological, and infrastructural factors that are not necessarily captured here, and future research should explore more to answer the issues raised.

Conclusion

The current study shows an interest to analyse the effect of, first the current level of EV policy effectiveness and EV incentives on EV adoption intention of Malaysian consumers. From the findings, there was a significant and positive correlation between the current EV policies and the intention to adopt EVs ($\beta = 0.264$, $p = 0.023$), and no significant correlation between the EVs incentives and the intention to adopt EV ($\beta = -0.151$, $p = 0.188$) was found. The results support the proposed model partially indicating the need for clear, consistent, and reliable policy environment to build consumers' confidence in EV adoption. The study adds the TPB, showing that other than traditional behavioral factors that influence adoption intention, institutional policy factors apply. Practical policy implications suggest that EV policies should be clear, consistent, accessible, and credible, and that financial and non-financial incentives are not enough to boost EV adoption intention. The next extended research should use a diverse sample with a large sample size and include other behavioural, economic, technological, and infrastructural factors that have been shown to influence EV adoption intention for a comprehensive explanation of intention to adopt EVs, especially in Malaysia, given the limited explanatory power of the model ($R^2 = 0.044$).

Acknowledgement

The authors would like to express their sincere gratitude to the Faculty of Technology Management and Technopreneurship (FPTT), Universiti Teknikal Malaysia Melaka (UTeM), for its continuous support and encouragement throughout this research. This study was also financially supported by the Short-Term Research Grant (PJP) Perspektif (Non-Science and Technology), Universiti Teknikal Malaysia Melaka (UTeM), Project No. PJP/2025/FPTT/PERSPEKTIF/SA0079.

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Charging Infrastructure as a Driver of Electric Vehicle Adoption Intention in Malaysia: An Application of the Theory of Planned Behavior

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Abstract

The transition towards electric vehicles (EVs) is essential for reducing greenhouse gas emissions and achieving Malaysia's sustainable mobility agenda under the National Energy Transition Roadmap (NETR). Despite continuous government initiatives to encourage EV adoption, the adoption rate remains relatively low due to inadequate charging infrastructure. In particular, the limited availability and accessibility of charging stations, uneven geographical distribution, insufficient fast-charging facilities, and restricted charging access in high-rise residential areas contribute to range anxiety and discourage consumers from adopting EVs. Although previous studies have examined infrastructure-related factors independently, limited research has specifically investigated how charging infrastructure availability and accessibility influence consumers' intention to adopt EVs within a unified theoretical framework. Therefore, this study aims to examine the influence of charging infrastructure, represented by availability and accessibility, on the intention to adopt EVs among Malaysian consumers. The study is underpinned by the Theory of Planned Behavior (TPB), which explains that infrastructure readiness enhances perceived behavioral control, subsequently strengthening consumers' intention to adopt EVs. A quantitative research approach will be employed using a structured questionnaire distributed to existing EV users and potential adopters in Malaysia. A total of 171 respondents have been selected using purposive sampling, and the collected data analysed using Statistical Package for the Social Sciences (SPSS) to examine the relationship between charging infrastructure availability, accessibility, and EV adoption intention. The findings are availability and accessibility of charging infrastructure significantly improve consumers' confidence, reduce charging-related concerns, and positively influence their intention to adopt EVs.

Introduction

The transportation sector is one of the largest contributors to greenhouse gas emissions, making the transition towards sustainable mobility an important national agenda. In Malaysia, the government has introduced several initiatives under the National Energy Transition Roadmap (NETR) to accelerate the adoption of electric vehicles (EVs) and reduce carbon emissions while supporting long-term environmental sustainability (Ministry of Economy, 2023). Despite these initiatives, the adoption rate of EVs in Malaysia remains relatively low compared to more developed countries. One of the major barriers is the inadequacy of charging infrastructure, which continues to influence consumers' confidence and willingness to adopt EVs. This study is grounded in the Theory of Planned Behavior (TPB), which explains that behavioural intention is influenced by perceived behavioural control, attitude, and subjective norms (Ajzen, 1991). In the context of EV adoption, adequate charging infrastructure is expected to enhance consumers' perceived behavioural control by improving charging convenience and reducing charging-related concerns. Therefore, this study aims to examine the influence of charging infrastructure availability and charging infrastructure accessibility on Malaysian consumers' intention to adopt electric vehicles.

Literature Review

Charging infrastructure has been widely recognised as a critical determinant of electric vehicle (EV) adoption because it directly influences charging convenience, range confidence, and the practicality of EV ownership. Two key dimensions of charging infrastructure are availability, referring to the adequacy and geographical distribution of charging stations, and accessibility, referring to the ease with which consumers can locate and use charging facilities. Previous studies have consistently reported that adequate and accessible charging infrastructure

enhances consumers' confidence, reduces range anxiety, and positively influences EV adoption intention (Rahman et al., 2024; Syahirah & Farah, 2024; Yusoff et al., 2023; Nor et al., 2025). Grounded in the Theory of Planned Behavior (TPB), this study proposes that charging infrastructure strengthens consumers' perceived behavioural control by reducing charging-related concerns and increasing confidence in EV usage (Ajzen, 1991). Although previous studies have confirmed the importance of charging infrastructure, most have examined infrastructure readiness as a single construct rather than distinguishing between availability and accessibility. This study addresses this gap by investigating these two dimensions separately to provide a more comprehensive understanding of their influence on Malaysian consumers' intention to adopt electric vehicles.

Theoretical Framework and Hypotheses Development

This study is grounded in the Theory of Planned Behavior (TPB) proposed by Ajzen (1991), which explains that an individual's behavioural intention is influenced by attitude, subjective norms, and perceived behavioural control. Among these constructs, perceived behavioural control is particularly relevant to electric vehicle (EV) adoption, as it reflects consumers' perceptions of the ease and convenience of using EVs. In this study, charging infrastructure availability and accessibility are expected to enhance perceived behavioural control by reducing charging-related concerns and increasing consumers' confidence in adopting EVs (Ajzen, 1991; Rezvani et al., 2022). While the Theory of Planned Behavior (TPB) has been widely used to explain electric vehicle (EV) adoption, previous studies have generally treated charging infrastructure as a single contextual factor. This study extends TPB by distinguishing charging infrastructure into two dimensions—availability and accessibility—and examining their individual effects on EV adoption intention. This approach provides a more refined understanding of how different aspects of infrastructure strengthen perceived behavioural control and influence EV adoption, particularly in the Malaysian context. Charging infrastructure availability refers to the adequacy and distribution of charging stations that support convenient EV charging. A sufficient number of charging stations reduces range anxiety and increases consumers' confidence in using EVs for daily transportation. Previous studies have reported that infrastructure readiness positively influences consumers' intention to adopt EVs (Yusoff et al., 2023; Nor et al., 2025). Therefore, the following hypothesis is proposed:

H1: Charging infrastructure availability positively influences consumers' intention to adopt electric vehicles.

H2: Charging infrastructure accessibility positively influences consumers' intention to adopt electric vehicles.

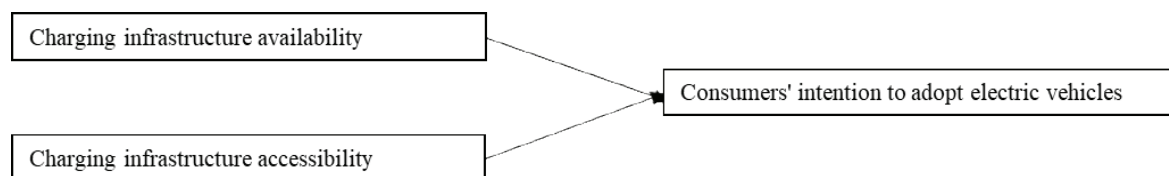


Fig. 14 Framework

Methodology

This study employed a quantitative research approach to investigate the influence of charging infrastructure on consumers' intention to adopt electric vehicles (EVs) in Malaysia. A quantitative method was appropriate as it enabled the measurement of relationships between variables through statistical analysis (Creswell & Creswell, 2018). The target population consisted of Malaysian consumers who were potential EV adopters or existing EV users.

Purposive sampling was employed to ensure that respondents possessed adequate awareness and understanding of EVs and charging infrastructure. A total of 171 respondents were selected, which was considered sufficient for multiple regression analysis and provided adequate statistical power for behavioural research (Hair et al., 2019). Data were collected using a structured questionnaire developed based on previously validated instruments related to EV adoption and charging infrastructure, following the questionnaire development procedures proposed by Sang and Bekhet (2015), He, Luo and Sun (2022) and Bhat et al., (2021). The questionnaire consisted of three sections: Section A captured respondents' demographic information, Section B measured the independent variables, namely charging infrastructure availability and accessibility, while Section C assessed consumers' intention to adopt EVs. Content validity was established through expert review, and face validity was conducted to ensure the clarity and appropriateness of the questionnaire items. A pilot study was subsequently conducted, and all constructs achieved Cronbach's alpha values exceeding the recommended threshold of 0.70, indicating satisfactory reliability. Participation in the study was voluntary, and informed consent was obtained from all respondents before data collection. Respondents were assured that their responses would remain anonymous and confidential and would be used solely for academic research purposes. The collected data were analysed using SPSS Version 29 through multiple regression analysis to examine the influence of charging infrastructure availability and accessibility on consumers' intention to adopt electric vehicles.

Result and Discussion

Overall, the 171 respondents comprised slightly more females (56.1%) than males (43.9%). Most respondents were aged 35–54 years (59.6%) and held a Bachelor's degree (36.8%). In terms of salary, the largest group earned RM3,001–RM6,000 (31.6%), while government employees represented the majority of respondents (61.4%). More than half of the respondents lived in urban areas (57.9%), indicating that the sample was predominantly composed of middle-aged, degree-educated, government-employed respondents residing in urban areas. The reliability analysis showed that all constructs achieved acceptable levels of internal consistency, with Cronbach's alpha values exceeding the recommended threshold of 0.70. This indicates that the items used to measure each construct were sufficiently consistent and reliable for further statistical analysis.

Table 1: Correlation Analysis

		Availability	Accessibility
Intention	Pearson Correlation	.513	.630
	Sig. (2-tailed)	.000	.000
	N	171	171

**. Correlation is significant at the 0.01 level (2-tailed).

Table 1 presents the results of the Pearson correlation analysis involving Availability, Accessibility, and Intention among 171 respondents. The results indicate that Availability has a moderate positive and significant relationship with Intention ($r = 0.513$, $p < 0.001$), while Accessibility has a strong positive and significant relationship with Intention ($r = 0.630$, $p < 0.001$). This indicates that higher levels of charging infrastructure availability and accessibility are associated with higher intention to adopt/use the technology. Since both p-values are below the 0.01 significance level, the relationships are statistically significant. Overall, Accessibility demonstrates a stronger relationship with Intention than Availability.

The multiple regression analysis indicates that the model comprising Availability and Accessibility significantly predicts Intention, with $R = .227$, $R^2 = .052$, and Adjusted $R^2 = .040$. This indicates that Availability and Accessibility jointly explain 4.0% of the variance in Intention. The ANOVA results show that the overall regression model is statistically

significant, $F(2,168) = 4.581$, $p = .012$. In terms of the individual predictors, Availability has a positive coefficient ($B = .107$, $\beta = .162$, $p = .033$), indicating a significant positive relationship with Intention, while Accessibility also has a positive and significant effect ($B = .133$, $\beta = .164$, $p = .030$). Based on the standardized beta coefficients, Accessibility ($\beta = .164$) is a slightly stronger predictor of Intention than Availability ($\beta = .162$). Therefore, both Availability and Accessibility significantly and positively contribute to Intention, although the overall explanatory power of the model is relatively low.

Table 2: Regression Analysis

Predictor	B	Std. Error	β	p-value	Result
Availability	0.107	0.049	0.162	0.033	Supported
Accessibility	0.133	0.061	0.164	0.030	Supported

Model Summary: $R = 0.227$; $R^2 = 0.052$; Adjusted $R^2 = 0.040$; $F(2,168) = 4.581$; $p = 0.012$.

The findings indicate that both charging infrastructure availability and charging infrastructure accessibility positively influence Malaysian consumers' intention to adopt electric vehicles (EVs). Adequate and easily accessible charging facilities enhance consumers' confidence, reduce charging-related concerns, and improve the perceived practicality of EV ownership. These findings are consistent with previous studies, which identified charging infrastructure as a critical determinant of EV adoption intention (Yusoff et al., 2023; Rahman et al., 2024; Nor et al., 2025; Siow & Chindamane, 2024). From a theoretical perspective, the findings support the Theory of Planned Behavior (TPB) by demonstrating that charging infrastructure strengthens consumers' perceived behavioural control, thereby enhancing their intention to adopt EVs. The study extends TPB by highlighting the role of infrastructure readiness as an important contextual factor in EV adoption. Practically, the findings suggest that policymakers and industry stakeholders should prioritise expanding charging networks and improving accessibility across urban and rural areas to strengthen Malaysia's EV ecosystem and accelerate the transition towards sustainable transportation.

Conclusion

This study demonstrates that charging infrastructure availability and accessibility significantly influence Malaysian consumers' intention to adopt EVs. The findings extend the TPB by highlighting the importance of infrastructure readiness in strengthening perceived behavioural control. Practically, policymakers should prioritise expanding charging infrastructure and improving accessibility to accelerate EV adoption. Future studies should employ larger samples and include additional infrastructure dimensions to improve the generalisability of the findings.

Acknowledgement

The authors are grateful to Universiti Teknikal Malaysia Melaka (UTeM) for providing the academic support required for this research. We also extend our appreciation to our colleagues and peer reviewers whose insightful suggestions improved the quality of this manuscript. This study was also financially supported by the Short-Term Research Grant (PJP) Perspektif (Non-Science and Technology), Universiti Teknikal Malaysia Melaka (UTeM), Project No. PJP/2025/FPTT/PERSPEKTIF/SA0079.

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ESG Institutionalization in Malaysia's Skills Development System: Governance, Competency Development, and Policy Alignment

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Abstract— Environmental, social, and governance (ESG) implementation in Malaysia's skills development system remains fragmented and compliance-oriented, limiting its integration into institutional structures and workforce practices. This critical review examines how governance, competency development, and policy alignment support ESG institutionalization. Guided by the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) framework and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, searches across Scopus, Web of Science, ScienceDirect, and Emerald Insight identified 182 records published between 2021 and 2026. Following duplicate removal, screening, and quality appraisal, 28 peer-reviewed articles entered the thematic synthesis, while 12 Malaysian policy documents provided contextual evidence. The findings identify governance as the foundation for accountability, stakeholder participation, oversight, and performance monitoring. Competency development translates ESG principles into occupational standards, curricula, assessment, trainer development, and workplace practice. Policy alignment connects sustainability objectives with accreditation, funding, quality assurance, and institutional delivery. Fragmentation across these dimensions sustains symbolic compliance and restricts system-wide implementation. The review proposes a three-stage framework comprising compliance, integration, and institutionalization. This framework provides analytical indicators for assessing institutional readiness and guiding a future case study within the Department of Skills Development Malaysia and national policy development.

Introduction

Environmental, social, and governance (ESG) principles shape organizational accountability, strategic decision-making, and workforce preparation. Institutionalization requires ESG to progress beyond disclosure-based compliance and become embedded within governance structures, operating models, and strategic priorities. This transition depends on capabilities translating regulatory and stakeholder expectations into coordinated procedures, employee competency development, and measurable practices. Integrated environmental responsibility, social value, and governance mechanisms also support stronger corporate sustainability performance [1].

In Malaysia, ESG research has primarily examined corporate practices and financial outcomes, while its relevance to skills development remains insufficiently explored. This limitation matters because technical and vocational education and training institutions develop occupational competencies required by sustainability-oriented industries. Evidence from Malaysian polytechnics identifies green knowledge, practical skills, values, and attitudes as essential to TVET curricula [2]. Governance responsibilities, ESG competency standards, and policy alignment across government agencies, training providers, certification bodies, and industry therefore require examination. Existing studies rarely integrate these institutional dimensions within a single analytical framework. This critical review addresses the gap by evaluating their relationships, identifying structural and implementation barriers, and proposing strategic priorities for ESG institutionalization in Malaysian skills development. The review provides a conceptual foundation for subsequent institutional assessment and national policy development.

Methodology

This study adopted a critical review to examine ESG institutionalization in Malaysia's skills development system through governance, competency development, and policy alignment. The review followed SPAR-4-SLR for search, selection, and synthesis decisions [3]. PRISMA 2020 principles guided identification, screening, eligibility assessment, and reporting [4]. The independent-study design strengthened methodological coherence and contribution [5].

Scopus and Web of Science were searched for English-language articles published from January 2021 to July 2026. ScienceDirect and Emerald Insight supplemented retrieval. Search strings combined “environmental social governance” OR “ESG” with “skills development,” “TVET,” “vocational education,” “competency,” “governance,” “policy alignment,” “institutionalization,” and “Malaysia.” Backward and forward citation tracking extended retrieval. Malaysian policy documents contextualized journal evidence. Studies addressing ESG governance, sustainability competencies, vocational or workforce development, institutional implementation, or policy coordination were included. Studies focused exclusively on investment returns, market valuation, or disclosure scores without workforce or institutional implications were excluded. Searches identified 182 records. After removing 54 duplicates, two reviewers screened 128 titles and abstracts and assessed 45 full-text articles. Twenty-eight peer-reviewed articles entered thematic synthesis. Twelve Malaysian policy documents supported contextual interpretation. An audit trail recorded search terms, exclusion reasons, and review decisions.

Quality appraisal examined research transparency, contextual relevance, evidence adequacy, and conceptual contribution, following established criteria [6]. Appraisal informed evidence weighting rather than automatic exclusion. An extraction matrix recorded bibliographic, contextual, and methodological information. Two reviewers independently completed screening and quality appraisal. Disagreements were resolved through discussion and consensus. Reflexive thematic analysis supported iterative coding and theme refinement [7]. The reviewers applied collaborative reflexive coding by comparing and refining interpretations. Evidence was coded within governance, competency development, and policy alignment before comparison across domains. The synthesis examined progression from compliance to institutionalization, identified convergent findings and unresolved tensions, and developed an integrated framework for Malaysian skills development. Triangulation of journal evidence and policy documents strengthened interpretive credibility, while the audit trail supported methodological transparency and analytical dependability.

Findings and Discussion

The critical synthesis identified three interdependent dimensions of ESG institutionalization within Malaysia's skills development system: governance, competency development, and policy alignment. Table 1 presents the dominant evidence patterns, institutional gaps, and required transitions across these dimensions.

Governance forms the foundation of ESG institutionalization. Regulatory requirements initiate compliance, while institutionalization requires ownership, leadership accountability, stakeholder participation, monitoring, and feedback [8]. Weak governance encourages symbolic reporting without changes to training systems, practices, or priorities. Competency development translates policy into workforce behaviour. Awareness programmes remain insufficient when ESG outcomes are absent from occupational standards, curricula, assessments, trainer development, and recognition systems. Competency development includes environmental responsibility, social inclusion, ethical judgement, regulatory literacy, data interpretation, and sustainable practice. Policy alignment coordinates objectives with institutional delivery through sustainability policies, industrial strategies, TVET standards,

funding, accreditation, and performance indicators [9]. Table 2 presents the institutionalization pathway and indicators for a future case study within the Department of Skills Development Malaysia (JPK).

Table 1: Critical Synthesis of ESG Institutionalization Dimensions

Dimension	Dominant evidence pattern	Institutional gap	Required transition
Governance	ESG implementation relies on regulatory pressure, reporting requirements, and organizational discretion [1], [8].	Fragmented accountability, weak monitoring, and limited stakeholder participation restrict sustained implementation.	Establish defined responsibilities, performance indicators, reporting structures, and cross-institutional oversight.
Competency development	ESG learning concentrates on awareness programmes, short courses, and general sustainability knowledge [2], [9].	Training lacks assessable occupational competencies, standardized outcomes, and workplace application.	Integrate ESG knowledge, technical skills, ethical judgement, and behavioural competencies into occupational standards and assessment.
Policy alignment	National sustainability, industrial, TVET, and workforce policies support related objectives [1], [9].	Policy instruments operate through separate mandates, timelines, standards, and monitoring systems.	Align national policies with occupational standards, curriculum requirements, accreditation, funding, and quality assurance.

Table 2: Proposed Transition Framework from ESG Compliance to Institutionalization

Development stage	Governance	Competency development	Policy alignment	Institutional indicator
Compliance	Responsibility responds to external requirements [1], [9].	ESG appears through awareness activities.	Institutions acknowledge national policies.	Reports, declarations, and isolated programmes
Integration	Agencies assign responsibilities and monitoring functions [8].	Standards and curricula include measurable ESG outcomes.	Policies connect with accreditation, funding, and quality assurance.	Coordinated implementation across institutional functions
Institutionalization	ESG becomes embedded in decision-making and accountability [1], [8].	Stakeholders demonstrate ESG competencies through routine practice.	Continuous feedback links policy design, standards, delivery, and evaluation.	Sustained ESG practice across the skills development system

The synthesis conceptualizes ESG institutionalization as an institutional capability rather than individual acceptance. Governance establishes authority, competency development converts policy into practice, and policy alignment ensures system-wide consistency. Failure within one dimension weakens the remaining dimensions. For the proposed case study, JPK should be examined through its occupational standards, accreditation mechanisms, quality assurance processes, trainer and assessor development, monitoring data, and inter-agency coordination. Differences across sectors, institutional settings, and ESG definitions restrict causal interpretation. The case study should test the proposed transition stages and identify the conditions supporting sustained ESG institutionalization.

Conclusion

This review establishes governance, competency development, and policy alignment as foundations of ESG institutionalization in Malaysia's skills development system. Governance

provides oversight, competency development converts ESG principles into assessable workforce practices, and policy alignment connects national objectives with standards, accreditation, funding, and quality assurance. Fragmentation across these dimensions sustains compliance-oriented implementation and limits institutional change. The Department of Skills Development Malaysia should embed ESG outcomes within occupational standards, curriculum guidance, trainer and assessor development, monitoring systems, and inter-agency coordination. The framework offers a basis for evaluating institutional readiness and progress. Future case studies should test the framework within JPK, examine stakeholder experiences, and identify organizational conditions supporting sustained ESG integration across Malaysia's skills development ecosystem.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia and the Department of Skills Development, Ministry of Human Resources, for their valuable academic and institutional support. The authors also extend their sincere appreciation to the FTKE and the SoTeCH Research Group, Universiti Teknikal Malaysia Melaka (UTeM) for their research support and contributions.

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Institutional Reform and Future Strategic Positioning of RELA: The Roles of Governance and Inter-Agency Collaboration

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Abstract— This study examines how institutional governance, leadership effectiveness, training and capability, digital transformation, and inter-agency collaboration influence the future strategic positioning of Jabatan Sukarelawan Malaysia (RELA). A quantitative cross-sectional correlational design was applied to 435 valid responses collected from 149,608 active RELA members through purposive sampling. Data were gathered using a 30-item, five-point Likert questionnaire and analysed through descriptive statistics, Pearson correlation, and multiple regression. Inter-Agency Collaboration recorded the highest mean score ($M = 4.14$), while Institutional Governance recorded the lowest ($M = 3.89$). All five reform factors showed significant positive correlations with Future Strategic Positioning. Inter-Agency Collaboration was the strongest correlate ($r = 0.88$) and the strongest independent predictor ($\beta = 0.415$, $p < 0.001$), followed by Institutional Governance ($\beta = 0.176$, $p = 0.002$). The model explained 51.3% of variance. Findings indicate that RELA should prioritise coordinated inter-agency mechanisms, governance clarity, accountability, role-based competencies, operationally aligned digital systems, measurable performance indicators, sustained institutional learning and adaptive reform capacity to strengthen institutional readiness and long-term strategic positioning.

Introduction

Jabatan Sukarelawan Malaysia (RELA) supports safety, emergency assistance, volunteer mobilisation, and national resilience. Growing expectations and service demands require RELA to strengthen its mandate, accountability, leadership, training, digital systems, and coordination. Public-sector reforms increasingly integrate performance management, collaborative governance, and institutional adaptation to improve responsiveness and value [1]. Leadership guides how public managers interpret responsibilities, mobilise personnel, and implement change within administrative structures [2].

Digital transformation represents a dimension of institutional readiness. Successful implementation depends on organisational capability, governance arrangements, and the integration of technology with operational processes [3]. Structural constraints, limited resources, routines, and resistance to change often impede digital-government initiatives, requiring strategies and reform leaders [4]. RELA's digital readiness must include data governance, staff competency, operational integration, and performance monitoring.

Inter-agency collaboration is important because RELA operates alongside emergency and community organisations. Malaysian evidence identifies unclear procedures, information systems, overlapping responsibilities, and weak information sharing as barriers to disaster coordination [5]. Despite RELA's role, limited evidence identifies which reform factors shape its future readiness. This study examines five institutional reform factors as predictors of RELA's future strategic positioning.

Methodology

This study employed a quantitative cross-sectional correlational design to examine institutional governance, leadership effectiveness, training and capability, digital transformation, and inter-agency collaboration as predictors of RELA's future strategic positioning. This design measured members' perceptions and assessed relationships among the six constructs.

The population comprised 149,608 active RELA members nationwide. Purposive sampling selected members with exposure to RELA’s institutional, operational, or volunteer functions. Defining the target population, eligibility criteria, and sampling procedure strengthened methodological transparency [6]. Sample adequacy was assessed against the population size and inferential analyses [7]. The study obtained 435 valid responses, exceeding the minimum of 384 and supporting correlation and multiple regression analyses. Data were collected online through RELA-related communication channels from 6 to 27 June 2026.

The questionnaire comprised respondent profile questions and 30 measurement items, with five items assigned to each construct. Responses were recorded on a five-point Likert scale ranging from 1, strongly disagree, to 5, strongly agree. Likert-scale principles guided item clarity, response consistency, and construct measurement [8]. Ishikawa Domain Mapping organised the five reform domains around future strategic positioning, while SWOT Analysis supported strategic interpretation of internal strengths and weaknesses and external opportunities and threats.

Responses were screened for incompleteness, duplication, inconsistent patterns, and eligibility. Frequencies and percentages described respondent characteristics. Means, standard deviations, and rankings assessed construct levels. Pearson correlation measured bivariate relationships, while multiple regression estimated each predictor’s unique contribution and the model’s explained variance. Normality, linearity, homoscedasticity, independence, and multicollinearity were examined before regression interpretation [9]. Anonymity, neutral wording, concise instructions, and statistical screening reduced common method bias associated with self-reported data [10].

Participation was voluntary. Respondents received study information before accessing the questionnaire, and submission indicated informed consent. No identifiers were collected. Findings were analysed and reported in aggregate form to protect confidentiality and maintain research integrity.

Findings and Discussion

The descriptive results indicated favourable perceptions across the five institutional reform constructs. As shown in Table 1, Inter-Agency Collaboration recorded the highest mean score ($M = 4.14$), indicating a strong institutional strength. Training and Capability ranked second ($M = 4.07$), reflecting a strong capability base. Leadership Effectiveness and Digital Transformation followed, with both constructs recording a mean score of 3.96. These results indicate positive perceptions, although stronger change execution remains necessary. Institutional Governance received the lowest mean score ($M = 3.89$), identifying it as RELA’s main improvement priority. The findings highlight the need to strengthen mandate clarity, accountability, decision transparency, and performance monitoring.

Table 1: Ranking of RELA Institutional Reform Constructs

Rank	Construct	Mean	Interpretation
1	Inter-Agency Collaboration	4.14	Strong institutional strength
2	Training and Capability	4.07	Strong capability base
3	Leadership Effectiveness	3.96	Positive but needs stronger change execution
4	Digital Transformation	3.96	Positive but needs stronger change execution
6	Institutional Governance	3.89	Main improvement priority

Table 2 shows significant positive correlations between every reform factor and Future Strategic Positioning. Inter-Agency Collaboration recorded the strongest relationship ($r = 0.88$, $p < 0.001$). Digital Transformation ($r = 0.81$), Training and Capability ($r = 0.78$), Institutional Governance ($r = 0.69$), and Leadership Effectiveness ($r = 0.61$) also recorded significant

relationships at $p < 0.001$. These findings indicate that improvement across each reform domain is associated with stronger perceptions of RELA's future readiness.

Table 2: Correlation and Multiple Regression Results for Future Strategic Positioning

Predictor	Pearson r	Correlation p-value	Standardized Beta	Regression p-value	Regression Result
Inter-Agency Collaboration	0.88	< 0.001	0.415	< 0.001	Significant
Institutional Governance	0.69	< 0.001	0.176	0.002	Significant
Digital Transformation	0.81	< 0.001	0.1	0.089	Not significant
Leadership Effectiveness	0.61	< 0.001	0.076	0.189	Not significant
Training and Capability	0.78	< 0.001	0.048	0.423	Not significant

The regression model was statistically significant and explained 51.3% of the variance in Future Strategic Positioning, with an adjusted R^2 of 0.507 and $p < 0.001$. Inter-Agency Collaboration emerged as the strongest independent predictor ($\beta = 0.415$, $p < 0.001$), supporting evidence that coordinated procedures and information sharing strengthen institutional response [5]. Institutional Governance was the second significant predictor ($\beta = 0.176$, $p = 0.002$). Its low descriptive ranking and significant predictive effect show that governance reform presents both RELA's main weakness and a strategic intervention point.

Digital Transformation, Leadership Effectiveness, and Training and Capability showed positive relationships but no significant independent effects due to shared variance. RELA should integrate these domains within reforms centred on institutional governance and inter-agency coordination.

Conclusions

This study confirms RELA's future strategic positioning depends primarily on inter-agency collaboration and institutional governance. Inter-agency collaboration produced the strongest independent effect, while institutional governance remained significant despite receiving the lowest mean score. These findings establish external coordination and internal accountability as reform priorities. Digital transformation, leadership effectiveness, and training and capability showed positive relationships but no significant independent effects, reflecting shared variance among the predictors. RELA should adopt a reform framework centred on mandate clarity, stronger accountability, formal joint procedures, improved information sharing, role-based competencies, and digital systems aligned with operational needs. Future studies should apply longitudinal designs, objective performance indicators, and comparisons with other public volunteer organisations to assess reform outcomes and sustainability.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia, for its academic guidance and research access. Appreciation is also extended to the Faculty of Electrical Technology and Engineering (FTKE) and the SoTeCH Research Group, Universiti Teknikal Malaysia Melaka (UTeM), for their valuable institutional and research support.

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Organisational Support, Leadership, and Work Environment as Predictors of Job Satisfaction in JKR Negeri Melaka

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Abstract— Employee job satisfaction is critical to workforce stability, organisational effectiveness and public-service performance. This study examines Organisational Support, Leadership and Work Environment as predictors of Job Satisfaction among employees of JKR Negeri Melaka. A quantitative cross-sectional survey involved 250 valid respondents selected through simple random sampling from a population of 545 employees across ten technical and administrative units. Data were collected using a five-point Likert questionnaire. A pilot study involving 30 respondents was conducted before the main survey, while construct reliability was assessed using Cronbach's alpha. All constructs demonstrated good internal consistency, with coefficients ranging from .84 to .89. Descriptive analysis showed that Organisational Support recorded the highest mean at 4.08, followed by Leadership at 3.96, Work Environment at 3.89 and Job Satisfaction at 3.84. All predictors showed significant positive relationships with Job Satisfaction. Organisational Support emerged as the strongest independent predictor ($\beta = .39, p < .001$), followed by Leadership ($\beta = .28, p < .001$) and Work Environment ($\beta = .19, p = .004$). The model explained 56.2% of the variance in Job Satisfaction. The findings support prioritising organisational support, leadership quality and workplace improvement to strengthen employee satisfaction, engagement and sustainable public-service performance.

Introduction

JKR Negeri Melaka supports infrastructure development and public-service delivery through diverse functions. Employee effectiveness depends on organisational practices, leadership quality and workplace conditions that sustain trust and Job Satisfaction. Recent evidence shows that leader behaviours are associated with trust and Job Satisfaction [1], while transformational leadership influences psychological empowerment, organisational commitment and career satisfaction [2]. Virtual leadership also affects Job Satisfaction through work-life balance and trust in leaders [3]. Perceived Organisational Support contributes to Job Satisfaction by strengthening perceptions of support, security and organisational commitment [4], [5]. Work Environment is similarly important, as job demands, job resources and workplace conditions are associated with employee well-being and work-related outcomes through psychological need satisfaction [7]. Leadership practices and reward systems further influence Job Satisfaction and employee performance [6]. These findings indicate that Work Environment, Leadership and Organisational Support should be examined together when evaluating employee outcomes.

Despite growing evidence on these relationships, limited institution-specific evidence is available on which organisational factor most strongly predicts Job Satisfaction within JKR Negeri Melaka's context. This study therefore examines Work Environment, Leadership and Organisational Support as predictors of Job Satisfaction across ten technical and administrative units. A quantitative cross-sectional survey is applied, using descriptive statistics, Pearson correlation and multiple regression to determine construct levels, relationship strength and each predictor's independent contribution. The findings are intended to establish evidence-based management priorities and support improvements in morale, engagement, retention, workplace effectiveness and sustainable public-service performance.

Methodology

This study applies a quantitative cross-sectional survey design to examine Work Environment, Leadership and Organisational Support as predictors of Job Satisfaction among employees of JKR Negeri Melaka. The quantitative approach enables numerical measurement, hypothesis testing and statistical assessment of relationships among organisational variables [8]. The cross-sectional design captures employee perceptions at one point in time without manipulating the organisational setting. Work Environment, Leadership and Organisational Support are treated as independent variables, while Job Satisfaction serves as the dependent variable.

The target population comprises 545 technical and administrative personnel across ten units within JKR Negeri Melaka. The official employee list was used as the sampling frame to ensure that all eligible employees had an identifiable and equal opportunity for selection. The minimum sample size was determined using the Krejcie and Morgan method for a finite population [11]. For a population of 545 employees, approximately 226 respondents were required. Simple random sampling was subsequently applied to select eligible respondents from the sampling frame. A total of 250 valid responses were included in the final analysis, exceeding the minimum sample requirement. Participation was voluntary, while respondent anonymity supported honest reporting and reduced social desirability effects.

Data were collected using a structured questionnaire with a five-point Likert scale ranging from 1, strongly disagree, to 5, strongly agree. Likert scaling provides a standardised approach for measuring workplace perceptions [9]. Questionnaire items assessed physical and psychosocial working conditions, leadership communication and support, recognition, organisational care, employee morale and Job Satisfaction. Work Environment items reflected evidence concerning job demands, job resources and workplace conditions [7]. Leadership items were informed by evidence concerning leadership behaviour, empowerment and Job Satisfaction [1]–[3]. Organisational Support items reflected studies on perceived organisational support and organisational commitment [4], [5]. Job Satisfaction measures were aligned with evidence linking leadership, rewards and employee outcomes [6].

Before the main survey, a pilot study involving 30 respondents with characteristics comparable to the target population was conducted to assess questionnaire clarity, usability and internal consistency. Pilot respondents were excluded from the final study sample. Cronbach's alpha was used to evaluate construct reliability, with coefficients of .70 or above considered acceptable.

The final dataset was screened for incomplete, duplicate and inconsistent responses before analysis. Frequencies and percentages described respondent characteristics, while means and standard deviations assessed construct levels and response dispersion. Pearson correlation examined the strength and direction of relationships between each predictor and Job Satisfaction. Multiple regression estimated the independent contribution of each predictor while controlling for the remaining variables [10]. Statistical significance was evaluated at $p < .05$. Regression assumptions covering linearity, normality, homoscedasticity and multicollinearity were examined before coefficient interpretation. Because the study used cross-sectional self-reported data, the findings support association and prediction rather than causal inference.

Findings and Discussion

A total of 250 valid responses were analysed from a population of 545 employees. Table 1 shows favourable perceptions across all four constructs. Organisational Support recorded the highest mean at 4.08, followed by Leadership at 3.96, Work Environment at 3.89 and Job Satisfaction at 3.84. All constructs demonstrated good internal consistency, with Cronbach's alpha coefficients ranging from .84 to .89.

Table 1: Descriptive Statistics and Reliability of the Research Constructs

Construct	Items	Mean	Standard Deviation	Cronbach's α	Interpretation
Organisational Support	5	4.08	0.68	0.89	Good
Leadership	5	3.96	0.72	0.87	Good
Work Environment	5	3.89	0.76	0.84	Good
Job Satisfaction	5	3.84	0.79	0.86	Good

Legend: $\alpha \geq 0.90$ = Excellent; 0.80–0.89 = Good; 0.70–0.79 = Acceptable.

Pearson correlation analysis identified significant positive relationships between all predictors and Job Satisfaction. Organisational Support showed the strongest relationship, $r = .71$, followed by Leadership, $r = .66$, and Work Environment, $r = .59$. These findings are consistent with previous evidence linking Organisational Support with employee satisfaction and commitment [4], [5], Leadership with Job Satisfaction and performance [1]–[3], [6], and Work Environment with employee well-being and work-related outcomes [7].

Multiple regression explained 56.2% of the variance in Job Satisfaction. Organisational Support remained the strongest independent predictor, $\beta = .39$, $p < .001$, followed by Leadership, $\beta = .28$, $p < .001$, and Work Environment, $\beta = .19$, $p = .004$.

Table 2: Correlation and Multiple Regression Results for Job Satisfaction

Predictor	Pearson r	Correlation p-value	Standardized Beta	Regression p-value	Result
Organisational Support	0.71	$< .001$	0.39	$< .001$	Significant
Leadership	0.66	$< .001$	0.28	$< .001$	Significant
Work Environment	0.59	$< .001$	0.19	0.004	Significant

Model summary: $R^2 = 0.562$

The stronger contribution of Organisational Support may reflect employees' dependence on recognition, resources, welfare support and management responsiveness within a public-sector environment. Leadership quality provides an additional contribution through communication, guidance and supervisory support. Work Environment remains significant, indicating that physical and psychosocial workplace conditions also contribute to Job Satisfaction. The findings therefore support prioritising organisational support, leadership effectiveness and workplace improvement as complementary workforce-management interventions within JKR Negeri Melaka.

Conclusion

This study identifies Organisational Support, Leadership and Work Environment as significant predictors of Job Satisfaction among employees of JKR Negeri Melaka. Organisational Support emerged as the strongest independent predictor, followed by Leadership and Work Environment, while the overall model explained 56.2% of the variance in Job Satisfaction. All four constructs demonstrated good internal consistency, supporting the reliability of the measurement framework. The findings indicate that recognition, welfare support, management responsiveness, leadership quality and workplace conditions should remain central workforce priorities. Management should therefore strengthen organisational support systems, supervisory effectiveness and workplace practices as complementary interventions to improve employee satisfaction, engagement and service performance. Because the study applied a cross-sectional self-reported design, the findings support association and prediction rather than causal inference. Future research should incorporate longitudinal designs, objective performance indicators, unit-level comparisons and qualitative evidence to examine changes

over time and across organisational functions, thereby supporting more targeted workforce interventions and sustainable public-service performance within JKR Negeri Melaka.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia, and JKR Negeri Melaka for their academic guidance, institutional cooperation and facilitation of research access. Appreciation is also extended to the Faculty of Electrical Technology and Engineering and the SoTeCH Research Group, Universiti Teknikal Malaysia Melaka, for their institutional and research support.

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The Unfinished Architecture: A Critical Review of TVET-Based Human Capital Development in Malaysia's Public Sector

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Abstract— Malaysia's public sector requires technical, digital, managerial and adaptive competencies to strengthen performance and service delivery. This critical review examines how governance, institutional capacity, competency development and workforce integration shape Technical and Vocational Education and Training (TVET)-based human capital development. Guided by the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) framework and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, the review searched Scopus and Web of Science for peer-reviewed articles published from January 2016 to July 2026. Database searches identified 236 records. Following duplicate removal and screening, 34 articles entered thematic synthesis, while 16 policy documents supported contextual analysis. Quality appraisal classified 12 articles as high quality, 18 as moderate quality and 4 as low quality. Findings identify fragmented governance, uneven delivery capacity, weak alignment between training and occupational requirements and limited integration with career progression and performance systems. The review proposes a five-layer Public Sector TVET Human Capital Architecture comprising strategic governance, policy alignment, delivery capacity, competency systems and workforce integration. The framework offers assessment indicators for institutional reform and supports empirical testing across Malaysian ministries, agencies, occupational groups and public training institutions.

Introduction

Technical and vocational education and training (TVET) supports public-sector capability by connecting occupational standards, professional development, and workforce performance. In Malaysia, policy commitment to TVET is extensive, yet fragmented governance, overlapping mandates, and weak institutional coordination continue to restrict coherent workforce development [1]. These conditions create an unfinished architecture in which training provision, competency recognition, career progression, and organizational outcomes remain insufficiently integrated. Industry 4.0 has expanded workforce requirements beyond technical proficiency to include digital literacy, problem-solving, communication, adaptability, and work-based learning [2]. Evidence from Malaysian state governments also links talent development and retention with employee performance [3]. Apprenticeship research identifies instructor capability, continuing professional development, employer engagement, and training-provider coordination as essential delivery conditions [4]. The National Occupational Skills Standard (NOSS) provides the formal basis for defining occupational competencies and assessment requirements [5]. Its alignment with public-service training, career progression, and performance systems remains underexamined.

This critical review examines how governance, institutional capacity, competency development, and workforce integration shape TVET-based human capital development in Malaysia's public sector. It evaluates areas of evidence convergence, disagreement, and weakness, then proposes an integrated architecture for institutional assessment, policy coordination, and future case-study research.

Methodology

This critical review examined TVET-based human capital development in Malaysia's public sector across governance, institutional capacity, competency development, and workforce

outcomes. SPAR-4-SLR guided search, selection, and synthesis decisions [6], while PRISMA 2020 informed identification, screening, eligibility assessment, and reporting [7].

Scopus and Web of Science were searched for English-language, peer-reviewed articles published from January 2016 to July 2026. Search strings combined “TVET” or “technical and vocational education and training” with “public sector,” “human capital development,” “workforce development,” “governance,” “institutional capacity,” “occupational standards,” “competency,” “career development,” “public service,” and “Malaysia.” Backward and forward citation tracking supplemented database retrieval. Eligible articles addressed institutional, occupational, workforce, or public-service implications. Studies without relevant TVET or workforce evidence were excluded. Policy evidence was retrieved from JPK, KESUMA, MOHE, MTVET, MQA, JPA, INTAN, and MAMPU repositories. Eligible Malay- or English-language documents published from 2016 to 2026 included policies, development plans, qualification frameworks, occupational standards, circulars, guidelines, and strategic reports. News items, speeches, promotional materials, duplicates, and documents without institutional relevance were excluded. Database exports contained 236 records, comprising 142 from Scopus and 94 from Web of Science. After removing 71 duplicates, two reviewers screened 165 titles and abstracts, excluded 107 records, and assessed 58 full texts. Twenty-four full texts were excluded for insufficient public-sector relevance ($n = 9$), absent TVET or workforce implications ($n = 7$), inadequate institutional evidence ($n = 5$), or unavailable analytical data ($n = 3$). Thirty-four articles entered thematic synthesis, while 16 policy documents supported contextual interpretation. An audit trail recorded searches, exclusions, and decisions. Two reviewers independently completed screening and quality appraisal, resolving disagreements through consensus. Articles received scores of 0–2 for research transparency, contextual relevance, evidence adequacy, and conceptual contribution [8]. Total scores classified 12 articles as high quality, 18 as moderate, and four as low. An extraction matrix captured bibliographic, methodological, and analytical data. Collaborative reflexive thematic analysis supported coding, cross-domain comparison, interpretation, theme refinement, and framework development [9].

Findings & Discussion

The thematic synthesis identified three interdependent dimensions shaping TVET-based human capital development in Malaysia’s public sector. These dimensions were governance and policy coherence, institutional and delivery capacity, and competency development and workforce outcomes. Table 1 summarises the principal findings, structural gaps, and reform implications.

Evidence converged on governance fragmentation as the main structural constraint, particularly where overlapping mandates separate funding, delivery, and performance accountability. Malaysian TVET studies supported competency-based training and Industry 4.0 capabilities. These studies primarily examined students and training institutions rather than serving public officers. Public-sector studies linked workforce development with managerial support, career systems, employee performance, and service delivery. Malaysian state-government evidence further associated talent management with employee performance. Apprenticeship research identified instructor capability, continuing professional development, employer engagement, and workplace coordination as institutional delivery constraints. National Occupational Skills Standards provides the formal basis for defining occupational competencies and assessment requirements. Their alignment with public-service training, career progression, and performance systems remains underexamined. Differences across the evidence base also reflected occupational roles, institutional maturity, delivery resources, and performance expectations. Table 2 integrates these convergent findings, contextual differences, and unresolved evidence gaps into an institutional assessment framework.

Table 1: Critical Synthesis of Public-Sector TVET Human Capital Development

Domain	Principal Finding	Structural Gap	Reform Implication
Governance and Policy Coherence	Multiple agencies support TVET through separate mandates, standards, and funding arrangements.	Fragmented authority, overlapping functions, and inconsistent performance measures	Establish coordinated governance, defined ownership, and shared accountability
Institutional and Delivery Capacity	Training delivery varies across agencies due to differences in resources, expertise, infrastructure, and employer engagement.	Uneven implementation, limited trainer development, and weak knowledge transfer	Introduce common delivery standards, trainer certification, and institutional capacity assessment
Competency Development and Workforce Outcomes	Programmes emphasise technical knowledge, while digital, behavioural, leadership, and adaptive competencies receive uneven attention.	Weak alignment between training, job roles, career progression, and organisational outcomes	Link competency standards with occupational requirements, assessment, and career pathways

Source: Authors' synthesis

Table 2: Proposed Public Sector TVET Human Capital Architecture

Architecture Layer	Required Mechanism	Expected Outcome	Assessment Indicator
Strategic Governance	Central coordination and role clarity	Reduced duplication	Mandate and accountability structure
Policy Alignment	Common standards and funding priorities	Consistent implementation	Cross-agency policy coherence
Delivery Capacity	Certified trainers and adequate infrastructure	Reliable programme quality	Trainer, facility, and digital readiness
Competency System	Role-based standards and assessment	Workplace-relevant competence	Competency attainment and transfer
Workforce Integration	Career pathways and performance linkage	Improved workforce outcomes	Progression, mobility, and service performance

Source: Authors' synthesis

The three review domains produced five layers: Strategic Governance, Policy Alignment, Delivery Capacity, Competency System, and Workforce Integration. Together, they distinguish strategic direction, implementation capacity, and workplace outcomes while maintaining institutional interdependence. Limited Malaysian evidence on competency transfer, career progression, inter-agency mobility, and service outcomes supports future case studies across ministries, agencies, occupational groups, and public training institutions.

Conclusion

This review identifies governance, institutional capacity, and competency development as interdependent foundations of TVET-based human capital development in Malaysia's public sector. Fragmented mandates, uneven delivery resources, and weak links between training, occupational requirements, and workforce outcomes leave the architecture incomplete. Reform should establish coordinated governance, performance indicators, consistent delivery standards, certified trainers, and role-based competency pathways. Public agencies should align TVET programmes with career progression, digital transformation, service priorities, and measurable workplace performance. The proposed Public Sector TVET Human Capital Architecture integrates these requirements into an institutional framework. Future research should test this framework through case studies across ministries, agencies, and training institutions. Longitudinal evidence should assess competency transfer, progression, service improvement, and institutional sustainability after implementation of the reforms.

Acknowledgement

The authors gratefully acknowledge the Faculty of Electrical Technology and Engineering (FTKE) and the SoTeCH Research Group, Universiti Teknikal Malaysia Melaka (UTeM), for their research support. Appreciation is also extended to City Graduate School, City University Malaysia, for its academic and institutional support.

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Body-Worn Cameras in Law Enforcement: A Critical Review of Integrity, Accountability and Officer Safety

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Abstract— Body-worn cameras support integrity, accountability, evidential reliability and officer safety across enforcement organisations. Their effectiveness depends on activation compliance, supervisory oversight, privacy safeguards and institutional capacity. This critical review examined the conditions shaping implementation and identified evidence gaps in maritime and specialised enforcement settings. Following the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) framework and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, Scopus articles published from January 2021 to 20 July 2026 were reviewed. Searches identified 258 records. After screening and appraisal, 38 peer-reviewed articles entered thematic synthesis alongside 15 Malaysian policy documents. Sixteen articles received high-quality ratings, 18 moderate ratings and four low ratings. Findings identified five domains: integrity and accountability, officer safety, evidential value, privacy and data governance as well as implementation capacity. Compulsory activation, metadata auditing, officer competency, secure evidence management and evaluation strengthened implementation. Evidence concerning physical safety and behavioural moderation remained mixed, while professional protection and evidential value received stronger support. The review proposes an institutional framework integrating governance, operational readiness, competency, technology and evaluation for responsible implementation. Future empirical research should assess implementation suitability within the Malaysian Maritime Enforcement Agency (MMEA).

Introduction

Body-worn cameras have become accountability and evidence technologies across enforcement organisations. Their adoption reflects expectations of integrity, transparent encounters, evidential records, fewer complaints and officer safety. Recorded footage does not guarantee these outcomes. Accountability benefits depend on consistent activation, supervisory review and metadata analysis to identify non-compliance and complaint patterns [1], [2]. Evidence concerning officer safety remains mixed, although recordings provide professional protection against inaccurate allegations [3]. Body-worn-camera footage improves report completeness and supports investigations. Yet reviewing footage before report completion influences officer recollection and accounts [4]. Recordings capture a restricted perspective and omit preceding events or interactions outside the camera frame [5]. These limitations create governance concerns involving activation discretion, privacy, access, retention, disclosure, evidential integrity and organisational capacity.

Existing studies predominantly examine conventional policing, correctional institutions and domestic-violence responses. Maritime, border and specialised enforcement settings remain underexplored despite operational conditions and evidential requirements. This review evaluates how governance, officer competency, technology, privacy and evidence management shape body-worn-camera outcomes. It asks under which institutional conditions these cameras strengthen integrity, accountability and officer safety. The review identifies contradictory evidence, implementation limitations and institutional safeguards for deployment across specialised enforcement environments.

Methodology

This critical review examined how body-worn cameras influence integrity, accountability, evidential reliability, officer safety, privacy and institutional readiness. SPAR-4-SLR structured search, selection and synthesis decisions [6]. PRISMA 2020 guided identification, screening, eligibility assessment and reporting [7].

Scopus was searched for English-language articles published from January 2021 to 20 July 2026. Search strings combined “body-worn camera,” “body camera” and “BWC” with law enforcement, policing, maritime enforcement, coast guard, integrity, accountability, officer safety, digital evidence, privacy and data governance. Citation tracking supplemented retrieval. Studies addressing adoption, governance, officer conduct, safety, evidence management, privacy or organisational outcomes were included. Studies lacking enforcement relevance, institutional implications or analytical evidence were excluded.

Multiple Scopus searches produced 258 records across overlapping search-string combinations. After merging search outputs, 72 duplicate records were removed, leaving 186 titles and abstracts for screening. Two reviewers excluded 125 records and assessed 61 full texts. Twenty-three articles were excluded for insufficient enforcement relevance ($n = 9$), limited institutional evidence ($n = 8$) or inadequate outcome reporting ($n = 6$). Thirty-eight peer-reviewed articles entered synthesis.

Fifteen Malay- or English-language policy documents were purposively retrieved from KDN, PDRM, EAIC, Personal Data Protection Department, Attorney General’s Chambers and APMR repositories. Eligible documents comprised acts, policies, directives, guidelines, strategic plans and operational procedures concerning recording technology, enforcement integrity, privacy or digital evidence. Superseded, duplicated or irrelevant documents were excluded.

Two reviewers independently completed screening and quality appraisal, resolving disagreements through consensus. Four criteria assessed methodological transparency, evidence adequacy, relevance and contribution [8]. Each criterion received 0–2 points. Total scores classified evidence as high quality (7–8), moderate quality (4–6) or low quality (0–3). Appraisal classified 16 articles as high, 18 as moderate and four as low quality. Results informed evidence weighting rather than exclusion. An extraction matrix recorded study characteristics, implementation conditions, outcomes and limitations. Reflexive thematic analysis examined convergence, disagreement, variation and research gaps [9]. Audit records documented searches, exclusions, appraisal scores and synthesis decisions.

Findings and Discussion

The synthesis identified five connected domains: integrity and accountability, officer safety, evidential value, privacy and data governance as well as implementation capacity. Table 1 links each domain with representative evidence from the 38 included articles. The results show conditional rather than uniform outcomes. Activation compliance, supervisory oversight, operational procedures, officer competency, technical reliability and evidence-management controls shaped implementation effectiveness.

Integrity benefits were strongest under compulsory activation, reviewed non-activation and metadata monitoring [1], [2]. Selective recording and weak enforcement reduced accountability. Recordings provided stronger protection against inaccurate allegations than measurable physical-safety improvement [3]. Evidential benefits included fuller reports and contemporaneous records. Footage review influenced recollection and reporting, supporting clear viewing protocols [4]. Camera footage offered a restricted perspective requiring corroborating statements, operational records and contextual evidence [5]. Policy documents reinforced the need for defined ownership, privacy safeguards, controlled access and secure evidential processes. Table 2 integrates these findings into three implementation domains.

Table 1: Critical Synthesis of Body-Worn-Camera Evidence

Domain	Convergent Finding	Variation or Limitation	Institutional Implication
Integrity and accountability	Recorded encounters strengthen complaint assessment and supervisory review [1], [2]	Benefits decline under discretionary activation, incomplete recording or weak monitoring [1]	Establish compulsory activation, documented exemptions and metadata auditing
Officer safety	Recordings strengthen professional protection against inaccurate allegations [3]	Evidence concerning physical safety and behavioural moderation remains mixed [3]	Separate physical, procedural and professional safety indicators
Evidential value	Footage supports reporting, investigation and case review [4], [5]	Viewing footage influences recollection while camera perspective excludes parts of the operational context [4], [5]	Preserve independent reporting, controlled viewing and contextual corroboration
Privacy and data governance	Recordings support transparency, evidential continuity and institutional memory [5]	Uncontrolled access, retention or disclosure creates privacy and procedural risks [5]	Establish access, redaction, retention and disclosure protocols
Implementation capacity	Supervision, metadata monitoring and clear procedures strengthen consistent use [1], [2], [4]	Weak compliance, technical limitations and procedural uncertainty reduce effectiveness [1], [4]	Integrate technology with competencies, procedures and institutional oversight

Source: Authors' synthesis

The findings frame body-worn cameras as institutional systems requiring coordinated governance, officer conduct, technology, privacy safeguards and evidence management. Evidence from maritime, border and specialised enforcement remains limited, reducing direct transfer from conventional policing. Context-specific empirical assessment is needed to establish operational suitability and specific implementation requirements.

Table 2: Review-Derived Institutional Framework for Body-Worn-Camera Implementation

Institutional Domain	Required Institutional Actions	Evaluation Indicator
Governance and accountability	Define policy ownership, activation rules, oversight authority and operational exemptions	Activation compliance reviewed non-activation cases and complaint resolution
Operational and competency readiness	Train officers in activation, notification, reporting, privacy and evidence handling	Competency results, officer acceptance and procedural compliance
Technology, evidence and evaluation	Ensure equipment reliability, secure storage, controlled access, chain of custody and impact assessment	Equipment failure, footage availability, audit compliance and outcome differences

Source: Authors' synthesis

Conclusion

This review establishes body-worn cameras as institutional systems whose outcomes depend on governance, officer behaviour, technical readiness and evidence management. Stronger integrity and accountability emerged under compulsory activation, metadata auditing, supervisory review and enforceable procedures. Professional protection against inaccurate allegations received clearer support than improvements in physical safety or behavioural moderation. Evidential value also depended on independent reporting, viewing protocols,

contextual corroboration and secure chain-of-custody controls. The review-derived framework integrates governance and accountability, operational and competency readiness as well as technology, evidence and evaluation. It offers enforcement organisations a basis for policy design, implementation planning and outcome assessment. Existing evidence remains concentrated in conventional policing and correctional environments, limiting direct application to maritime, border and specialised operations. A context-specific empirical study should therefore examine body-worn-camera implementation within the Malaysian Maritime Enforcement Agency (MMEA). The study should assess operational suitability, activation compliance, officer acceptance, privacy safeguards, evidential quality, integrity outcomes and implementation capacity before wider deployment.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia, and the Malaysian Maritime Enforcement Agency (MMEA) for their academic and institutional support. The authors also extend their appreciation to the FTKE and the SoTeCH Research Group, Universiti Teknikal Malaysia Melaka (UTeM), for their valuable institutional and research support.

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Proactive Leadership, Ethical Perseverance, Behavioral Role Modeling, and Inspirational Motivation in Public-Sector Enforcement Agencies: A Critical Review

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Abstract— Leadership in public-sector enforcement agencies requires initiative, ethical consistency, credible conduct and sustained purpose under operational pressure. This critical review examined how proactive leadership, ethical perseverance, behavioral role modeling and inspirational motivation influence integrity, discretionary conduct, employee commitment and institutional performance. Scopus searches covering January 2021 to July 2026 identified 400 records. After duplicate removal, staged screening and quality appraisal, 38 articles entered reflexive thematic synthesis. Findings show that proactive leadership supports timely action when authority, accountability and role expectations are clear. Ethical perseverance sustains principled judgment, although direct empirical measurement remains limited. Behavioral role modeling strengthens credibility through consistent conduct, while inspirational motivation connects institutional purpose with commitment and performance. The four attributes operate as interdependent leadership capabilities reinforced by organizational accountability, institutional protection and supportive leadership conditions. Evidence remains concentrated in policing, street-level administration and local government, with limited research across maritime, border, immigration and regulatory enforcement. The review proposes an integrated framework linking initiative, integrity, conduct and purpose while identifying priorities for longitudinal, multisource and comparative research within diverse public-sector enforcement contexts.

Introduction

Public-sector enforcement agencies operate under legal scrutiny, uncertainty, public expectations and discretionary authority. Leadership in these environments requires initiative without weakening ethical boundaries, accountability or institutional control. Proactive leadership can strengthen anticipatory problem-solving and employee initiative when authority, role expectations and responsible discretion are clearly defined [1]. Ethical leadership also influences how frontline officers interpret rules, exercise judgment and respond to competing demands through psychological empowerment and principled decision-making [2]. Ethical voice is further shaped by value internalization and integrity identity when employees face pressure, ambiguity or organizational silence [3].

Behavioral role modeling represents a visible dimension of ethical leadership because leaders communicate standards through consistent decisions and conduct [4]. Inspirational motivation complements this process by connecting institutional purpose with commitment, public service motivation and performance [5]. However, these attributes are rarely examined as an integrated leadership system. Ethical perseverance remains conceptually underdeveloped, while evidence from maritime, border, immigration and regulatory enforcement remains limited. This critical review examines how the four attributes interact to influence integrity, discretionary conduct, employee commitment and institutional performance while developing an integrated framework for enforcement leadership research.

Methodology

This study adopted a critical review to examine proactive leadership, ethical perseverance, behavioral role modeling and inspirational motivation in public-sector enforcement agencies. Review design, search strategy, study selection and synthesis followed systematic literature review guidance to strengthen transparency and reproducibility [6]. Quality appraisal informed

assessment and weighting of included studies [7], while reflexive thematic analysis supported coding and interpretation [8].

Scopus was searched for English-language articles published from January 2021 to July 2026. Search terms combined the four leadership attributes with public administration, policing, regulatory officers, street-level bureaucrats, border services and enforcement agencies. Targeted manual reference tracking supplemented searching. Studies were included when they examined a leadership attribute within public-sector or enforcement contexts. Articles without leadership relevance, institutional evidence or reported outcomes were excluded. Books, conference papers, editorials, dissertations, non-English publications and studies outside the period were excluded. The search identified 400 records. After 92 duplicates were removed, two reviewers screened 308 titles and abstracts, excluding 247 records. Sixty-one full texts underwent eligibility assessment. Twenty-three were excluded for insufficient enforcement relevance ($n = 10$), limited institutional evidence ($n = 7$) or inadequate outcome reporting ($n = 6$). Thirty-eight articles entered synthesis. An audit trail documented search dates, combinations, duplicate removal, exclusion reasons and screening decisions.

Two reviewers conducted screening and quality appraisal. Disagreements were resolved through consensus. Each article received scores from zero to two for research transparency, methodological suitability, contextual relevance and evidence adequacy. Total scores classified studies as high quality (7–8), moderate quality (4–6) or low quality (0–3). Appraisal guided evidence weighting rather than exclusion. An extraction matrix recorded context, design, sample, leadership construct, outcomes, limitations and quality score. Stronger studies received greater interpretive emphasis. Reflexive thematic analysis organized evidence across the four attributes, examined convergence, disagreement and contextual variation, and supported development of the integrated framework [8]. Restricting retrieval to Scopus improved consistency but excluded non-indexed research.

Findings and Discussion

The review identified four interrelated leadership attributes, as summarized in Table 1. Proactive leadership was associated with anticipatory problem-solving, employee initiative and operational responsiveness, particularly when supported by clear authority, role expectations and accountability [1]. Ethical perseverance received indirect support from studies showing that psychological empowerment, value internalization and integrity identity influence principled judgment, ethical voice and responsible discretion [2], [3]. However, direct empirical measurement of ethical perseverance remains limited, suggesting that the construct requires clearer operational definition and validation.

Table 1: Critical Synthesis of Leadership Attributes

Leadership attribute	Evidence pattern	Critical interpretation	Methodological limitation
Proactive leadership	Anticipatory action and employee initiative [1]	Effective when guided by accountability and role clarity	Limited enforcement-specific testing
Ethical perseverance	Empowerment, ethical voice, and integrity identity [2], [3]	Supports principled judgment under pressure	Mostly inferred from related constructs
Behavioural role modelling	Ethical role modeling among United States local-government managers [4]	Supports role modeling as a dimension of public-sector ethical leadership	Not directly tested within enforcement agencies
Inspirational motivation	Shared purpose, commitment, and performance [5]	Connects institutional mission with employee effort	Limited maritime, border, and regulatory evidence

Source: Authors' synthesis

Behavioral role modeling emerged as an observable mechanism through which ethical standards are translated into managerial conduct. Evidence from public organizations indicates that leadership credibility depends on consistency between decisions, communication and responses to ethical issues [4]. Inspirational motivation complements this process by connecting institutional purpose with commitment, public service motivation and performance [5]. Across the reviewed studies, the four attributes were more influential when reinforced by organizational accountability, institutional protection and credible leadership conduct. Their effectiveness therefore appears dependent on interaction rather than isolated application.

Table 2: Integrated Leadership Framework for Public-Sector Enforcement Agencies

Attribute	Institutional requirement	Implementation risk	Expected outcome
Proactive leadership	Clear authority and supervisory control	Inconsistent discretion	Timely operational response
Ethical perseverance	Protection for ethical voice and responsible dissent	Silence under pressure	Sustained integrity
Behavioural role modelling	Consistent decisions and misconduct responses	Loss of leader credibility	Ethical conduct
Inspirational motivation	Credible purpose and organizational support	Symbolic motivation	Commitment and performance

Source: Authors' synthesis

The integrated framework positions proactive leadership, ethical perseverance, behavioral role modeling and inspirational motivation as mutually reinforcing institutional capabilities. Proactive leadership enables timely action, while ethical perseverance sustains principled judgment under operational pressure. Behavioral role modeling strengthens credibility by translating institutional values into consistent conduct. Inspirational motivation connects credible leadership behaviour with institutional purpose, commitment and performance. Together, these attributes form an interdependent pathway linking initiative, integrity, conduct and purpose. The framework extends beyond individual leadership traits by showing how organizational conditions shape leadership effectiveness. Evidence remains concentrated in policing, street-level administration and local government, while maritime, border, immigration and regulatory enforcement contexts remain comparatively underexplored.

Conclusion

This review identifies proactive leadership, ethical perseverance, behavioral role modeling and inspirational motivation as interdependent leadership capabilities in public-sector enforcement agencies. Proactive leadership supports timely action when guided by clear authority and accountability. Ethical perseverance sustains principled judgment under pressure, while behavioral role modeling strengthens credibility through consistent conduct. Inspirational motivation connects credible leadership behaviour with institutional purpose, commitment and performance. The integrated framework shows that these attributes are most effective when reinforced by organizational accountability, institutional protection and supportive leadership conditions. Evidence remains concentrated in policing, street-level administration and local government, with limited research across maritime, border, immigration and regulatory enforcement contexts. Future studies should use longitudinal, multisource and comparative designs to test the relationships among these attributes and their effects on integrity, discretionary conduct, employee commitment, institutional performance and public trust.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia, and the Immigration Department of Malaysia (JIM) for their academic and institutional support. The

authors also extend their appreciation to the Faculty of Electrical Technology and Engineering (FTKE) and the Socio-Technical Competencies for Community Empowerment (SoTeCH) Research Group, Universiti Teknikal Malaysia Melaka (UTeM), for their institutional and research support.

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Youth Empowerment in Higher Education Uniformed Programs: A Critical Review of Volunteer Readiness and Operational Evidence

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Abstract— Higher education uniformed programs combine disciplined training, leadership practice, teamwork, community service and emergency-oriented learning. This structured critical review examined how such programs support youth empowerment and volunteer readiness beyond participation-based outcomes. Scopus-indexed, English-language journal articles published from January 2016 to July 2026 were systematically searched, screened and critically synthesised. Thirty-four studies met the eligibility criteria, while 15 policy and program documents informed contextual interpretation. The evidence supported four outcome domains: personal agency, collective capability, civic commitment and operational readiness. Cadet studies linked resilience and self-efficacy with academic, professional and instructor-rated performance, while volunteering studies associated sustained engagement with connectedness, service intention and perceived preparedness. However, direct evidence from civilian university uniformed programs remained limited, geographically uneven and dominated by cross-sectional self-reports. Based on the synthesis, the authors propose a review-derived framework linking structured practice, progressive responsibility, realistic simulation, guided reflection and institutional support with readiness indicators. The framework distinguishes developmental outcomes from verified operational competence and identifies priorities for longitudinal, multisource and context-sensitive evaluation across higher education and volunteer settings for future policy development.

Introduction

Higher education uniformed programs integrate disciplined training, leadership practice, teamwork, community service and emergency-oriented learning. Their value depends on whether participation develops transferable competence rather than ceremonial involvement. Military-academy studies link cadet resilience, self-efficacy and personality traits with professional, academic and instructor-rated performance [1], [2]. These findings support personal development within structured cadet environments, although their relevance to civilian university uniformed programs remains uncertain.

Existing evidence is fragmented across related fields. University volunteering research emphasises social connectedness, well-being and engagement [3], while emergency-preparedness studies focus on perceived competence, attitudes, institutional support and willingness to volunteer [4]. Higher education volunteerism also supports sustainability engagement yet sustained post-graduation service remains insufficiently established [5]. These streams rarely examine whether developmental outcomes translate into coordinated performance, durable civic commitment or observable operational readiness within higher education uniformed programs. This review therefore aims to critically synthesise evidence on personal, collective, civic and operational outcomes associated with such programs. It also aims to distinguish evidence-supported developmental outcomes from review-derived indicators of transferable volunteer readiness, providing a clearer basis for evaluating program effectiveness beyond participation or self-reported development across diverse higher education contexts.

Methodology

This study adopted a structured critical review to examine youth empowerment and volunteer readiness in higher education uniformed programs. SPAR-4-SLR guided search, selection,

evaluation and synthesis decisions [6], while PRISMA 2020 structured identification, screening, eligibility and inclusion reporting [7].

Scopus was searched for peer-reviewed articles published from January 2016 to July 2026. Searches examined titles, abstracts and keywords using combinations of higher education, students, uniformed programs, cadets, civil defence, emergency services, youth empowerment, leadership, volunteering, preparedness and operational readiness. Citation tracking extended retrieval. Policy and program documents were included when defining program structures, competencies, assessment requirements or volunteer functions. Eligible studies examined university-based uniformed, cadet, emergency-service or structured experiential programs and reported leadership, self-efficacy, teamwork, civic responsibility, volunteering, preparedness, competency transfer or performance. School programs, sports, ceremonial participation, military studies without educational relevance and unstructured volunteering were excluded. Overlapping Scopus searches yielded 191 records. Removing 43 duplicates left 148 titles and abstracts for screening. Two reviewers independently screened records, excluded 96 and assessed 52 full texts. Eighteen articles failed eligibility criteria, leaving 34 studies for synthesis. Fifteen policy and program documents informed contextual interpretation.

Two reviewers independently completed screening and quality appraisal, resolving disagreements through discussion and consensus. Agreement was established through consensus at title-abstract and full-text stages. QuADS assessed methodological and reporting quality across 13 criteria [8]. Item-level profiles informed evidence weighting based on design transparency, sampling adequacy, outcome validity and analytical clarity without unsupported aggregate cut-offs. An extraction matrix recorded setting, participants, program design, exposure, measures, findings, limitations and relevance. Collaborative reflexive thematic analysis supported coding, theme development and refinement [9]. Synthesis compared convergence, disagreement, methodological variation and transfer limitations across four outcome domains. The complete Scopus Boolean search string and screening log were retained in the review audit trail for reproducibility.

Findings and Discussion

The synthesis identified four outcome domains: personal agency, collective capability, civic commitment and operational readiness. Evidence for personal agency was strongest in cadet settings, where resilience and self-efficacy were associated with professional achievement [1]. Self-efficacy and selected personality traits were also linked with academic results and instructor-rated military performance [2]. These findings support developmental outcomes within cadet environments, although transfer to civilian university uniformed programs remains uncertain. Table 1 presents these evidence-supported domains alongside their principal empirical limitations across contexts.

Table 1: Critical Synthesis of Evidence-Supported Outcome Domains

Outcome domain	Evidence pattern	Critical interpretation
Personal agency	Resilience and self-efficacy linked with cadet performance [1], [2].	Stronger cadet evidence. Civilian transfer remains uncertain.
Collective capability	Structured programs emphasised teamwork and shared responsibility.	Objective team-performance evidence remains limited.
Civic commitment	Volunteering linked with connectedness and engagement [3], [5].	Sustained service remains unclear.
Operational readiness	Preparedness and self-efficacy linked with willingness to volunteer [4].	Verified operational performance remains limited.

Source: Authors' synthesis

Evidence for civic commitment and readiness was more indirect. Longer volunteering engagement was associated with social connectedness and well-being [3]. Among nursing students, willingness to volunteer during emergencies was associated with self-efficacy, positive attitudes and perceived preparedness [4]. Higher education volunteering supported engagement, while continuity after graduation remained inconsistent [5]. Evidence for collective capability was less direct because objective measures of coordination and team performance were uncommon. Cross-sectional self-reports dominated personal and civic outcomes, while supervisor ratings, competency measures and longitudinal follow-up remained limited. Direct Malaysian evidence was scarce. Studies rarely assessed deployment quality, competency retention, volunteer continuity or community effects. Table 2 therefore presents a review-derived framework rather than an empirically validated causal model. Structured practice, progressive responsibility, realistic simulation, guided reflection and institutional support are proposed mechanisms requiring direct testing.

Table 2: Review-Derived Outcome and Readiness Assessment Framework

Outcome level	Program mechanism	Proposed Assessment Indicators
Personal agency	Leadership roles and progressive responsibility	Self-efficacy, judgement, initiative
Collective capability	Collaborative tasks and scenario exercises	Communication, coordination, team performance
Civic commitment	Community service and sustained engagement	Service duration, retention, continuity
Operational readiness	Simulation and competency assessment	Response accuracy, role performance and preparedness

Source: Authors' synthesis

Institutions should combine participant perceptions with simulations, competency assessments, service records, supervisor observations and graduate tracking when evaluating volunteer readiness.

Conclusion

This review indicates that higher education uniformed programs support personal agency, collective capability and civic commitment, while evidence of operational readiness remains limited. Cadet studies link resilience and self-efficacy with assessed performance [1], [2], while volunteering studies associate engagement, connectedness and perceived preparedness with service-related outcomes [3]– [5]. Evidence remains dominated by cross-sectional self-reports, with limited objective assessment of team performance, deployment quality, competency retention and service continuity. The proposed framework therefore separates developmental outcomes from verified readiness indicators. Institutions should evaluate program outcomes through competency assessment, simulation, service records, supervisor observation and graduate tracking. Future longitudinal, multisource and comparative studies should examine whether developmental gains persist beyond participation, transfer into organized volunteer service and produce measurable operational performance. Malaysian research should examine differences across institutions, uniformed units, disciplines and agency partnerships before standards are established.

Acknowledgement

The authors acknowledge City Graduate School, City University Malaysia, Jabatan Sukarelawan Malaysia (RELA) and the Faculty of Electrical Engineering Technology,

Universiti Teknikal Malaysia Melaka, for academic, institutional and research support. Appreciation is also extended to the Socio-Technical Competencies for Community Empowerment Research Group for its contribution to the development of this study.

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Digital Learning Quality and Student Engagement in Higher Education: A Critical Review

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Abstract— Digital learning quality shapes student engagement in higher education, yet its effects vary across technological, pedagogical and learner contexts. This critical review examined how system usability, instructional design, teaching and social presence, and learner support influence behavioural, cognitive, emotional and social engagement. A structured review of Scopus-indexed English-language journal articles published from January 2016 to July 2026 identified 1,688 records. After duplicate removal, screening and quality appraisal, 42 articles entered the synthesis. Findings showed that instructional design provided the strongest support for behavioural and cognitive engagement, while teaching presence and learner support strengthened interaction, persistence and participation. System usability supported access and task completion but showed weaker independent influence. Methodological limitations included cross-sectional designs, self-reported measures and heterogeneous engagement instruments. The review proposes an integrated digital learning quality framework linking technological, pedagogical, relational and learner-support conditions with multidimensional engagement. Higher education institutions should combine learning analytics with validated engagement measures, assessment performance and student experience to improve digital learning quality and evaluation.

Introduction

Digital learning shapes higher education through learning management systems, blended courses and online platforms. Its educational value depends less on technological availability than on the quality of design, interaction and support. Studies show that instructor presence and interactive tools strengthen engagement and satisfaction, but their effects depend on how students experience the learning environment [1]. Instructional strategies in blended online courses also influence behavioural, cognitive and emotional engagement, indicating that technology functions through pedagogy rather than as an independent driver [2].

These relationships remain conditional. Student engagement varies across course modalities, learning activities, interaction patterns and levels of support [3]. Engagement also extends beyond observable platform activity to include behavioural participation, cognitive investment, emotional involvement and social connection. Measurement remains problematic because studies apply different definitions, datasets and indicators, with self-report and externally observed measures capturing different aspects of engagement [4]. Meta-analytic findings report a small-to-medium association between engagement and learning outcomes, which supports its importance while showing that high platform activity should not be treated as equivalent to meaningful learning [5].

Current research therefore presents a fragmented picture rather than a single quality-effect relationship. Differences across disciplines, delivery modes, student groups and measurement choices limit comparison. This critical review integrates technological, pedagogical, relational and learner-support dimensions, evaluates their relative contributions and limitations, and identifies which quality conditions most consistently support behavioural, cognitive, emotional and social engagement in higher education.

Methodology

This study used a structured critical review to examine how digital learning quality shapes multidimensional student engagement in higher education. Review design, search transparency, study selection and synthesis supported reproducibility and analytical contribution rather than descriptive coverage [6]. Recent guidance for systematic literature

reviews also informed reporting of search decisions, screening criteria, exclusions and synthesis procedures [7].

Scopus was searched for English-language peer-reviewed journal articles published from January 2016 to July 2026. Titles, abstracts and keywords were searched using Boolean operators and wildcards combining digital learning, e-learning, blended learning, learning management systems, instructional design, teaching presence, interaction, learner support, student engagement and higher education. Overlapping outputs were merged. The final search was completed on 1 July 2026.

Eligible studies examined technological, pedagogical, relational or learner-support dimensions of digital learning quality and reported engagement outcomes among higher education students. Studies centred on schooling, platform adoption without engagement outcomes, non-peer-reviewed publications or technology use without educational-quality implications were excluded. Searches identified 1,688 records. Removing 126 duplicates left 1,562 records for title and abstract screening. Two reviewers excluded 1,432 records and assessed 130 full texts. Eighty-eight articles were excluded for insufficient higher-education relevance ($n = 25$), absent engagement outcomes ($n = 23$), absent digital-learning-quality components ($n = 22$) or inadequate empirical information ($n = 18$). 42 articles entered synthesis. Search exports, dates, screening decisions and exclusion reasons formed the audit trail. Two reviewers independently screened and appraised the included studies. Appraisal examined sampling transparency, measurement validity, analytical appropriateness, reporting clarity and acknowledgement of limitations, reflecting quality principles for heterogeneous research [8]. Studies with stronger design transparency and validated engagement measures received greater interpretive weight. Studies relying on single-source self-reports, weak construct validation or cross-sectional designs were retained for contextual comparison but treated as methodologically weaker. This replaced the unresolved placeholder and made strength judgments explicit.

The extraction matrix recorded context, participants, discipline, delivery mode, design, quality dimensions, engagement measures, outcomes and limitations. Direct studies linked quality dimensions with engagement outcomes. Adjacent studies examined satisfaction, continuance or platform use and were not treated as equivalent to engagement. Reflexive thematic analysis supported iterative coding, comparison and theme refinement [9]. Synthesis examined convergence, contradiction, methodological limitations and contextual variation across four domains.

Findings and Discussion

The synthesis of 42 articles identified four interdependent dimensions of digital learning quality: system usability, instructional design, teaching and social presence, and learner support. Rather than indicating a uniform technology effect, the studies showed that engagement depended on how these dimensions operated together. Heilporn, Lakhali and Bélisle found that instructional strategies influenced behavioural, cognitive and emotional engagement in blended online courses, showing that platform capability alone was insufficient [2]. Heilporn, Raynault and Frénette further demonstrated that engagement varied across course modalities, reinforcing the need for multidimensional rather than activity-based assessment [3]. Table 1 summarises representative studies, strength of support and key limitations. Instructional design showed the strongest support for cognitive and behavioural engagement. Teaching and social presence also supported interaction, satisfaction and persistence [1]. System usability remained necessary for access and task completion but showed weaker independent influence. Learner support contributed to persistence, confidence and participation equity.

Table 1: Critical Synthesis of Digital Learning Quality Dimensions

Quality dimension	Representative studies	Key finding	Strength	Limitation
System usability	Heilporn et al. [2], [3]	Supports access and participation but does not sustain engagement alone.	Moderate	Often measured through platform activity.
Instructional design	Heilporn et al. [2]	Structured activities and feedback strengthen behavioural and cognitive engagement.	Strong	Mainly cross-sectional and self-reported data.
Teaching and social presence	Roque-Hernández et al. [1]	Instructor interaction strengthens engagement and satisfaction.	Moderate to strong	Effects vary by course context and delivery mode.
Learner support	Heilporn et al. [3]	Guidance and accessibility support persistence and participation.	Moderate	Limited longitudinal assessment.
Engagement measurement	Karimah and Hasegawa [4], Doo and Kim [5]	Multidimensional measures provide stronger interpretation than platform activity alone.	Moderate to strong	Measures remain heterogeneous.

Source: Authors' synthesis

Measurement remained a major limitation. Engagement definitions, datasets and estimation methods varied substantially across studies [4]. Self-reports were vulnerable to common-source bias, while learning analytics captured activity more effectively than cognitive, emotional or social engagement. Cross-sectional designs also limited temporal interpretation.

Table 2: Integrated Digital Learning Quality and Engagement Framework

Framework component	Quality mechanism	Engagement outcome	Strength	Limitation
Technological quality	Reliable and accessible platforms	Access, participation and task completion	Moderate	Analytics may not reflect deeper engagement.
Pedagogical quality	Structured activities and feedback	Cognitive and behavioural engagement	Strong	Longitudinal evidence remains limited.
Relational quality	Teaching presence and peer interaction	Emotional and social engagement	Moderate to strong	Effects vary across contexts.
Learner support	Guidance, accessibility and self-regulation support	Confidence, persistence and participation equity	Moderate	Diverse learner groups remain underrepresented.
Integrated evaluation	Combined quality dimensions	Sustained multidimensional engagement	Emerging to strong	Requires multisource and longitudinal measures

Source: Authors' synthesis

Meta-analytic findings showed a small-to-medium relationship between engagement and learning outcomes [5]. Table 2 therefore frames digital learning quality as an integrated system linking technological, pedagogical, relational and learner-support conditions. Institutions should combine platform analytics with validated engagement measures, assessment results, interaction quality and student experience. Future studies should prioritise longitudinal, multisource and comparative designs to distinguish participation, engagement and achievement.

Conclusion

This review identifies system usability, instructional design, teaching and social presence, and learner support as interdependent dimensions of digital learning quality. Instructional design showed the strongest support for behavioural and cognitive engagement, while relational and support conditions strengthened interaction, persistence and participation equity. System usability remained necessary but insufficient when considered independently. Methodological weaknesses, including cross-sectional designs, self-reported measures and inconsistent engagement instruments, limit causal interpretation. Higher education institutions should evaluate digital learning through combined technological, pedagogical, relational and learner-support indicators. Future studies should use longitudinal, multisource and comparative designs to distinguish platform activity from sustained engagement and learning outcomes across disciplines, delivery modes and learner groups.

Acknowledgement

The authors gratefully acknowledge City Graduate School, City University Malaysia, for its academic guidance and research support. Appreciation is also extended to the Faculty of Electrical Technology and Engineering (FTKE) and the Socio-Technical Competencies for Community Empowerment (SoTeCH) Research Group, Universiti Teknikal Malaysia Melaka (UTeM), for their valuable institutional and research support.

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Enhanced Micromixing Techniques in Microfluidics for the Application in Point-Of-Care diagnostic

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Abstract— Lamination-based passive micromixers have been largely used in point-of-care (POC) devices. This, however, requires a long mixing channel to mix fluid or bioassays completely. For this reason, many designs have been introduced in terms of structured mixing channels as an alternative to achieve the same mixing performance but with a shorter channel length. In this present review, types of micromixers were discussed in terms of their microchannel geometries and fluid mixing performances. In addition, some appropriate micropump designs that have potential to be integrated with micromixers were also discussed. The Integration of micromixer - micropump is crucial for the realization of an operational POC unit, and their types and designs were discussed based on their flow rate performances.

Introduction

From the literature, characterizations on micropumps used in microfluidic systems were only made onto a standalone micropump operation without integrating with any micromixers. Integrated micromixer-micropump unit for a successful liquid mixing has never been comprehensively studied [1-11]. Accurate diagnosis of a microfluidic-based POC device is attributed to the mixing performance of the integrated micromixer-micropump unit. Thus, a comprehensive study on the micromixing performance of liquid and the micropumping performance are essential to be carried out

Micromixers in POC devices

Micromixers are majorly classified as either active or passive micromixers [21]. Active micromixers usually have simpler microchannel designs but embedded with external auxiliary-energy drives such as sound, thermal, pressure, electrical and magnetic fields, to further enhance fluid mixing. Passive micromixer utilizes the fundamental concept of enhancing the diffusive effect between fluids by increasing the contact surface area between the mixing samples.

Micropumps in POC devices

Incorporation of micromixers in POC devices often integrates along several other microfluidic units including micropumps to accomplish the complete assay of biomaterials on a single platform. Micropumps can be loosely categorized into either actively or passively driven [5, 24]. Active-driven micropumps utilise the auxiliary power to drive and control either by using mechanical actuators; (electromagnetic, electrostatic, thermos-pneumatic, shape memory alloy, electro-active polymer), or non-mechanical actuators; (electro-hydrodynamic, electroosmotic, magneto-hydrodynamic, electro-chemical). On the other hand, passive micropumps are further classified based on their fluid pumping method of either direct pressure-based, capillary-based and air transfer-based. The overview of micromixers [1-3, 6-23], and micropumps [5, 24-45] categories are shown in Figs. 1 and 2, respectively.

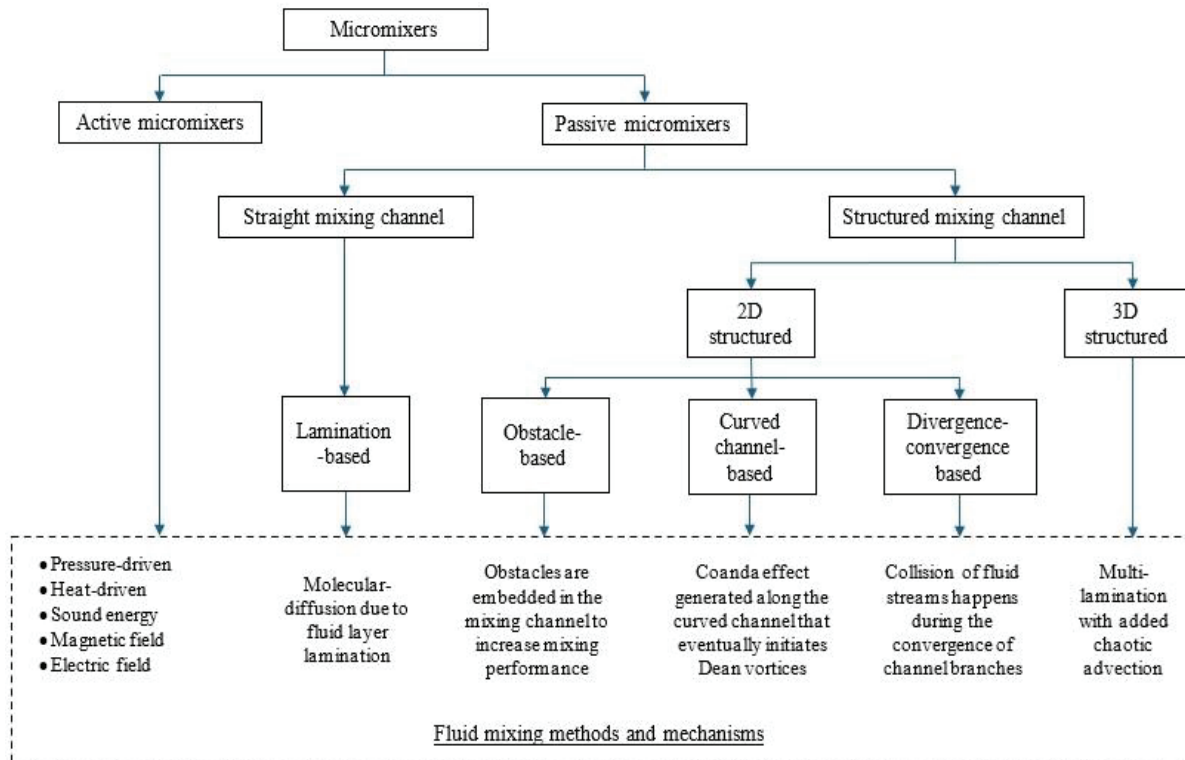


Fig. 1. Micromixers categories

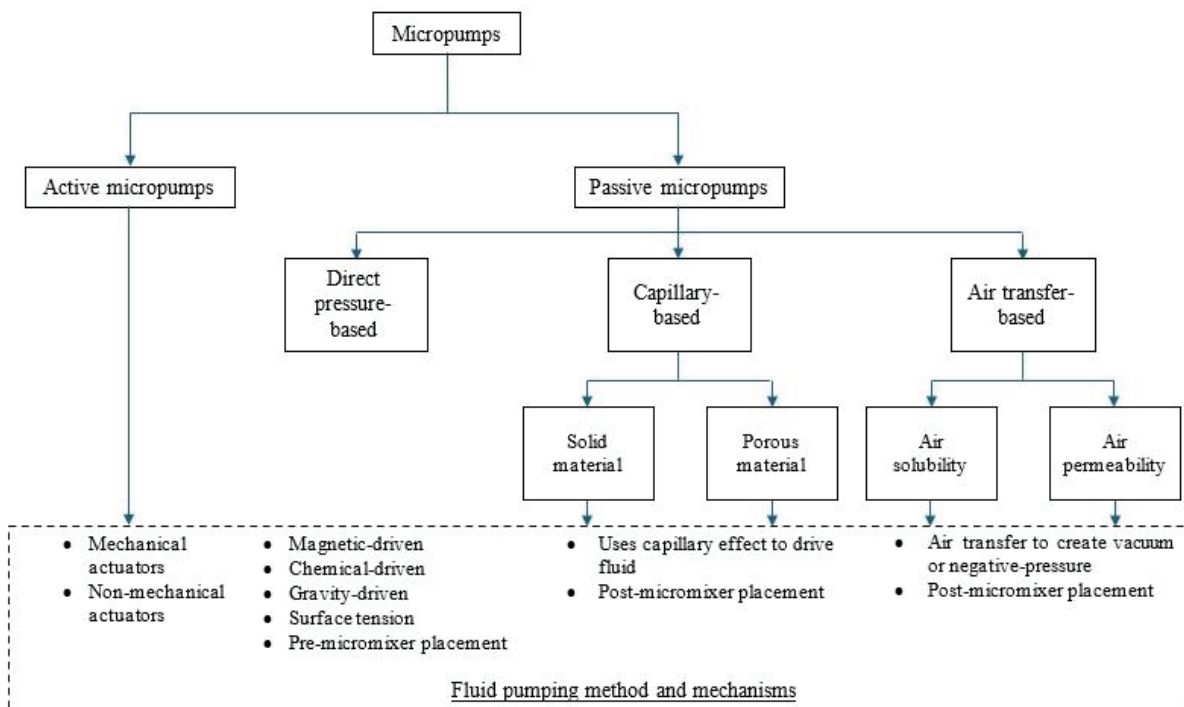


Fig. 2. Micropumps categories

Results and Discussion

The summary on the problems or disadvantages of micromixers and micropumps used in POC devices is tabulated in Table 1.

Table 1. Summary on the problem/disadvantages of micromixer-micropumps used in POC device

No.	Unit	Disadvantages	Possible solutions
1.	Micromixers	i.Active micromixers are not suitable for POC devices ii.Lamination-based micromixers require long mixing channels to achieve complete mixing iii.3D-structure and Obstacle-based micromixers must utilize precision fabrication techniques and equipment	i.Utilize passive micromixers for POC devices ii.Manipulate channel geometry to get shorter length of mixing channel iii.Avoid 3D-structure and Obstacle-based micromixers to avoid precision-based fabrication. Integration of the curved-based and convergence-divergence based micromixer elements is needed to enhance micromixing based on Dean vortices and fluid collision
2.	Micropumps	i. Active-driven full-size benchtop pumps are usually used i. Most pumps are placed at the micromixer inlet. This setting usually operates with considerably higher working pressure, making the assembly prone to leakage. Multiple units of pumps are required to drive fluids into a multi-inlet micromixer	i. Small sized and portable passive-driven micropump is preferable ii. Low-vacuum pumping method is preferable to avoid fluid leakage. Micropump shall be placed at the micromixer outlet to avoid multiple pumps being used in a multi-inlet micromixer
3.	Integrated micromixer-micropump unit	i.Micropumps are usually characterized in a standalone operation only ii.Integrated micromixer-micropump unit for successful liquid mixing has never been comprehensively studied	Selected passive micropump is integrated with selected passive micromixer, and characterized so that successful liquid mixing is achieved

Conclusion

Micromixers and micropumps that are applicable to POC devices are reviewed in terms of designs, fabrication, and applications, and presented the recommended approach for designing the integrated micromixer-micropump is suggested in this present review.

Acknowledgment

The authors gratefully thank the *i*-CATS University College for the full support received on equipment and facilities.

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An AI-Powered Mobile Application for Accessible Food Label Recognition

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Abstract— Food labels provide essential information to support informed dietary choices; however, many consumers face challenges in understanding ingredient lists, nutritional information, and potential allergens due to language barriers and accessibility limitations. This paper presents IngreScan, a smart mobile application that leverages recognition of images, optical character recognition, multilingual translation, dietary restriction detection, AI chatbot assistance and text-to-speech to make food labels more accessible. The proposed system captures food label images, extracts relevant information, translates the content into the preferred language of the user and highlights ingredients related to pre-defined dietary restrictions. A usability evaluation with 20 participants showed positive user acceptance, with 94.4% of responses rated as 'good' or 'excellent', and functional testing achieved an overall success rate of 80%. The results show that IngreScan can help users better understand the information in packaged food and make healthier and safer food choices. Future enhancements will focus on improving the accuracy of food-specific translations and expanding intelligent recommendation capabilities.

Introduction

Food labels, including nutrition facts panels, ingredient lists, and front-of-pack labels, serve as important sources of information that help consumers understand the nutritional composition, ingredients, and potential health implications of packaged food products. The World Health Organisation has identified the use of interpretive FoPLs as an effective public health strategy within these labelling systems because they simplify complex nutritional information and promote healthier dietary choices at the population level [1][2]. Likewise, nutrition facts panels and ingredient lists provide detailed information that allows consumers to evaluate food products based on their dietary needs and health considerations and also encourages manufacturers to improve the nutritional quality of their products [3].

Recent research highlights that emerging technologies can enhance the effectiveness of nutritional labelling by improving consumers' processing and interpretation of nutrition information [4][5]. Franco et al. [6] studied 13 popular dietary apps and found that the apps used mainly food diaries, text search, and barcode scanning alone, with very few apps using more advanced technologies such as recognising images, natural language processing, and artificial intelligence to provide support for customised nutrition. Silva et al. [7] reported that front-of-pack nutrition labelling using smartphone applications improved the purchasing decisions of consumers and their recognition of products rich in vital nutrients. Mariappan et al. [8] have proposed a framework based on AI and QR codes for personalised nutrition labels. These studies demonstrate the potential of digital and AI-based solutions to enhance the accessibility and interpretation of food labels. Despite these advancements, food labels remain challenging for many consumers to effectively utilise due to complex information, small text sizes, and limited accessibility for users with diverse visual needs, particularly those who experience difficulty reading small text. In multicultural environments like Malaysia, these challenges are made even harder by the presence of different languages and imported food products that can make it more difficult to understand ingredient lists, nutrition information and allergen warnings. This situation in turn could make it hard for consumers to make informed choices about what food to eat and could lead them unwittingly to eat inappropriate ingredients. In this paper we present the design, development and evaluation of IngreScan AI, a mobile application developed to address these issues. The app is designed to (1) capture and

recognise food label images to extract relevant text information using OCR and translate the extracted information into the user's preferred language; (2) identify and highlight ingredients of concern based on users' pre-defined dietary restrictions, such as allergens and specific additives; (3) provide an AI-powered chatbot that enables users to ask questions and receive contextual explanations regarding scanned food labels, ingredients, nutrition information, and potential dietary concerns; and (4) convert analysed text into audio output and provide image zoom functionality to provide accessibility support through adjustable text size and text-to-speech features..

Methodology

The IngreScan app is developed using Android Studio with Kotlin with hybrid on-device and cloud-based architecture. The main label scanning functions are integrated within the Android device itself to ensure privacy and offline capability, with only the AI chatbot module needing an internet connection to communicate with the Google Gemini API for intelligent conversational support. The application uses the Android built-in Text-to-Speech (TTS) for audio output, the CameraX API for image capture and SharedPreferences for storing user preferences, such as user profiles, language preferences and allergy profiles. The system architecture of the proposed IngreScan mobile application is shown in Fig. 1, and the interface of its main functionalities is illustrated in Fig. 2. This architecture decreases the dependency on the cloud and simultaneously offers advanced AI capabilities with Gemini integration.

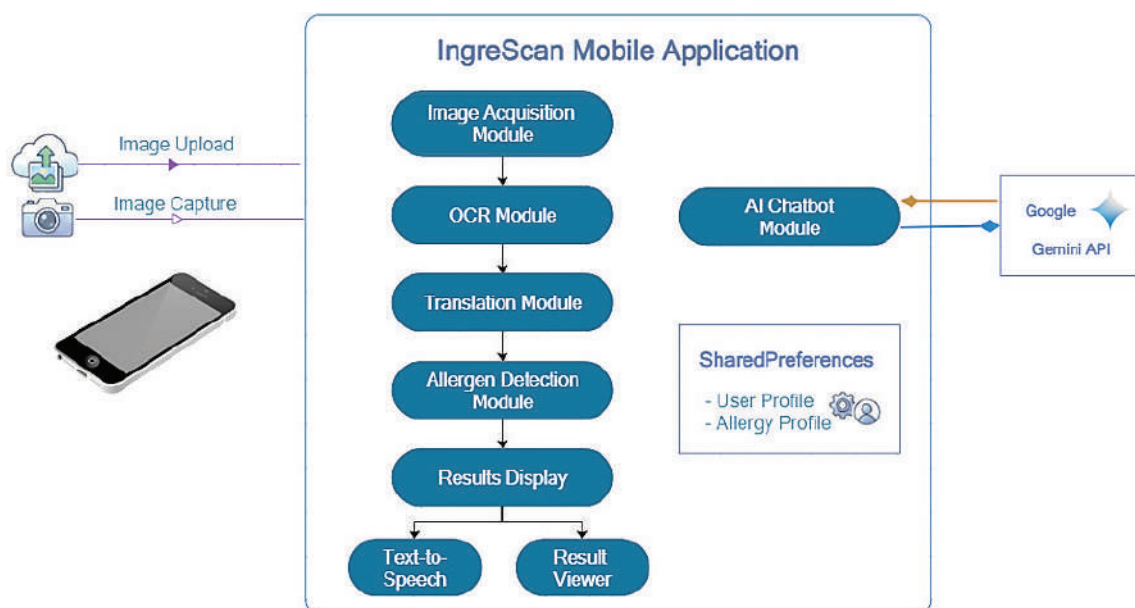


Fig. 15 System Architecture of the IngreScan Mobile Application

The application begins with the Image Acquisition module, where users capture or upload a food label image. The image data is passed to the Optical Character Recognition (OCR) module to extract the textual data, and then it is translated into the language preferred by the user by the Translation module. The Allergen Detection module inspects the translated ingredients to search for potential allergens according to a pre-defined allergen database and the user's allergy profile. The processed results (original image, extracted text, translated content and allergen warnings) are shown with the user interface with Image Zoom and Text-to-Speech features to improve accessibility. The AI chatbot is a separate module and interacts with the Google Gemini API to deliver explanations regarding nutrition, respond to ingredient queries, and extend conversational assistance.

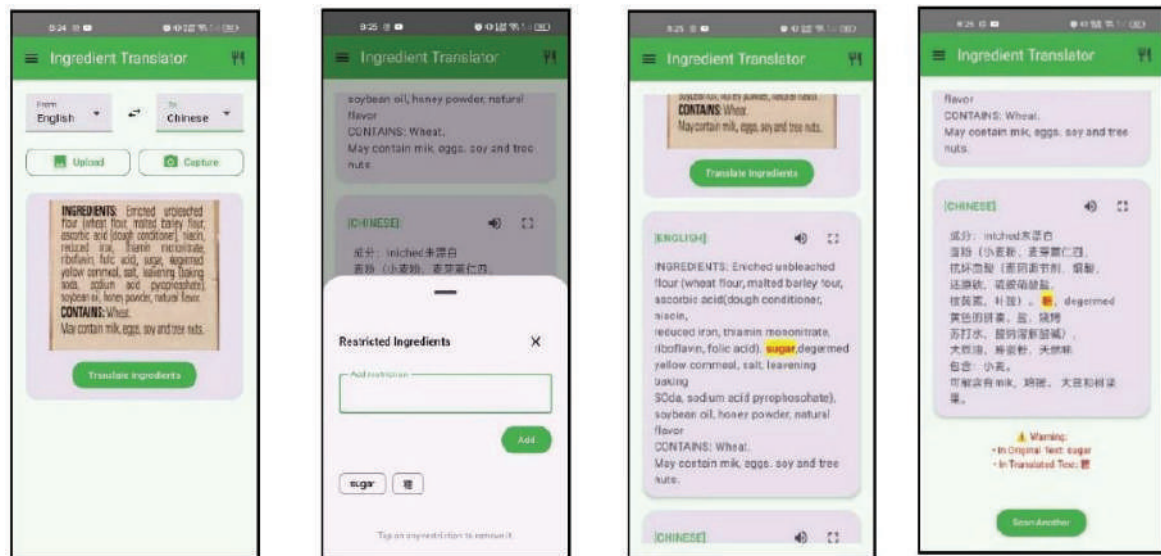


Fig. 2 IngreScan App Interfaces

Results and Discussion

The testing conducted in this study represents a preliminary user evaluation and functionality validation phase, assessing the general usability and user acceptance of the proposed application by 95% of the participants. The evaluation involved a total of 20 participants, including 10 elderly participants and 10 young and middle-aged adults, including gym-goers, people on weight-loss diets and those with general food-awareness interests. Participants rated the IngreScan mobile application on eight usability attributes on a five-point Likert scale from Very Poor to Excellent. The application was rated very positively on all attributes we evaluated (see Table 1). The most preferred attribute was restriction preferences (rated as 'excellent' by 95% of the participants), followed by AI chatbots (90%) and navigation and upload & capture (85% each). The interface was also well received, with all participants rating it as either Good (45%) or Excellent (55%). The text extraction module was rated positively by most participants, with 95% of them rating it as 'Good' or 'Excellent', suggesting that the OCR-based extraction worked reliably under normal conditions of use. The TTS feature received relatively low ratings, with 35% of participants rating it as 'average', indicating there is room for improvement in terms of speech quality, pronunciation accuracy or audio clarity. Nevertheless, 60% of users still rated the feature as Good or Excellent. The general acceptance of the application was very high by users, with 94.38% of all responses rated as 'Good' or 'Excellent' and only 5.63% rated as 'Average' or below. The findings show that the proposed IngreScan application has a user-friendly user interface and is effective in food label recognition, dietary restriction identification, multilingual translation and AI-assisted interaction.

For functional testing, all participants confirmed that the system operated without technical issues. The restriction highlighting and full-screen dialogue received 100% successful responses, indicating reliable performance in identifying dietary concerns and presenting information clearly. The translation function had a lower success rate of 40%. This limitation may be due to the selection of the on-device translation model from Google ML Kit, which was chosen to support offline translation. An ingredient-specific offline dictionary and a hybrid cloud fallback for terms that can't be translated accurately locally may alleviate the limitation in future deployment. This application demonstrates the promise of integrating OCR, translation and allergen detection to support more accessible and informed reading of food labels.

Table 1: User Evaluation Results of the Proposed IngreScan Mobile Application

Attribute	Average (%)	Good (%)	Excellent (%)	Overall Positive Rating (%)
Navigation	0	15	85	100
Interface	0	45	55	100
Upload & Capture	0	15	85	100
Text Extraction	5	70	25	95
Restriction Preferences	0	5	95	100
Text-to-Speech	35	30	30	60
AI Chatbot	0	10	90	100
Satisfaction	0	55	45	100
Overall	5.0	30.6	63.8	94.4

Conclusion

In this research, IngreScan was introduced, an intelligent mobile application that aims to enhance food label accessibility by means of recognising images, optical character recognition (OCR) text extraction, multilingual translation, detection of ingredient restrictions, AI chatbot support, and accessibility features such as text-to-speech and image zoom. The evaluation results showed that the proposed system had a positive user acceptance, with 94.4% of usability responses rated as 'Good' or 'Excellent' and functional testing with an overall success rate of 80%. Results suggest that IngreScan has the potential to help users interpret food label information and make more informed dietary decisions, especially for users with language barriers, dietary restrictions, and accessibility challenges. However, the translation module requires more improvements as it struggles with food-specific terminologies and the limitations of offline translation models. Future work will involve improving the accuracy of translation using domain-specific food vocabulary, improving the AI chatbot capabilities, and evaluating with a larger and more diverse group of users.

Acknowledgement

This research received financial support from *i-CATS* University College.

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DispatchGo: A Mobile-First Logistics Management System for Small Distribution Companies in Sarawak

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Abstract— Distribution companies in Sarawak face persistent operational challenges, including delivery chargebacks, inefficient proof-of-delivery (POD) handling, and poor communication between drivers and dispatchers. Although enterprise-grade logistics management systems provide comprehensive solutions, they are often inaccessible to small distribution companies due to high implementation costs and technical complexity. This paper presents DispatchGo, a mobile-first logistics management system designed specifically for small distribution companies in Sarawak. The system integrates digital proof of delivery with photographic evidence and customer signatures, real-time GPS tracking with dynamic estimated time of arrival (ETA), in-app driver-dispatcher communication, automated customer notifications, and a real-time delivery dashboard within a single platform. DispatchGo was developed using Android Studio, Firebase, and Google Maps SDK, enabling deployment on standard Android devices without requiring specialized hardware. Developed using an Agile methodology, the system demonstrates that affordable cloud-based technologies can provide practical logistics management capabilities for underserved distribution businesses while supporting the digital transformation of the logistics sector.

Introduction

The logistics industry in Malaysia is undergoing rapid digital transformation, driven by the growth of e-commerce and increasing customer expectations for faster deliveries and real-time shipment visibility [1]. Despite this progress, most logistics management solutions are designed for large enterprises, making them financially and technically inaccessible to small distribution companies. Previous studies have identified implementation cost as one of the primary barriers preventing Malaysian small and medium-sized enterprises (SMEs) from adopting digital technologies [2].

Small distribution companies continue to rely on manual processes for delivery management, resulting in operational inefficiencies and increased business risks. Three major operational challenges are consistently reported in the literature. First, the lack of real-time shipment tracking limits delivery visibility, delays exception management, and increases operational costs [3][4]. Second, paper-based proof-of-delivery (POD) processes frequently result in missing documentation, delayed verification, and disputes regarding successful deliveries [5][6]. Third, conventional communication methods between drivers and dispatchers are often ineffective because drivers cannot safely respond to calls while operating vehicles, resulting in delayed coordination and slower response to delivery issues [7][8].

Existing research suggests that key areas such as real-time tracking, digital proof of delivery and efficient communication contribute to an improved logistics performance. But still, little research has been accounted on integrated logistics management systems that would satisfy the operational and monetary constraints of small sized distribution companies. To fill in this gap, we propose DispatchGo: a mobile-first logistics management system targeting small distribution companies situated within Sarawak. By merging digital proof of delivery with photo evidence and customer signatures, real-time GPS tracking with an adaptive ETA, in-app communication between the driver and dispatcher, automated customer notifications and a real-time delivery dashboard into one system. A practical case using an inexpensive, cloud-based technologies shows that physical hardware may be avoided for running cost-effective logistics management.

Methodology

DispatchGo was developed using an Agile software development methodology adapted for a single-developer environment. Agile was selected because it supports iterative development, continuous feedback, and evolving requirements, making it suitable for mobile logistics applications where user needs may change throughout development [9].

The development process consisted of four iterative sprints. The first sprint established the system architecture by implementing Firebase Authentication, role-based access control, and the core user interface. The second sprint focused on developing the digital proof-of-delivery module, including photo capture, customer signature collection, GPS coordinate recording, timestamps, and delivery status updates. The third sprint implemented real-time GPS tracking, the dispatcher dashboard using Google Maps SDK, and an in-app messaging module for communication between drivers and dispatchers. The final sprint integrated automated customer notifications, reporting functions, failed delivery management, and usability evaluation to validate the completed system. The system was developed using Android Studio for the mobile application, Firebase Firestore and Firebase Authentication for cloud services, Google Maps SDK for location tracking and ETA computation, and GitHub for version control.

Findings and Arguments

System Architecture

DispatchGo adopts a three-tier architecture consisting of an Android mobile application for drivers, a web-based dashboard for dispatchers, and a cloud-based backend as shown in Fig 1. Firebase Firestore provides real-time data synchronization between system components, while Google Maps SDK enables continuous GPS tracking and dynamic ETA calculations. This architecture supports scalability while minimizing infrastructure costs, making the system suitable for small distribution companies with limited resources.

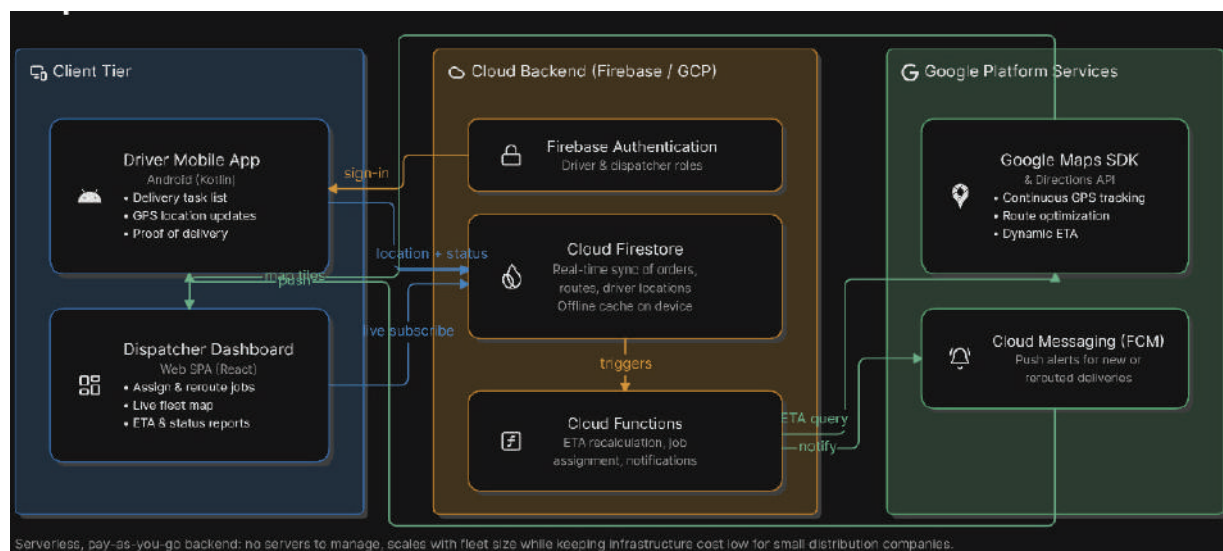


Fig. 16 A three-tier architecture of DispatchGo

System Features and Discussion

The completed system integrates six key functions that directly address the operational challenges identified in the literature. The digital proof-of-delivery module captures photographic evidence, customer signatures, timestamps, GPS coordinates, and driver information, providing secure delivery verification and reducing disputes. Real-time GPS tracking enables dispatchers to monitor delivery progress and respond proactively to delays. The integrated messaging module allows communication between drivers and dispatchers

without relying on conventional phone calls, while automated customer notifications improve customer awareness throughout the delivery process.

The failed delivery management module records unsuccessful deliveries, stores exception reasons, and supports delivery rescheduling to reduce repeated delivery attempts. In addition, the real-time dashboard provides operational visibility through delivery progress monitoring and performance indicators such as on-time delivery percentage and redelivery rates.

Table 1 compares DispatchGo with existing logistics applications. The comparison shows that although enterprise systems provide many advanced capabilities, DispatchGo combines the essential logistics functions required by small distribution companies while maintaining affordability and accessibility through the use of standard mobile devices and cloud-based services.

Table 1. Feature Comparison Between DispatchGo and Existing Logistics Applications

Feature	Lalamove	Routific	Bringg	Poslaju	DispatchGo
Real-time GPS tracking	✓	✓	✓	✓	✓
Digital proof of delivery	✓	✓	✓	✓	✓
Photo capture of POD	✓		✓		✓
Dispatcher dashboard			✓		✓
Driver-dispatcher messaging			✓	✓	✓
Failed delivery logging			✓	✓	✓
Affordable for SMEs	✓	✓			✓

Conclusion

In this paper, we introduced DispatchGo to support the operational needs of small distribution companies in Sarawak. The proposed system simultaneously addresses three significant problems highlighted in the literature: lack of real-time tracking of shipment, inefficient management of proof-of-delivery and improper communication between driver and dispatcher. Combining digital proof of delivery, GPS tracking, in-app messaging and automated notifications with live order status updates on a simple to use platform; DispatchGo shows that implementable logistics management systems can be built reliably with widely available low cost technologies. This research indicates that cloud computing mobile technologies offer an effective option other than costly logistics enterprise system, which allows small companies to achieve greater efficiency without requiring extensive infrastructure. This helps achieve the goals of the Sarawak Digital Economy Blueprint 2030 by encouraging digitization among smaller logistics operators. The limitation of the current study is that some of the advanced features like route optimization and working in the offline mode are not yet integrated into the application. In future, work will be done on implementing the above-mentioned features and integration with the existing logistics system in the offline mode where there is lack of network connectivity. As a conclusion, DispatchGo shows the possibility of developing a logistics management system that is affordable and meets the need of the local logistics industry.

Acknowledgement

The authors would like to express their sincere gratitude to *i-CATS RISE* (Research, Innovation, Support, & Enterprise) for providing financial support for this work and the conference participation.

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EchoServe: An AI-Powered Voice-Driven Point-of-Sale System with Presence Detection for Small Food and Beverage Businesses in Sarawak

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Abstract— Small and medium food and beverage (F&B) businesses in Sarawak remain largely excluded from the operational benefits of self-ordering kiosks (SOKs) due to high hardware costs, touchscreen-dependent interfaces that alienate elderly and digitally unfamiliar customers, and physical interaction constraints that limit hands-free use. This paper presents EchoServe, an AI-powered voice-driven Point-of-Sale system that combines a conversational AI ordering agent, computer-vision-based presence detection, and a real-time merchant dashboard to deliver an accessible, low-cost alternative to enterprise SOK systems. Unlike existing commercial voice-ordering platforms, which operate only in off-premises channels and require manual activation, EchoServe is designed for in-store deployment, is multimodal, and is intended to proactively detect and greet customers without any activation step. The system is being developed using an Agile methodology enriched with Extreme Programming practices across four sprints, using React.js, FastAPI, the OpenAI API, OpenCV, and Firebase; the voice, vision, and conversational-AI components are currently under active implementation. This paper outlines the problem context, objectives, development methodology, and resulting system architecture, positioning EchoServe as a practical response to the digital-inclusion goals of the Sarawak Digital Economy Blueprint 2030.

Introduction

Malaysia's F&B sector is projected to process nearly USD 184 million through digital platforms by 2025, and the Sarawak Digital Economy Blueprint 2030 identifies artificial intelligence as a central driver of inclusive digital growth [1]. Despite this, self-ordering kiosks remain largely confined to large restaurant chains; small independent eateries in Sarawak face three persistent barriers. First, cost: enterprise-grade SOK systems require proprietary hardware and ongoing maintenance that few SMEs can afford, with cost identified as the most cited obstacle to technology adoption among Malaysian SMEs and structural adoption gaps persisting across Malaysia's retail and F&B sectors [2][3]. Second, accessibility: perceived ease of use is the strongest determinant of kiosk acceptance [4] and elderly or digitally unfamiliar customers frequently abandon touchscreen kiosks in favour of cashier service [5][6]. Third, physical interaction constraints exclude customers whose hands are occupied or whose mobility is limited, a gap that voice interfaces are shown to address [7].

In order to solve such issues, this paper introduces the design and implementation of a conversational AI-enabled voice-based Point-of-Sale system named EchoServe that is intended to cater to small and medium size F&B establishments in Sarawak. This system aims at providing a more affordable solution in comparison to existing self-ordering systems in the form of a conversational AI system with a Voice User Interface (VUI) built using Speech-to-Text and Text-to-Speech technologies, a presence-detection module that uses OpenCV to proactively greet customers, a dashboard for restaurants' operators to maintain the menu, pricing, and current orders, and a reporting module for sales reporting that works with Ringgit Malaysia denominations. The system is designed for customers without user accounts, eliminating the need for registration. It also provides an intuitive interface that enables restaurant owners and staff with limited computer skills to manage daily operations efficiently.

Methodology

EchoServe is being developed using an Agile methodology enriched with Extreme Programming (XP) practices, adapted for a solo-developer context, as Agile approaches are shown to reduce project failure rates and better accommodate evolving requirements than

traditional Waterfall development [8][9]. Requirements were gathered through direct consultation with F&B business owners in Kuching, Sarawak, and are being refined iteratively across four planned sprints, each following a Plan-Develop-Review-Retrospective cycle with bi-weekly supervisor consultation.

Table 1 summarises the planned four sprints. Sprint 1 focuses on establishing the backend REST API and integrating the Web Speech API and OpenAI API to deliver a voice-ordering prototype. Sprint 2 introduces OpenCV-based presence detection, enabling autonomous transition between idle and active ordering states. Sprint 3 delivers the Firebase-backed merchant dashboard with real-time order synchronisation. Sprint 4 completes the sales reporting module and conducts usability (System Usability Scale) and performance evaluation. Privacy of the customers is protected since the camera frame is processed only to detect presence only which will be stored in the temporary memory. After the presence detection, the camera frames are deleted so that the customers' images and videos are not stored, to save storage and privacy concern.

Table 1: Sprint Summary

Sprint	Focus	Key Activities	Evaluation / Output	Duration
1	Foundation and voice ordering core	React.js setup; Web Speech API (STT/TTS); FastAPI backend; OpenAI API integration; ordering dialogue flow	Functional voice ordering prototype	Weeks 1-4
2	Presence detection and session management	OpenCV webcam integration; human detection model; idle-to-active session transition; automatic reset	Functional presence detection and session management	Weeks 5-8
3	Merchant dashboard and Firebase integration	Firebase Firestore setup; real-time order push; live order queue; menu and pricing management	Functional merchant dashboard and real-time order management	Weeks 9-12
4	Sales reporting, refinement and evaluation	Daily sales report module; SUS usability evaluation; STT latency and AI accuracy testing; final documentation	The evaluation achieved a mean SUS score of XX/100, an average STT response latency of XX ms, and an AI intent recognition accuracy of XX%.	Weeks 13-16

The technology stack was selected for cost-effectiveness and SME suitability: React.js for the kiosk interface; the browser-native Web Speech API for zero-cost Speech-to-Text and Text-to-Speech; FastAPI for asynchronous backend processing; the OpenAI API for natural-language order parsing, chosen over rigid intent-based frameworks because it handles ambiguous, multi-item, and modified orders more reliably; OpenCV for webcam-based presence detection, avoiding proprietary sensor hardware; and Firebase for real-time order synchronisation to the merchant dashboard.

System Design and Implementation Status

EchoServe's core contribution lies in three features that distinguish it from existing commercial voice-ordering platforms. Table 2 compares EchoServe against Kea and VoicePlug, the two closest commercial systems [10][11]. Both existing platforms operate exclusively in off-premises channels (phone and drive-thru/web), rely solely on audio input, and require the customer to actively initiate a session. EchoServe instead targets the in-store walk-up context, is multimodal by combining voice interaction with OpenCV-based vision, and is proactive, autonomously detecting and greeting customers without manual activation. Both existing platforms are also priced for enterprise clients, whereas EchoServe is designed to run on any standard device with a webcam and browser, requiring no proprietary hardware investment.

Once the voice, vision, and conversational-AI components are integrated, evaluation will proceed along three measures. Usability will be assessed using the standard ten-item System Usability Scale (SUS) questionnaire, administered to a sample of representative users immediately after each completes an order with the kiosk; each response will be scored using the standard SUS formula (0–100 per participant) and reported as a mean score alongside the

sample size. Speech-to-Text (STT) latency will be measured by timestamping the interval between the end of user speech and receipt of the transcribed text, averaged across a fixed set of test utterances to yield a mean response time in milliseconds. AI order-parsing accuracy will be measured against a labelled test set of sample utterances, including multi-item, modified, and ambiguous orders, by comparing the OpenAI API's parsed output to the expected order for each utterance and calculating the percentage correctly parsed. These three measures will together provide the usability and performance evidence required to validate the system against its stated objectives.

Table 2: Feature comparison of Kea, VoicePlug, and EchoServe

Feature	Kea	VoicePlug	EchoServe (proposed)
Deployment context	Phone ordering	Drive-thru / web	In-store kiosk
Interaction modality	Audio only	Audio only	Multimodal: audio + vision (OpenCV)
Interaction model	Reactive	Reactive	Proactive: auto-detects and greets customer
Accessible for SMEs	No (enterprise pricing)	No (enterprise pricing)	Yes: web-based, no proprietary hardware

In its intended operation, a customer entering the interaction zone will be detected by the OpenCV module, which will trigger an AI greeting delivered via Text-to-Speech. The customer will then place, modify, and confirm an order entirely through spoken dialogue; the confirmed order will be written to Firebase and will appear on the merchant dashboard in real time without a manual refresh, supporting efficient kitchen workflow. Payment will be simulated in this version, with live payment gateway integration identified as future work. Fig 1 shows the intended software architecture of EchoServe; implementation of the voice, vision, and conversational-AI pipeline depicted is currently in progress.

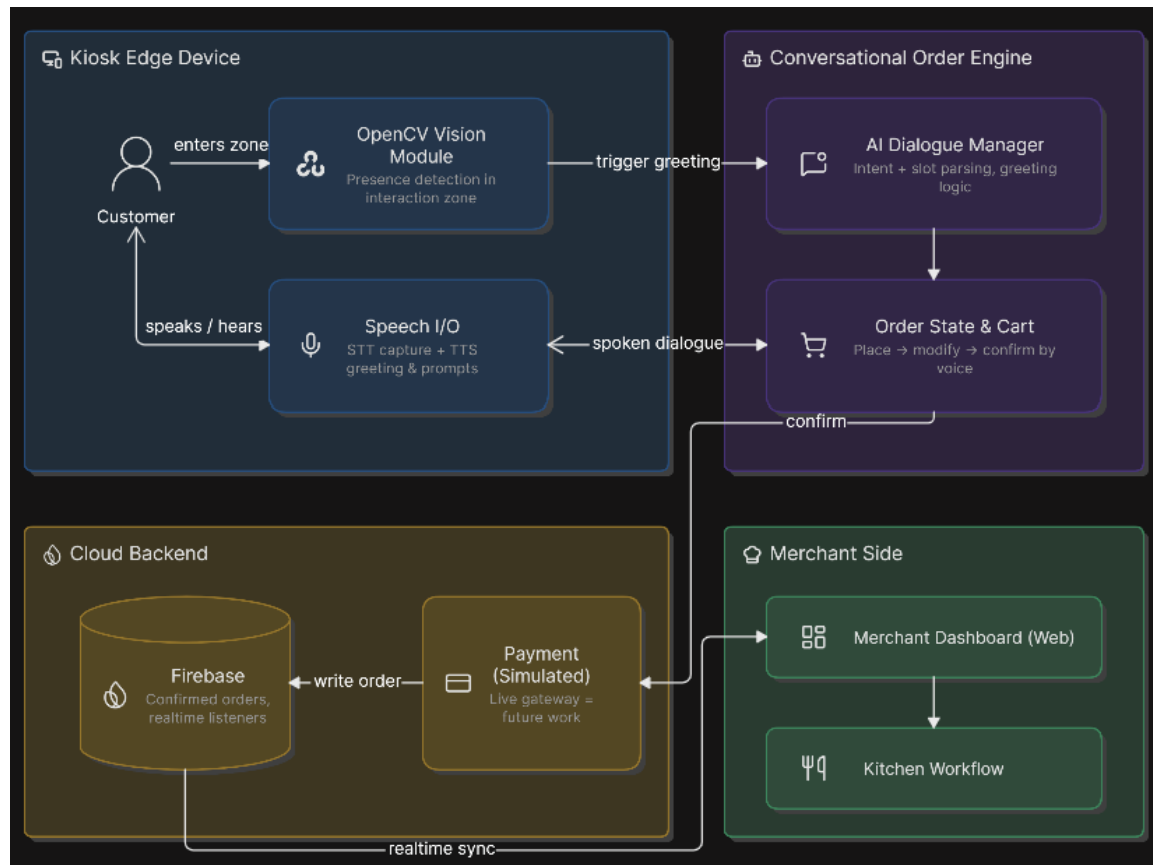


Fig. 1 Voice-Driven Ordering Kiosk – Runtime Architecture

Customer privacy in the presence-detection module is addressed by design: webcam frames are intended to be processed transiently in memory by the OpenCV pipeline solely to determine whether a person is present within the interaction zone, with no frame written to disk, stored in a database, or transmitted beyond the local detection process. Only a boolean presence state (idle or active) is retained; the underlying image data is discarded immediately after each detection cycle. This privacy safeguard is part of the module's design and will be validated during implementation and testing.

Two practical challenges are anticipated for real-world deployment in Sarawak F&B settings and will be assessed once the voice pipeline is operational. First, ambient noise typical of coffee shops and open-air eateries, including overlapping conversation, kitchen equipment, and street noise, may degrade Web Speech API transcription accuracy, particularly for soft-spoken customers or during peak hours. Second, the browser-native STT engine is tuned primarily for standard English pronunciation and may underperform on Sarawakian-accented or code-switched English, which is common in everyday F&B ordering speech. Addressing both challenges, for example through noise-robust STT configuration or a custom vocabulary for local menu terms, is identified as necessary refinement work following initial implementation.

Conclusion

This paper presented the design and ongoing development of EchoServe, an AI-powered voice-driven POS system intended to bring accessible, low-cost self-ordering technology to small F&B businesses in Sarawak. By combining conversational AI, computer-vision-based presence detection, and real-time merchant tooling on standard consumer hardware, EchoServe is designed to address the cost, accessibility, and interaction barriers that have excluded small operators from the benefits already enjoyed by large restaurant chains. The Agile-with-XP development approach allows the system's voice-ordering behaviour, presence-detection configuration, and dashboard features to be shaped through iterative feedback from real F&B operators rather than fixed upfront specification. As of this writing, the voice interface, presence-detection module, and conversational-AI order parsing are still under implementation. Immediate future work includes completing and integrating these core components, followed by usability evaluation using the System Usability Scale, measurement of STT latency and AI order-parsing accuracy, integration of a live payment gateway, expansion of language support beyond English to reflect Sarawak's linguistic diversity, and field evaluation across multiple deployment sites.

Acknowledgement

The authors would like to express their sincere gratitude to *i-CATS RISE* (Research, Innovation, Support, & Enterprise) for providing financial support for this work and the conference participation. The author thanks Ms. Ain Nazihah for her supervision and guidance throughout the development of this project.

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A Multi-Agent Framework for Internship Placement: A Case Study of i-CATS University College

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Abstract— Internship programmes are a key element of higher education whereby students gain real-world industry experience while ensuring cooperation between universities and their industry partners. In i-CATS University College (i-CATS UC), the internship placement process entails various entities such as the students, programme coordinators and the companies that offer internships. This makes the internship placement process more complicated as the number of enrolled students and industry partners increase. Presently, the internship placement process is mainly carried out manually thus increasing the administrative load and inefficiencies. In some cases, there may be mismatches between the skills of the students and those needed by the employer. This paper provides a case study analysis of the internship placement process in i-CATS University College and the creation of Multi-Agent Framework for Intelligent Internship Placement. The framework is designed based on Design Science Research approach and comprises six intelligent agents namely; Student Agent, Employer Agent, Recommendation Agent, Negotiation Agent, University Coordinator Agent and Monitoring Agent. The framework is aimed at automating the internship placement process, improving communication between stakeholders and data-driven decision-making during internship placements. Evaluation through scenarios shows the benefits that the framework offers for the process of internship placement.

Introduction

The internship is an important element in many higher education programs offered in Malaysia which helps students to practically apply theoretical knowledge into the professional field by acquiring industry required skills. Successful internship placements would be helpful for all stakeholders including the students, the universities, and the industries since it will help students to have an industrial exposure and the industries to get suitable interns. In the case of internship placement in i-CATS UC Process, it involves many steps in which the students, the program coordinators, the industrial training coordinators, and the industrial participants need to work together. Research into internship recommendation has been conducted using rule-based systems, recommender systems, and machine learning algorithms [1]. While these systems enhance the quality of the recommendations, their shortcomings include the ability to cater only to one particular stakeholder and insufficient cooperation amongst universities, students, and employers. Multi-Agent Systems (MAS), which involve agents that are autonomous and able to communicate and coordinate, have proven to be useful in solving decision-making problems in educational institutions, manufacturing industries, and smart systems [2][3]. Research into MAS for internship allocation in Malaysian institutions of higher learning is still sparse.

This paper seeks to fill this gap through the use of a case study of i-CATS University College. In particular, the research focuses on the internship placement process in place at i-CATS University College and the difficulties that hinder effective placement of internships. From these observations, a framework based on multi-agent systems is designed to support AI-based intelligent internship placement. The paper also highlights how such a framework can promote the effectiveness of the cooperation between the university and industry using AI.

Methodology

The internship placement process at i-CATS University College was used as the basis for identifying workflow activities, stakeholders, and operational challenges. The information

obtained was translated into a conceptual Multi-Agent Framework designed to address the identified issues. The research process was divided into five main stages. The first stage of research involved the case study analysis of the current process of internship placement within *i-CATS* University College. The second stage included the problem identification where problems associated with the process of manual internship placement, communication barriers, and problems associated with collaboration were identified. During the third stage, the framework design was done. The multi-agent architecture was proposed considering the needs and roles of different stakeholders. In the fourth stage, the proposed framework was validated via the scenario-based analysis of several internship placement cases. Finally, during the fifth stage, the evaluation of benefits and practical implications of the proposed framework was done. The proposed framework includes six intelligent agents.

The Student Agent is responsible for storing data about students such as profiles, records, skills, career interests, and preferences for internship. The Employer Agent stores information about internship vacancies, organisational requirements, and open internships offered by industrial partners. The Recommendation Agent analyzes the compatibility of the profile of a particular student with internship opportunities and produces sorted placement recommendations. This agent rank student based on their profile and placement requirements. Skill-weighted scoring used for essential skill required by the industry while other factors such as student performance also considered. The Negotiation Agent is responsible for solving conflicts when more than one student is recommended to one internship position using priority-driven approaches. To identify placement arrangement, agent will prioritise the mandatory constraint, followed by lower priority.

The University Coordinator Agent checks the internal policy of the university regarding internship placement and eligibility of the student. Finally, the Monitoring Agent is responsible for monitoring internship process and gathering the feedback from students and industrial supervisors.

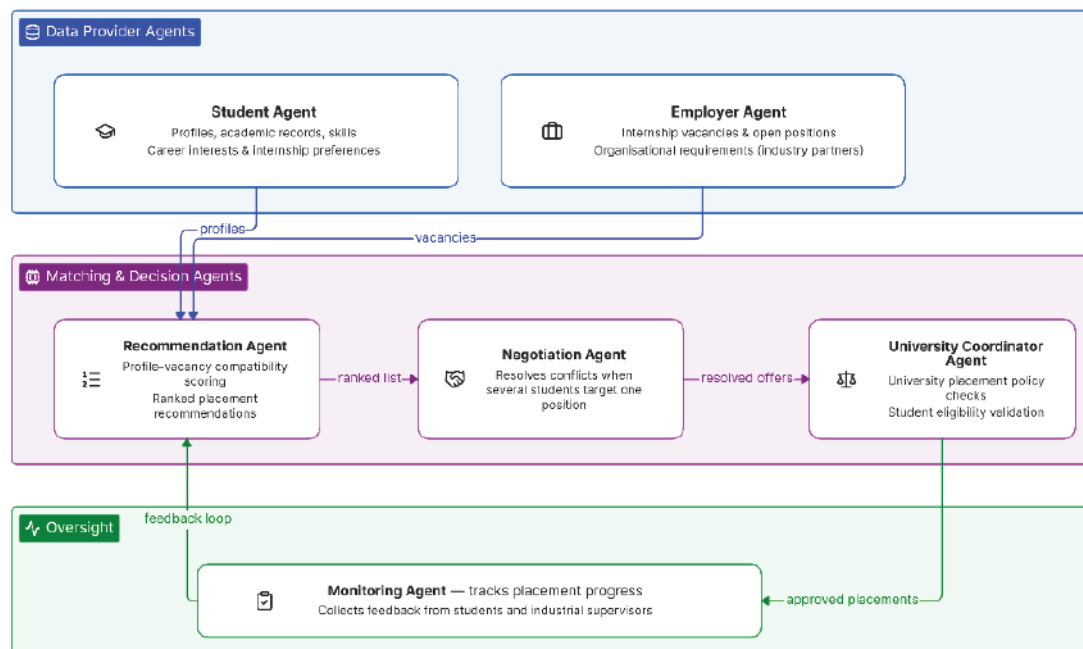


Fig 1 The proposed Multi-Agent Framework for internship placement

Findings and Discussion

There were several difficulties with the present internship placement system in *i-CATS* University College as established from the case study. This includes manual matching of interns to internship positions, constant communication between coordinators and employers, long verification processes, and lack of assistance in matching the competency of the intern to

the needs of the company. This makes the process more tedious and can even affect the efficiency of the entire process. The proposed Multi-Agent Framework solves these problems through decentralization of tasks to specialized intelligent agents. Every agent operates independently but interacts with other agents in order to facilitate decision making as a team during the placement process. From a scenario based assessment, the framework is able to make internship placement process easier.

Table 1. Expected outcomes of the proposed framework

Performance Aspect	Current Practice at i-CATS UC	Proposed Multi-Agent Framework	Potential Evaluation Indicator
Internship matching	Manual	Intelligent automated recommendation	Matching accuracy
Administrative workload	High	Autonomous agent support	Number of manual tasks needed
Communication	Multiple manual interactions	Coordinated agent communication	Number of manual interactions
Placement efficiency	Moderate	Automated matching and coordination	Average placement processing time
University–industry collaboration	Coordinator-dependent	Continuous AI-supported collaboration	Response time

These results indicate that the proposed model can potentially enhance efficiency and transparency within the decision-making process for internship placements. In addition, the model promotes better cooperation between i-CATS University College and industry partners through intelligent information exchange during the internship period.

Conclusion

This paper provided a case study of the internship placement process at i-CATS University College and proposed the development of a Multi-Agent Framework that enhances the process of internship management using Artificial Intelligence technology. As the students, employers, and university coordinators are represented as autonomous agents, the proposed framework facilitates collaborative decision making, automates the administrative tasks and matches internships according to a set of parameters. The development of the suggested framework contributes to digital transformation of higher education institutions in terms of how Multi-Agent Systems could improve collaboration between universities and industry as well as the process of internship placement. While the framework is theoretically verified with the help of case study scenarios, there was no attempt to implement the framework into the current system of internship management at i-CATS UC. Thus, future research is needed for developing a Minimum Viable Product (MVP) of the framework, utilizing Artificial Intelligence methods like large language models for semantic profile matching, as well as evaluating the effectiveness of the framework using actual data of internship placements at i-CATS UC. The progress would focus on one agent at a time. After all agents implemented, by using existing data from the system, it will be used for testing, enhancement of decision-making mechanisms, and evaluating the framework/product.

Acknowledgement

The authors would like to express their sincere gratitude to *i-CATS RISE* (Research, Innovation, Support, & Enterprise) for providing financial support for this work and the conference participation.

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Skill Bridge: Digital Labour Platform for Trusted and Equitable Handyman Gig Workers in Malaysia

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Abstract— The Skill Bridge is a digital labour platform designed with Malaysian gig workers specializing in handyman services. The digital labour platform features a mobile application that acts as an intermediary between the handyman also known as the contractor and customers. It facilitates tasks like matching customer to required service provider contractor as well as subsequent coordination in making appointment, negotiations, payments and verification. To achieve this, the mobile application would be equipped with real-time notifications, chat features, location marketing as well as a system of rating and review to promote trust and transparency. The contractors in turn are supported by being enabled to showcase services, manage bookings and entire workflow right to completion all using the same mobile application. Currently there are mature digital labour platform like Grab that addresses the food related gig economy in Malaysia but not for handyman services and their equivalent. A viable digital labour platform must not only be perceived as useful but eliciting trust and self-efficacy. Design Science Research Methodology (DSRM) was used. The mobile application was successfully developed and survey results by both generic and industry experts attested to viability of Skill Bridge as trusted and equitable mobile platform addressing the gap for industry ready and scalable solution for the local gig economy.

Introduction

There is no doubt that smartphone ownership and Internet usage has reached a near universal status as far as Malaysians are concerned [1]. This trend in turn will spur the gig economy scene that almost necessitates the use of some kind digital labour platform to cater for informal, short stint works with opportunities to gig workers to engage in such, as well as marketing the services or products to customers [2]. The digital labour platform acts as digital intermediary that brings together customers and service providers and providing coordination that extends into search, delivery and payment. Grab and the like are some excellent examples of such platforms as far as food related gig economy is concerned. However when it comes to handyman services and their equivalents, where gig workers may not have established and long term premises or there being a prolonged search for right customer-service-contractor fit, suddenly a gap is readily discerned, at least in Malaysian gig economy. Concerns by customers for vetted contractors, negotiations, search and administrative support for handyman gig workers wishing to manage the business dealings on the same app, make it apparent for the need to build a new labour digital platform. If successful, such platform may contribute to sustainable gig economy in Malaysia.

Literature Review

The participation of gig economy is closely associated with the practicality of the digital labour platform [3] itself, at least among university students. The perception of usefulness and ease of use were primary drivers in promoting gig economy participation among the university students surveyed [3]. The same limitations, like blocked account, lack of transparency and other risks associated with the digital labour platform are also the dissatisfiers that caused the gig workers to withdraw from gig economy. Just because the digital platform may yield useful products and services, there is no guarantee such perception would lead to mobile commerce adoption [4]. Other factors like perceived trust and perceived self-efficacy to be more important in driving mobile commerce adoption [4]. As such a digital labour platform that matches contractors and customers is not sufficient, but also elicits trust and self-efficacy in

customers. Finally, the role of AI applications in prior sales services as well as after sales services might be considered [5]

The current developer, the second author, being proficient with JavaScript and associated tools like Expo, Supabase, and Node.js, would be informed by literature to adopt modern cross platform frameworks like React Native over Flutter and Xamarin [6]. Flutter would be ideal for porting existing native projects and requires learning Dart programming language similar to C. Xamarin would be for optimal performance and .NET programmers. Taking all these into account, since the project's priority is more of proof of concept and the learning curve involved, React Native would be the preferred choice.

Stripe supports various types of payments, from credit/debit cards to digital wallets and even local payment systems such as FPX in Malaysia and above all a sandbox testing for a project like this [7]. As such Stripe was used for the payment method.

Methodology

The Design Science Research Methodology (DSRM) [8][9] was used. The first step “Identify Problem and Motivate” and second step “Define Objectives of a Solution” were carried out during a pitching contest in LaunchX, which is a start-up incubation program exploring ideation for commercialization. The project was developed during third step “Design and Development”. This was followed by the fourth and fifth step “Demonstration” and “Evaluation”. During these steps, test akin to user acceptance test was conducted amongst potential users and demonstration was made before industry expert evaluators. An online survey was completed by each evaluator. The final step 6 Communication is currently being carried out through submission of manuscript to scholarly publications.

Results and Discussion

A total of 32 participants at Vivacity Megamall and i-CATS University College campus were approached to test the Skill Bride mobile app. This would be deemed acceptable as prior literature would use university students in researching the gig economy. Furthermore, Antionette Goh Wei Ting, Manager of Research and Development at the Sarawak Digital Economy Corporation (SDEC) was engaged as special evaluator. SDEC is a state agency entrusted with a mission to drive economy digitalization especially through start-ups incubation and research commercialization. Antionette and her two other colleagues would be industry expert evaluators.

A dedicated project demonstration was conducted virtually via Google Meet specifically for industry expert evaluators to allow for in-depth assessments. Other respondents would be given opportunities to use the Skill Bridge app or seeing demonstration. Likert scale (of 1 to 5: strongly disagree, disagree, neutral, agree and strongly agree) questionnaire was administered for UAT assessing the following aspects: Section A: Contractor Discovery and Booking A1. Mobile app quickly finds and books suitable verified contractors, A2. Select contractors based on service type, location availability and urgency, Section B: Chat and Consultation, Section C: Review and Rating System, Section D: AI Chatbot for Service Inquiry, D1. Helpful AI response/recommendation, D2. Improves appointment experience, Section E: Shuffle Recommendation, Section F: Generic Usability, F1. Interface and navigation, F2. Acceptable response time and 3. Satisfaction with overall function and usability. The Skill Bridge mobile application was deemed successful based on feedback by the 32 respondents with 87.5% in favour (i.e. a combination of Strongly Agree and Agree rating and applicable for subsequent favourable finding) and the remaining 12.5% neutral. The latter were likely due to weak-performing areas pertaining to AI: “helpful AI response/recommendation” at 51.6% in favour and “AI improves appointment experience” at 59.4%. “Shuffle Recommendation” also earned somewhat less favourable assessment at

71.9% and was followed by “review and rating system” at 75%. Meanwhile the “review and rating system” might not be perceived as highly valuable. Despite the shortcomings, the survey reported most favourable results, at 90.6% each, in the following areas: “interface and navigation”, “acceptable response time”, “finding and booking verified contractors” and “chat and consultation”. These are the core functions. The small percentage of detractors for these were likely due to subjective preferences of human-computer interface. When compared with panel of three industry expert’s reviews, the findings were consistent with the above with the slight exception for “review and rating system” at 100% in favour compared to only 75% in generic survey. This was hardly surprising as the experts did frequent evaluations and so would assign higher value on rating system. The experts agreed with previously identified shortcomings: AI features and “Shuffle Recommendation”. Also, one expert did deem AI appointment experience to be favourable. Currently the “shuffle recommendation” works by taking the rating, the category of service and proximity into consideration. It might be speculated that unreliable or less precise answers to complex queries and the doubtful perception of AI’s usefulness contributed to the negative results. This and the “Shuffle Recommendation” apparently required future enhancements.

Overall, considering the industry experts and general public surveyed, Skill Bridge proved to be viable, trusted and equitable mobile platform addressing the gap for industry ready and scalable solution for the local gig economy.

Selected interfaces of the app:

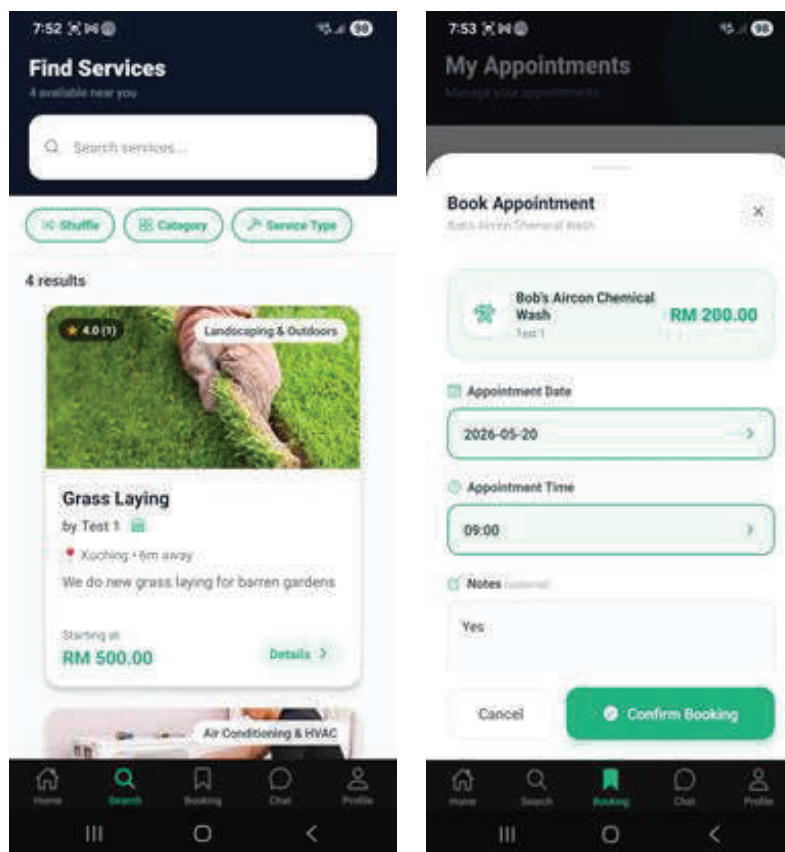


Fig. 1 Service Page and Booking Service

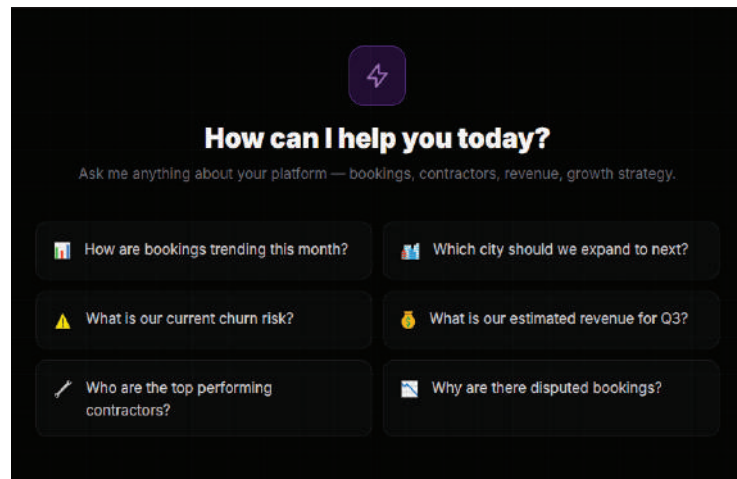


Fig. 2 AI Insight page for quick analysis.

Conclusion and recommendations

The preliminary results show that Skill Bridge would have the potential to be a successful and viable digital labour platform for handyman services for Malaysian gig economy befitting its perceived usefulness as well as other factors like trust and self-efficacy. The latter can only be assessed and validated fully in future study where the project will actually be put to use and further surveys conducted.

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An Augmented Reality Framework for Enhancing Rural Heritage Visibility and Sustainable Tourism Engagement: A Case Study of Serian Villages, Sarawak

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Abstract— Most tourism attractions are well-known landmarks, but few tourists get to know the real historical and cultural values of these places, especially in hidden area. Nonetheless, the lack of promotional and passive platforms – such as flyers, newspapers, or static websites – has caused potential spots in small towns to be overlooked. This study presents an innovative way for visitors to access to historical and cultural attractions in Serian villages, Sarawak, using Augmented Reality (AR) – based mobile app. The app works as a prototype, allowing users to explore spots through interactive AR content, retrieve heritage information, and submit reviews, while also enabling administrators to monitor user engagement. The app was developed using a structured software development approach and evaluated in terms of usability and user experience. The evaluation results showed over 70% positive user acceptance, indicating that the app is effective, easy to use, and encourages engagement with added value of learning about local history and culture. These findings support the potential of AR technology to improve heritage accessibility and promote interactive tourism, especially in rural areas.

Introduction

Tourism spots are well-known for their landmarks and natural heritage. It is difficult to understand the historical values and practices of the place without a promotional material in hand, or having a local guide providing explanations. For hidden attractions, recognition is barely given. Most promotional materials available are always static where information flows only in one direction. There are numerous Serian villages with unique cultural and historical values worth to retain, yet their tourism potential remains underdeveloped. Little or no interactive platforms are in place to do effective promotion. Therefore, innovative approaches are in need to promote village visibility, also in supporting sustainable rural tourism development. The integration of digital information and physical environments through Augmented Reality (AR) technology has become a recent trend in digital transformation in many sectors. The potential is especially clear in tourism, where visitors can gain new experiences while exploring places in a more interactive way. The following Table 1 highlights some of these possibilities.

Table 1: Findings on AR potentials in tourism applications

Author(s)	Findings
Zhao and Ji (2025) [1]	developed a context-aware AR smart guiding platform that integrated deep learning based personalized recommendation, showing improvements in various aspects including tourist engagement, satisfaction, and cultural learning experiences through AR-supported guidance and user behavior analysis.
Fan et al. (2025) [2]	revealed that AR experiences can influence visitor attention, emotional responses, and perceptions of heritage environment. It is firm to say that AR is an effective medium to enhance interaction between visitors and cultural resources, rather than just a visualization tool.
Shehade (2024) [3]	AR transformed rural cultural resources into immersive tourism experiences through digital storytelling and gamification, allowing visitors in developing a deeper understanding and appreciation of local heritage.
Ou-yang et al. (2025) [4]	stated that visitors feel more connected to local culture using AR-based applications on their fingertips, through interactive digital elements.
Jian et al. (2022) [5]	AR technology can bridge digital experiences with cultural heritage, contributing to improved visitor engagement and sustainable rural economic development.

Existing studies that reviewed AR related tourism such as the above, focused mainly on established cultural destinations, museums and city sites. It is obvious that there is still lack of reviews on how effective AR application can assist in promoting hidden rural attractions.

To address this gap, a mobile app prototype is developed to assess its' effectiveness in improving the visibility and accessibility of local historical and cultural attractions in Serian villages. The proposed prototype contains features that allow users to interact with AR-based elements, to access digital cultural information while exploring the villages, share experience reviews, and also let administrators monitor user engagement. The objective of this study is to evaluate the app's usability, user experience, and effectiveness in delivering heritage information. The positive findings from this study suggest that AR can be a practical way to improve rural tourism, not just by making trips more engaging for visitors, but also by helping preserve local culture and supporting more sustainable tourism practices.

Methodology

This study uses a design and development approach to build an AR-based tourism prototype, with the intention to promote historical and cultural attractions in Serian villages. The Kanban framework is used, following an Agile software development methodology, due to its iterative and flexible nature that allows continuous improvements throughout the process. Another main contributor to the choice of Kanban is the availability of testers to be involved in the development. With rapid feedback from testers, tasks like user interface design, AR content integration, database management, and system refinement can be carried out more systematically.

Fig.1 shows the use case diagram of the proposed AR Tourism Application. The main users are visitors exploring Serian villages. They can browse attractions, scan AR markers, access historical and cultural information, submit reviews, and to manage their own accounts. On the admin side, the app lets them manage content, handle reviews, manage system settings, and track data to see how visitors are engaging with the attractions.

The prototype uses marker-based augmented reality to deliver interactive digital experiences for selected historical and cultural attractions. Marker-based AR was chosen because it enables accurate recognition of predefined targets while maintaining efficient performance on mobile devices. The system also has an information management module to store attraction data, AR content, user profiles, and review records.

To address unreliable cellular network coverage in some villages, the prototype was made to work offline. The AR markers and 3D assets are packaged locally within the app itself via upfront installation on the device, so users do not have to download anything during AR interactions. The app only checks for updates when a stable network connection is detected, and if newer assets have been released, it downloads them. This way, the core AR features – recognition and visualization - stay fully functional even without any cellular coverage.

After the prototype was developed with all major features, a User Acceptance Testing (UAT) was conducted to evaluate not only the app's functionality and usability, but also how users experienced the app. Analysis was done to the collected responses to see how well the app worked for heritage exploration, and whether it has the potential to improve access to some of the lesser-known attractions in Serian villages.

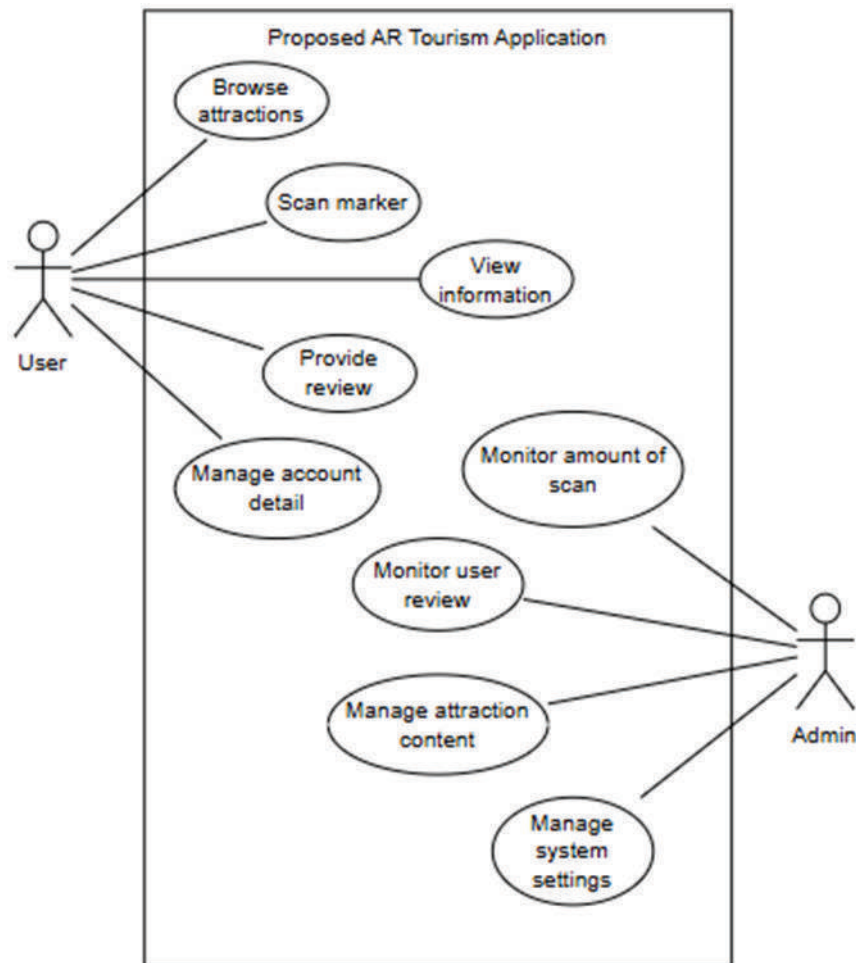


Fig. 17 Use case diagram of the proposed AR tourism application

Results and Discussion

For the UAT, 20 testers were randomly selected, with all sessions conducted on-site in Serian. The locations included the town's wet market, the Bidayuh Longhouses, and Panchor Hot Springs, along with other points of interest within the area. Every participant owned a mobile phone and was accustomed to regular use. This is the only practical consideration given as the prototype operates through mobile augmented reality. No other restrictions regarding age, educational attainment, or prior experience with AR technologies were imposed. All participants interacted with the prototype in an actual environment rather than in a simulated laboratory setting.

Every tester was asked to accomplish a series of predefined tasks – access attraction information, view AR content, navigate through application features, and submit reviews. Feedback was then collected through an online survey based on several evaluation criteria, including system usability, user interface design, information accessibility, performance, AR experience enhancement, information quality, user interaction functionality, user satisfaction, and recommendation intention.

Analysis was done on collected feedback to assess user acceptance and to discover potential areas for improvement. The results have indeed provided some useful insights for the app's future enhancement. Overall, the UAT findings helped validate that the AR Tourism App was suitable for supporting visitors in exploring the villages and cultural attractions of a tourism spot.

Table 2 shows the 10 assessed usability and user experience criteria in the study, along with the corresponding user evaluation results. The findings reveal favorable scores from most

criteria, ranging from 75% to 95% response rates. The highest rate – 95% – was for “Information Accessibility”, where most of the testers agreed that attraction-related information was easy to find and view. This suggests that the app delivered content effectively, even for users who have no AR interface experience. The next highest rate was indicated at 90% for several criteria including usability, AR experience enhancement, review submission, overall satisfaction and user recommendation. These results indicated that the testers found the app easy to use and helped enhancing their experience. Overall, the consistently high scores across diverse criteria suggest that the prototype received broad user acceptance.

Table 2: User evaluation results of the application

Category	Positive Response Rate	Key Finding
Usability	90%	The app is easy to navigate.
User Interface Design	75%	The app's design is visually appealing.
Information Accessibility	95%	Information about attractions is easy to find.
AR Loading Speed	85%	AR content loaded quickly.
AR Tracking Stability	85%	AR content was stable and well-aligned.
AR Experience Enhancement	90%	The AR experience enhanced users' understanding.
Information Quality	85%	The information provided was interesting and informative.
Review Submission	90%	Submitting a review was easy.
User Satisfaction	90%	Users were satisfied with the overall application experience.
User Recommendation	90%	Users would recommend the application to others.

The next positive rating was achieved at 85%, specifically for several AR-related features, including loading speed and content stability. This suggests that the augmented reality components worked as intended during actual use. Content quality came in at the same rate, with users commenting that the information viewed on the app was useful and interesting. Although User Interface Design scored the lowest at 75%, the results remained generally positive while highlighting the exact areas for fixing. Testers complained about small fonts and cluttered menus. These issues will be addressed in the next development cycle through a cleaner layout, larger touch targets and better contrast. Overall, the evaluation results demonstrate that the application successfully provides an effective and satisfactory AR-based user experience.

Conclusion

This study set out to propose and evaluate an AR-based mobile application, with the goal of promoting the historical and cultural heritage found in Serian villages. The developed prototype brings together interactive AR visuals, digital heritage content, user reviews, and attraction monitoring – all aimed at offering a more engaging alternative to traditional travel guides and information boards. Based on the evaluation results, testers responded positively to the prototype's usability, functionality, and overall experience, suggesting it does help them access heritage content and stay engaged. The evaluation results have not only highlighted the improvement rooms for visual design, but also suggested that AR has real potential in promoting lesser-known cultural sport and supporting heritage tourism. Future research could look at adding intelligent features like personalized recommendations or multilingual support, and examine how AR apps actually affect visitor behaviour and rural tourism over time.

Acknowledgement

This research received financial support from *i*-CATS University College.

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A Smart Driver Fatigue Monitoring System Based on Eye Aspect Ratio with Vibration Seat and Alarm Notifications

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Abstract— Driver drowsiness caused by fatigue is a major road safety concern, contributing to thousands of accidents, injuries, and fatalities each year. To address this issue, this project presents the design and development of a Driver Fatigue Monitoring Seat equipped with a vibration alert system, an audible buzzer, and LED warning indicators. Powered by a Raspberry Pi 4, the system performs real-time eye tracking and facial landmark detection using an onboard camera. The monitoring system detects signs of drowsiness by analyzing eye blink patterns through the Eye Aspect Ratio (EAR) and a drowsiness detection algorithm that evaluates prolonged eye closure. When drowsiness is detected, the system activates three warning mechanisms: seat vibration, an audible buzzer, and a red LED indicator, while a green LED remains illuminated during normal operation. The proposed product is a compact, self-contained, cost-effective, and real-time solution designed to reduce fatigue-related road accidents. Furthermore, it operates independently without requiring internet connectivity or external communication modules.

Introduction

Driver fatigue is a major contributor to road traffic accidents, causing numerous injuries and fatalities each year. Fatigue impairs reaction time, attention, and decision-making abilities, often without the driver's awareness. Unlike other risk factors, such as speeding or alcohol impairment, fatigue is difficult to detect and regulate, making it a significant threat to road safety [1]. Drowsiness, a common consequence of fatigue, is defined as a state of sleepiness that may occur while driving. Although it may last only a few seconds, its consequences can be severe. Drowsiness is often caused by insufficient sleep, prolonged driving periods, or driving during normal sleeping hours. As a result, drivers may experience reduced concentration and slower reaction times, increasing the likelihood of accidents [2]. Most existing vehicle safety systems are designed to minimize the impact of accidents rather than prevent them. Although advanced driver monitoring systems are available in some premium vehicles, their high cost limits widespread adoption [3]. Furthermore, conventional fatigue detection methods, such as lane departure warning systems and steering behavior analysis, may not consistently detect early signs of drowsiness under varying driving conditions.

To address these limitations, this project proposes a real-time Driver Fatigue Monitoring Seat based on a Raspberry Pi 4 and a camera module. The system utilizes facial landmark detection and the Eye Aspect Ratio (EAR) technique to continuously monitor the driver's eye behavior and identify signs of fatigue as shown in Fig. 1 and 2. When drowsiness is detected through prolonged eye closure or abnormal blinking patterns, the system activates a vibration motor, an audible buzzer, and LED warning indicators to alert the driver immediately [4]. The proposed system offers a compact, cost-effective, and standalone solution for real-time driver fatigue detection without requiring internet connectivity or external communication modules. By providing early warnings through multiple alert mechanisms, the system aims to enhance driver awareness, reduce fatigue-related accidents, and improve overall road safety.



Fig. 1 EAR Landmarks

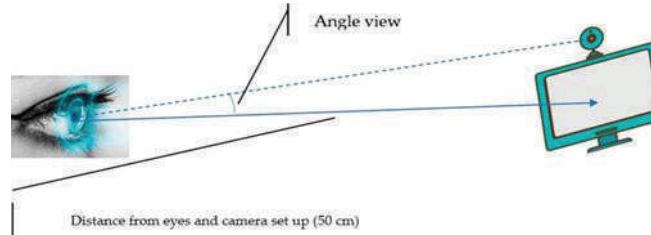


Fig. 2 EAR signal plot showing multiple blinking events over time

Methodology

Overall, the research methodology adopted for the development of the Driver Fatigue Monitoring Seat with Vibration Alerts and Alarm System is structured and focuses on system design, implementation, and performance validation. The process begins with identifying user and system requirements, followed by the development of a system design that integrates computer vision-based fatigue detection with an embedded alarm system. Key phases include hardware selection, facial image processing using the Eye Aspect Ratio (EAR) method, real-time alert system integration, and system testing under various operating conditions.

The flowchart illustrates in Fig.3 the operational logic of the Driver Fatigue Monitoring Seat system. The process begins with the initialization of hardware components, including a Raspberry Pi 4, camera module, vibration motor, buzzer, and red and green LED warning lights. Once the system is powered on, the camera continuously captures the driver's facial images in real time. Facial landmark detection is then performed to identify key points around the eyes. The detected landmarks are used to calculate the Eye Aspect Ratio (EAR), a measurement that indicates whether the driver's eyes are open or closed. The Eye Aspect Ratio (EAR) was calculated using six eye landmarks identified through facial landmark detection, as illustrated in Fig. 1. Let p_1 to p_6 represent the six landmark coordinates surrounding the eye. The EAR is computed as: where p_i-p_j denotes the Euclidean distance between two landmark points. The numerator represents the sum of the two vertical eye distances, while the denominator represents twice the horizontal eye width. When the eyes are open, the EAR remains relatively constant. During blinking or prolonged eye closure, the vertical distances decrease, causing the EAR value to drop below a predefined threshold. Persistent EAR values below the threshold are interpreted as signs of driver fatigue and trigger the alert mechanisms. This process is carried out continuously in real time to ensure effective monitoring of the driver's alertness and fatigue level.

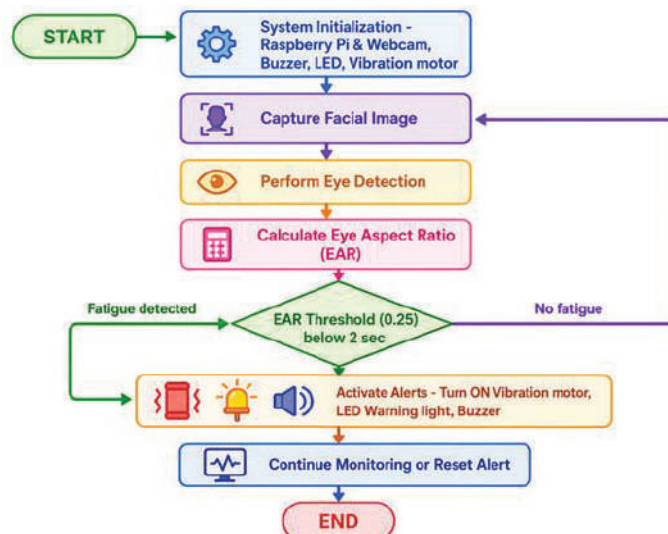


Fig. 3 flow chart the operational logic of the Driver Fatigue Monitoring Seat System

Results and Discussion

The Driver Fatigue Monitoring Seat with Vibration Alerts and Alarm System was implemented using a Raspberry Pi 4 and a camera-based fatigue detection approach as shown in Fig. 4. The system continuously captures the driver's facial images and processes them using the Eye Aspect Ratio (EAR) algorithm to monitor eye closure in real time. Experimental results demonstrated that the system effectively distinguishes normal eye blinking from fatigue-related eye closure. When the EAR value remained above the predefined threshold, the driver was classified as alert and no warning signals were generated. Conversely, prolonged eye closure below the threshold triggered a fatigue detection event, causing the Raspberry Pi to activate the vibration motor, buzzer, and LED warning indicators through its GPIO outputs.

Despite the promising performance observed during testing, several real-world factors may affect system accuracy. Low-light environments can reduce the quality of facial landmark detection, potentially affecting EAR calculation reliability. Similarly, dark sunglasses may partially or completely obscure the eyes, limiting the effectiveness of vision-based monitoring. Rapid head movements, extreme head poses, or temporary occlusion of the face may also cause momentary landmark tracking errors. Although the proposed system demonstrated stable operation under normal lighting and positioning conditions, future work could incorporate infrared cameras, adaptive image enhancement techniques, or head-pose compensation algorithms to improve robustness under challenging driving environments.

Experimental evaluation was conducted using 1 subject and a total of 4 testing sessions under controlled conditions. Each trial included both normal eye-blinking and simulated prolonged eye-closure events to assess the accuracy and responsiveness of the proposed fatigue monitoring system. The results verified that the alert mechanisms were activated only under genuine fatigue conditions, thereby minimizing false alarms during normal driving. The system exhibited reliable real-time performance, accurately identifying driver drowsiness while maintaining stable operation throughout the testing period as illustrates in Fig. 5. Furthermore, the warning duration was proportional to the persistence of the fatigue condition, ensuring that alerts remained active only when necessary and were immediately deactivated once the driver regained alertness. Compared with conventional drowsiness detection systems that require multiple sensors, wireless communication modules, or Internet of Things (IoT)-based connectivity, the proposed system utilizes a single-camera EAR-based approach, reducing hardware complexity and implementation cost. The integration of multimodal alerts, including visual, auditory, and tactile feedback, further enhances driver awareness and response. These findings demonstrate that the proposed system provides a reliable, cost-effective, and practical solution for real-time driver fatigue monitoring and road safety applications.

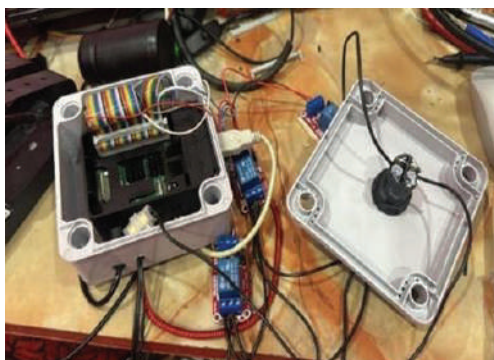


Fig. 4 Constructed Hardware

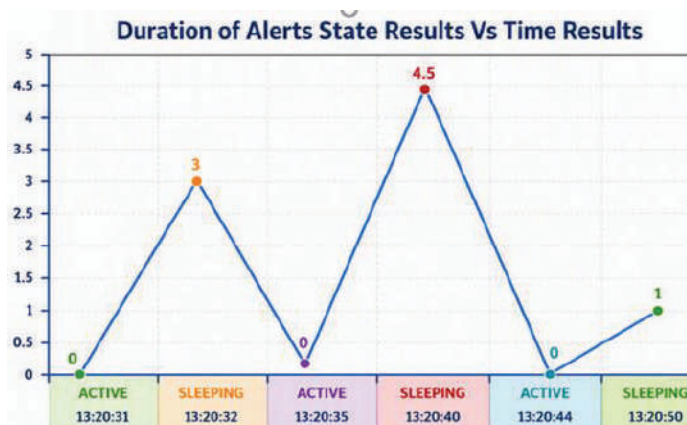


Fig. 5 Duration of Alerts State Results Vs Time Results and Alert Output Response Results

Conclusion

The Driver Fatigue Monitoring System developed in this project demonstrates the effectiveness of integrating a camera-based vision system with low-cost embedded hardware to enhance driving safety. By utilizing a Raspberry Pi 4 and a USB camera, the system continuously monitors the driver's eye condition using the Eye Aspect Ratio (EAR) method to assess alertness in real time. The system successfully classifies the driver's state into two categories, namely Driver Active and Sleeping Detected, enabling fast and reliable decision-making during operation.

When prolonged eye closure is detected, the system automatically activates multiple alert mechanisms, including a buzzer, LED indicators, and a vibration motor through relay control. These alerts remain active for the duration of the fatigue condition and are immediately deactivated once the driver's eyes reopen, indicating restored alertness. Experimental testing confirmed that the system can accurately distinguish between normal blinking and fatigue-related eye closure, thereby minimizing false alarms while ensuring timely intervention. Furthermore, the integration of image processing, GPIO control, relay switching, and alert outputs operated reliably throughout the testing process without significant delay or instability. Overall, the project successfully achieved its objectives by developing a functional, cost-effective, and real-time driver fatigue monitoring solution. The findings demonstrate that the proposed system is capable of providing accurate fatigue detection and immediate warning responses, making it a practical approach for enhancing driver awareness and reducing the risk of fatigue-related road accidents. The combination of computer vision-based monitoring and multimodal alert mechanisms highlights the system's potential for implementation in real-world vehicle safety applications.

Acknowledgement

This study was funded by Universiti Teknikal Malaysia Melaka (UTeM) through the Geran Penyelidikan Jangka Pendek (PJP) Perspektif (Sains dan Teknologi), Grant No. PJP/2025/FTKIP/PERSPEKTIF/SA0118. The authors would also like to express their sincere appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for its continuous support and assistance throughout this research.

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QUALITY SYSTEMS



Bridging Design and Production: A DFMA-Based Approach to Manufacturing Process Planning for a Mozzarella Cheese Stretchability Testing Machine

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Abstract - The development of testing equipment for food products requires not only functional performance but also manufacturability and ease of assembly to ensure efficient production and implementation. This study aims to develop a structured and efficient manufacturing process design for the redesigned mozzarella cheese stretchability testing machine by applying the Design for Manufacture and Assembly (DFMA) approach. Alternative manufacturing processes for each component were then evaluated using a weighted decision-making method based on criteria including process simplicity, production cost, processing time, product quality, setup time, and technological requirements. The selected manufacturing alternatives were subsequently integrated into a comprehensive manufacturing process plan and visualized using an Operation Process Chart (OPC) to provide a clear representation of the production workflow. Finally, a preliminary performance test was conducted to verify the operational functionality of the manufactured machine. The results demonstrate that the DFMA approach effectively supports the development of a manufacturable and assembly-oriented production process for the mozzarella cheese stretchability testing machine. The weighted evaluation successfully identified the most appropriate manufacturing methods for each component, resulting in a systematic and practical manufacturing process plan suitable for implementation in medium-scale industries. Furthermore, performance testing confirmed that the machine was capable of providing consistent stretching motion and controllable angular adjustment, indicating that the proposed manufacturing process design can support the intended functional requirements of the testing system.

Introduction

Mozzarella cheese is among the most widely consumed cheese varieties worldwide because of its excellent melting and stretching characteristics, particularly in pizza and other baked products [1] & [2]. Stretchability represents one of the primary indicators of mozzarella cheese quality and directly affects consumer satisfaction. It is an important thing to ensure this characteristic to meet the customer expectation, by testing the stretchability of mozzarella cheese [3]. Nevertheless, industrial stretchability evaluation in Indonesia is commonly performed using manual methods, particularly the fork test, whose results are highly influenced by operator experience, pulling speed, and environmental conditions. Consequently, the test outcomes exhibit limited repeatability and reproducibility, leading to reduced measurement accuracy and reliability. Therefore, a repeatability and measurement accuracy remain major challenges [4] & [5]. Several studies have evaluated the quality of mozzarella cheese by measuring its stretchability through pulling the cheese strands until they separate from the pizza surface [6] [7].

There are several rheological test techniques for evaluating the stretchability of cheese [8]. It emphasizes the application of nonlinear viscoelasticity techniques and dynamic testing, which can be done with texture analyzers and tensile testing equipment. The usefulness of this approach for testing cheese stretchability was demonstrated by the results, which showed considerable increases in peak force with increasing speeds and temperatures. This equipment is not specifically designed to assess the stretchability of mozzarella [9]. Previous study created a prototype of a mozzarella cheese stretchability testing apparatus that could generate more controlled stretching movements [10]. Nevertheless, research has not yet been done on how to create an effective manufacturing process from the prototype. To simplify product design, save manufacturing and assembly costs, enhance product quality, and expedite product

development, it is crucial to use a methodical approach that incorporates Design for Manufacturing (DFMA) [11] - [12]. DFMA evaluates component geometry, manufacturing complexity, assembly relationships, and process feasibility, enabling designers to reduce production cost and improve manufacturability [13] - [14]. In order to create a methodical manufacturing process for the mozzarella cheese stretchability testing equipment, this study uses the DFMA technique.

Methodology

In order to comprehend the machine's general structure and the connections between its various parts, the inquiry started with a thorough examination of its design. A Bill of Materials (BOM) was then created to methodically list every part that makes up the machine. The resulting BOM, which consists of several subassemblies and individual parts, shows the hierarchical assembly structure. The Design for Manufacture and Assembly (DFMA) methodology is used to assess component geometry and manufacturing complexity based on this data. Each component's complexity, geometry, and manufacturability were evaluated using the DFMA approach. The evaluation of production needs and the degree of process complexity involved in creating each part is made easier by this approach. Several viable manufacturing process options were found based on the DFMA assessment in accordance with the component manufacturing requirements [15]. Then, working with manufacturing specialists, a weighted scoring methodology was used to choose the best manufacturing technique.

Findings and Arguments

A detailed description of the main machine components is presented in Table 1, and design of each component as shown in Figure 1. A popular multicriteria decision making method for ranking and assessing potential solutions according to a predetermined set of evaluation criteria is the Weighted Scoring Method (WSM) [16]. By taking into account various technical and practical aspects at once, this approach makes systematic decision-making easier and allows for the selection of the best option among a number of workable options [17]. The WSM was employed in this study to determine which production method was best for each machine component. Each manufacturing option was compared to a set of criteria during the selection process, and each criterion was given a weighting factor based on how important it was. Each criterion's performance rating was multiplied by its appropriate weight, and the weighted scores were then added to determine each alternative's overall score. Because it best met the prototype's design, production, and financial requirements, the manufacturing procedure with the greatest overall score was determined to be the best option.

The planning of manufacturing process focused primarily on custom-made components whereas standard components were procured. In general, the manufacturing operations included material cutting, drilling, tapping, welding, surface finishing (sanding), and assembly. These processes were selected according to the geometric characteristics and manufacturing to achieve an efficient production while maintaining the required dimensional accuracy and structural integrity. A summary of the primary manufacturing processes for each custom component is presented in Table 2.

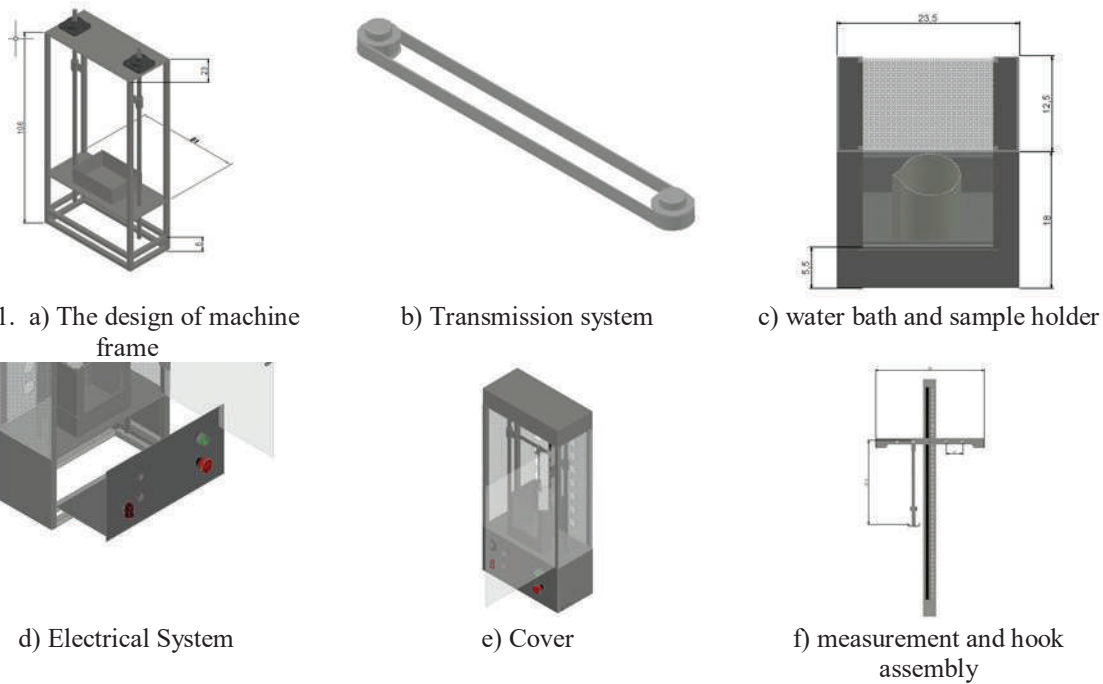


Fig 1. Design of main machine components

Table 1. Description of the main machine components

Specification Category	Specification	Description
General Machine Specifications	Overall dimensions (L × W × H)	546 mm × 246 mm × 940 mm
	Drive system	DC motor with speed controller
	Power transmission system	Lead screw, pulley, and timing belt
	Heating system	Electric heater
	Heater power	1500 W
	Heating medium	Water
	Sample container capacity	500 g
	Primary construction materials	Stainless steel, acrylic, and glass
	Motor speed	2000 rpm
	Measurement scale length	570 mm ruler
Testing Operation Specifications	Maximum measurement length	300 mm
	Pulling angle adjustment	Inclination adjustable in 5° increments
	Sample heating time	15 min
	Water heating temperature	60–90 °C

Table 2. Primary manufacturing processes

Assembly Group	Tools and Materials	Manufacturing Process Sequence
Machine Frame and Screw System	Angle grinder, cutting disc, flap disc, GTAW welding machine with stainless steel filler wire, hand drill, drill bits, M20 tap, tap wrench, clamping jig/clamps, scribe, marker, and engineer's square	Cutting, drilling, tapping, welding, sanding, assembly
Transmission System	Wrenches, pulleys, timing belt, screwdrivers	Assembly
Water Bath and Sample Holder	Angle grinder, 4-inch cutting disc (1.2 mm), 4-inch flap disc (120 grit), diamond glass cutter, kerosene (glass cutting lubricant), GTAW welding machine, stainless steel filler wire, clamping fixtures, glass panels, stainless steel sheet, sealant, ruler, and marker	Cutting, bending, welding, sanding, assembly

Protective Cover	Angle grinder, 4-inch thin cutting disc (1.2 mm), 4-inch flap disc (120 grit), hand drill, drill bits, screwdrivers, screws, hinges, GTAW welding machine, stainless steel filler wire, handle, ruler, and marker	Cutting, bending, welding, sanding, assembly
Electrical System Compartment	Acrylic sheet (550 mm × 120 mm), hole saw, soldering iron, adhesive, and marker	Cutting, assembly
Measurement Components and Hook Assembly	Angle grinder, 4-inch thin cutting disc (1.2 mm), 4-inch flap disc (120 grit), GTAW welding machine, filler wire, hand drill, drill bits, M6 × 1.0 tap, tap wrench, vertical-axis bracket	Cutting, sanding, bending, drilling, welding, assembly

Conclusion

This study used the Design for Manufacture and Assembly (DFMA) approach to successfully build a systematic manufacturing process for a mozzarella cheese stretchability testing machine. Using the Weighted Scoring Method, DFMA successfully determined appropriate manufacturing techniques for every component and assisted in the selection of workable production technologies. In order to make the production process viable for small and medium-sized manufacturing enterprises, the suggested manufacturing method places an emphasis on accessible technologies such as angle grinding, drill pressing, manual tapping, welding, and selective outsourcing for high-precision components. A thorough production guideline is provided by the resulting Operation Process Chart, which consists of 41 operations and 9 inspections. The suggested DFMA-based manufacturing process provides a workable foundation for the future commercialization of mozzarella cheese stretchability testing equipment while also improving manufacturability, production efficiency, assembly consistency, and product quality.

Acknowledgements

The authors would like to express their sincere gratitude to the BPPM Faculty of Engineering, Universitas Brawijaya, for providing financial support through the Faculty Research Grant, which made this research possible.

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Enhancing Lean Manufacturing Decision-Making Through the Integration of Value Stream Mapping, Discrete Event Simulation, and Time-Driven Activity-Based Costing

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Abstract Manufacturing organizations are increasingly challenged to improve productivity while simultaneously reducing operational costs in highly competitive markets. Although Lean Manufacturing (LM) provides effective tools for identifying process inefficiencies, conventional approaches such as Value Stream Mapping (VSM) are limited by their inability to evaluate dynamic manufacturing behaviour and quantify the financial impact of improvement initiatives. Similarly, Discrete Event Simulation (DES) enables the evaluation of manufacturing scenarios but primarily focuses on operational performance, whereas Time-Driven Activity-Based Costing (TDABC) provides detailed cost information without considering production system dynamics. This study proposes an integrated decision-support framework that combines VSM, DES, and TDABC to support manufacturing improvement from both operational and financial perspectives. A case study was conducted at EPMB PEPS-JV Melaka Sdn. Bhd., involving the Honda CR-V rear frame component production line. Production data were collected through direct observation, time studies, interviews, and company record to develop the current-state VSM and a validated Arena simulation model. Improvement scenarios were subsequently evaluated using DES, and the simulation outputs were integrated with TDABC to estimate resource utilization and activity costs. The proposed production strategy reduced production time from 12 to 10 hours, eliminated overtime, reduced the workforce requirement from 10 to 5 operators, and lowered the total daily manufacturing cost while maintaining the required production target. These findings demonstrate that the proposed VSM–DES–TDABC framework provides lean practitioners with an effective decision-support tool for simultaneously evaluating operational performance and financial outcomes prior to implementation.

Introduction

Manufacturing industries are under increasing pressure to improve productivity, reduce operational costs, and enhance resource utilization while maintaining product quality. Consequently, Lean Manufacturing (LM) has become one of the most widely adopted improvement philosophies due to its ability to eliminate waste and improve operational efficiency [1], [2].

Among various lean tools, Value Stream Mapping (VSM) is widely used to identify bottlenecks and non-value-added activities. However, its static nature limits the evaluation of dynamic production behaviour and the prediction of improvement outcomes [3]. To overcome this limitation, Discrete Event Simulation (DES) enables manufacturing systems to be modelled and improvement scenarios to be evaluated without disrupting actual production [4]. Nevertheless, most simulation studies focus primarily on operational performance while providing limited assessment of financial implications [5].

From a financial perspective, Time-Driven Activity-Based Costing (TDABC) estimates resource consumption and activity costs but does not represent the dynamic interactions within manufacturing systems [6]. Consequently, operational and financial evaluations are often conducted separately, limiting comprehensive decision-making.

To address this gap, this study proposes an integrated decision-support framework combining VSM, DES, and TDABC to evaluate manufacturing improvement initiatives from both

operational and financial perspectives. The framework is demonstrated through a case study at EPMB PEPS-JV Melaka Sdn. Bhd., focusing on the Honda CR-V rear frame component production line. The proposed framework provides lean practitioners with a systematic approach for selecting improvement strategies based on quantitative operational and financial evidence.

Methodology

A single-case study was conducted at EPMB PEPS-JV Melaka Sdn. Bhd. involving the Honda CR-V rear frame component production line. As illustrated in Figure 1, production data were collected through direct observation, time studies, interviews, and company records. Value Stream Mapping (VSM) identified bottlenecks and improvement opportunities, while Time-Driven Activity-Based Costing (TDABC) quantified resource consumption and activity costs. A validated Arena-based Discrete Event Simulation (DES) model was subsequently developed to evaluate improvement scenarios. The operational and financial performances of each scenario were compared to identify the most effective production strategy for evidence-based manufacturing decision-making.

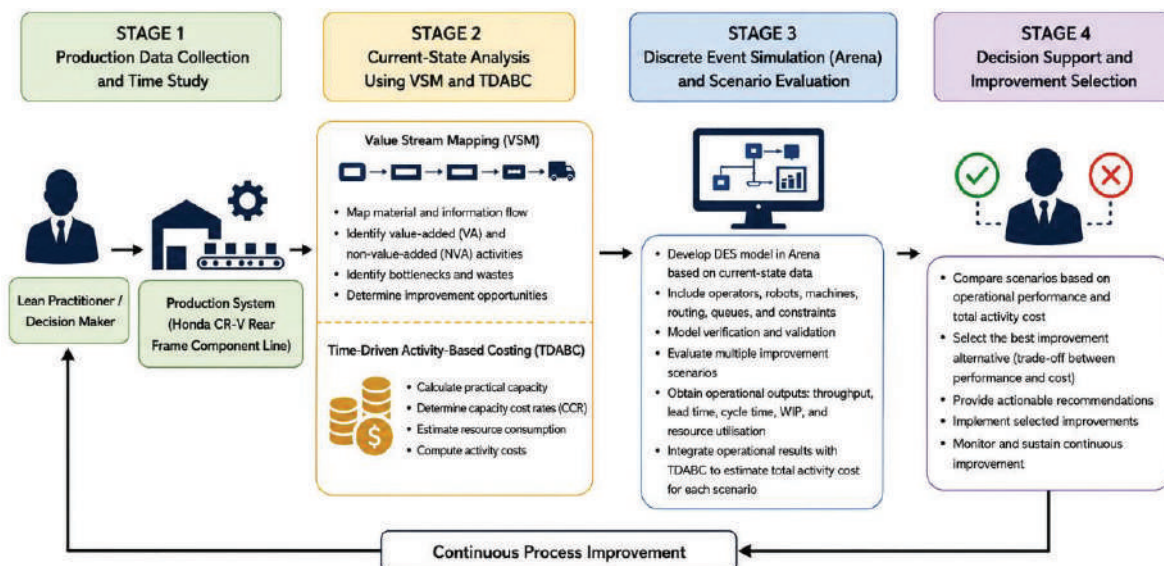


Fig. 1 Integrated Decision-Support Framework for Enhancing Manufacturing Decision-Making Through the Integration Of VSM, TDABC and DES

Results and Discussions

The current-state Value Stream Mapping (VSM) identified robotic spot-welding Workstations 1 and 2 as the primary production bottlenecks due to their relatively long processing times, resulting in excessive waiting time and reduced production flow. Based on these findings, improvement scenarios were developed and evaluated using a validated Arena Discrete Event Simulation (DES) model.

The simulation results demonstrated that the proposed sequential production strategy successfully maintained the required production target of 120 components while reducing the total production time from 12 hours to 10 hours. The current production system operated two parallel production lines, requiring duplicated manpower. By redesigning the production sequence and validating it through Arena simulation, the proposed method demonstrated that the same production target could be achieved using a single production line operating sequentially. As a result, the workforce requirement was reduced by 50%, production time decreased by two hours, and overtime was eliminated. Consequently, the required production output was maintained while reducing both production time and labor requirements,

demonstrating that process reconfiguration can improve operational efficiency without compromising manufacturing capacity. Table 1 compares the operational and financial performance of the existing and proposed production systems. The proposed production strategy reduced production time, labour requirements, and manufacturing costs while maintaining the required production output.

Table 1. Comparison of Operational and Financial Performance between the Existing and Proposed Production Systems

Operational Measure	Current System	Improved System
Components	118	120
Production Time	12 Hours	10 Hours
Cycle Time	336 sec	300 sec
Overtime Required	Yes	No
Number of Operators	10	5
Total Daily Manufacturing Cost	RM 6657	RM 5442

The operational improvements were subsequently evaluated using Time-Driven Activity-Based Costing (TDABC) to quantify their financial implications. The reduction in production time, labour requirements, and overtime resulted in lower resource consumption and reduced daily manufacturing cost while maintaining the required production capacity. Unlike DES, which evaluates operational performance, TDABC provides visibility into resource capacity utilization and activity-level cost drivers. The integration of DES and TDABC therefore enables simultaneous evaluation of operational performance and economic feasibility, allowing lean practitioners to select improvement strategies based on quantitative operational and financial evidence rather than intuition alone.

Conclusion

This study proposed an integrated decision-support framework that combines Value Stream Mapping, Discrete Event Simulation, and Time-Driven Activity-Based Costing to support lean manufacturing improvement. The case study demonstrated that the proposed production strategy successfully maintained the required production target while reducing production time, labour requirements, overtime, and manufacturing cost. By integrating operational simulation with cost analysis, the proposed framework enables evidence-based evaluation of improvement alternatives before implementation, thereby reducing decision uncertainty and supporting more effective manufacturing decision-making. The proposed production strategy maintained the required production target while reducing production time, labour requirements, overtime, and manufacturing cost. The findings demonstrate the potential of the framework to support evidence-based lean decision-making. Future research may incorporate real-time production data, digital twin technologies, and artificial intelligence to further enhance manufacturing decision-making.

Acknowledgement

The authors gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) for providing financial and research support for this study.

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Efficient Flow: Strategies for Right-Sizing Work in Progress Inventory

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Abstract— Work-In-Progress (WIP) inventory optimization is important for manufacturing production efficiency and effectiveness since too much WIP incurs expenses and limits flexibility. The purpose of this study is to identify the critical issues of maintaining an appropriate inventory limit without going overboard and to focus on the application of ABC Analysis with Lean manufacturing concepts in related manufacturing operations. Then, analysing the actual condition, applies ABC Analysis, and assesses its performance. This study, which was carried out as a case study in the food industry. The results showed that revision of the ABC classification system will improve inventory status. As a necessary step, the analysis will determine the actual Safety Stock and Reorder Points.

Introduction

Optimizing Work-In-Progress (WIP) inventory is important for decreasing costs, improving production flow, and increasing performance of efficiency. WIP inventory levels, which include materials and WIP, will increase costs, decrease flexibility, and generate waste. Normally, lean manufacturing tools such as Just-In-Time (JIT) production and Kanban systems will support minimizing WIP while ensuring continuous operational progress. Besides, ABC Analysis will prioritize inventory based on a specific measured value, allowing managers to focus on critical items. Additional techniques, such as agile project management, real-time monitoring tools, and effective management, further support WIP level handling. The improvements in decrease waste, cycle times, and coordination towards better performance and are related to customer satisfaction.

Problem Statement

Industries always have more efforts with WIP inventory issues, facing difficulty in reducing excess while sustaining appropriate supply. Latest practices underutilize implemented lean and agile concepts. This research identifies the related shortcomings of conventional methods such as ABC Analysis, which are challenged by data observation and market fluctuation. Besides, evaluates modern alternatives in technology and management.

This research aims to determine the appropriate inventory levels for the manufacturing sector utilising the ABC Analysis method. This study needs to have the following specific goals in mind in relation to the important target:

- To look into the current state of the Work-in-Process inventory in the manufacturing industry.
- To put the ABC Analysis system into use in the manufacturing sector.
- To check the level of available stock/inventory in the manufacturing industry.

Understanding of Inventory Management

Lean manufacturing, advanced IT tools, data analysis, and ideas like Just-In-Time (JIT), Economic Order Quantity (EOQ), and ABC analysis all help to make processes more efficient, cut down on waste, and increase output. Supply chain management includes managing demand, making sure that products are available, and working together. Lean principles, as [1] stated, put efficiency first by creating the best use of supporting resources and eliminating all waste.

This technique is able to refine your business in order to make more profit and stay in business even when times are too difficult. Toyota introduced lean manufacturing in order to make the best use of manpower, lower costs, and shorter lead times of operations by increasing productivity and eliminating waste in the manufacturing process [2,3]. In current industries, lean ideas are critical to adopt with competition from around the world and market changes. They need to eliminate the seven kinds of waste, such as high inventory levels and defects [1]. Demand changes make it difficult to practice lean, but strategies like forecasting, safety stock, EOQ, and ABC Analysis are able to support and manage the inventory better and respond to market changes more effectively. [4][5][6], Enhance flexibility, adaptability, and cost of control while providing new opportunities. In the latest business situation, manufacturing industries that need to maximize their business should practice lean manufacturing. By reducing a large amount of waste in time, materials, and processes, lean, which is introduced from the Toyota Production System (TPS), ensures that things are done in a timely to enhance [7].

Methodology

This study employs a mixed-method approach, combining quantitative inventory data analysis with qualitative process observations to develop and validate an optimized WIP management framework.

- (i) **ABC Classification Criteria:** Inventory were categories into three items (A, B, and C) based on their yearly amount of value and their importance and criticality to the overall production operation. The related detail explanation are as below:
 - a) **A-Category Items (High Criticality):** These categories normally make up approximately 10-15% of overall inventory items but account for 70-80% of the yearly consumption value. Their stockout would cause an immediate halt or significant delay in operations.
 - b) **B-Category Items (Moderate Criticality):** These categories represent about 20-25% of the overall amount and account for 15-20% of the annual consumption value. Stockout would cause some disruption but not a complete shutdown, meaning that they are moderately critical.
 - c) **C-Category Items (Low Criticality):** These bring to 60-70% of overall value but represent only about 5-10% of the annual consumption value. They are typically low-cost.
- (ii) **Safety Stock Formula (Equation 1):** To ensure the appropriate safety stock levels for every single item, considering the food manufacturing context, the appropriate formula was adapted to use shelf life:

$$\text{Safety Stock} = (Z \times \sigma_{dLT} \times \sqrt{LT}) + (SLA \times AD) \quad (1)$$

Where:

Z = Z-score corresponding to the desired service level (e.g., 1.65 for 95% service level).

σ_{dLT} = Standard deviation of daily demand. LT = Average lead time (in days) for replenishment. SLA = Shelf Life Allowance factor (a percentage of average daily demand, AD , to account for potential spoilage). For this study, SLA was set at 5% for A-items, 3% for B items, and 1% for C-items, based on the shelf life of the specific ingredients. AD = Average daily demand. This formula helps reduce the risk of waste from expired materials, and keeps maintaining the buffer for demand, and accounts for product shelf life.

- (iii) **Data Collection & Analysis:** Historical data on demand, lead times, inventory levels, and spoilage rates for the past 24 months were collected from the manufacturing facility's ERP system. This data was used to calculate the ABC classification and optimize safety stock levels.

Results

The implementation of the proposed ABC classification and the revised safety stock formula yielded significant quantifiable improvements in WIP management, as shown in Table 1.

Table 1: Before vs after optimization

Metric	Before Optimization	After Optimization	Change (%)
Total WIP Value (RM)	RM2,450,000	RM1,837,500	-25%
Average WIP Days of Stock	18 days	12 days	-33%
Inventory Holding Cost (Annual)	RM367,500	RM275,625	-25%
Spoilage / Expiry Rate	4.2% (of total WIP value)	2.1% (of total WIP value)	-50%
Stockout Frequency (A-items)	2 times per year	0 times per year	-100%

Conclusion

This research demonstrates that an integrated approach, combining ABC Analysis with lean principles and food-specific inventory policies, significantly enhances WIP inventory management in the manufacturing sector. By prioritizing inventory based on value and criticality, and by incorporating shelf-life considerations into safety stock calculations, organizations can achieve substantial cost savings, reduce waste, and improve operational performance. The study successfully addressed the initial problem statement by providing a quantifiable methodology to reduce excess WIP while safeguarding adequate supply. Future research could explore the integration of predictive analytics and machine learning to further refine demand forecasting and inventory optimization in dynamic market conditions.

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An Integrated Overall Resource Effectiveness Framework for Production Loss Assessment and Manufacturing Performance Improvement

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Abstract— Manufacturing companies require comprehensive performance evaluation methods to improve resource utilization and reduce production losses. This study employs a structured approach utilizing Overall Resource Effectiveness (ORE), loss analysis, and Root Cause Analysis (RCA) to evaluate production resource effectiveness and determine improvement priorities for the 311-can production line. ORE evaluated manufacturing performance through seven resource dimensions, while Pareto analysis and Fishbone diagrams identified dominant production losses and their root causes. The average ORE was 49.31%, indicating that manufacturing resources were not utilized optimally. Availability of facility (76.90%) and performance efficiency (72.52%) were the main contributors to reduced effectiveness. Pareto analysis showed that speed reduction loss, tool and blade change loss, and breakdown loss accounted for 79.02% of total production losses. Root cause analysis revealed inadequate condition monitoring, non-standardized maintenance procedures, deteriorated machine components, and unfavorable environmental conditions as the primary improvement priorities. This approach allows the results of resource effectiveness measurements to be systematically followed up with the identification of production time losses, the determination of dominant losses, and root cause analysis, enabling improvement priorities to be established based on the most critical production issues.

Introduction

Improving manufacturing performance is essential for companies seeking to remain competitive while utilizing production resources efficiently. Besides production output and product quality, manufacturing performance is strongly influenced by how effectively resources are managed throughout the production process. However, production interruptions caused by machine downtime, equipment failures, speed reduction, material shortages, and maintenance issues continue to reduce operational efficiency and increase production costs. Therefore, evaluating manufacturing resource effectiveness is crucial for supporting continuous improvement.

Overall Equipment Effectiveness (OEE) is widely used to measure manufacturing performance based on availability, performance, and quality [1]. However, OEE primarily focuses on equipment utilization and does not fully account for other production resources, such as manpower, materials, production readiness, and changeover activities. To overcome this limitation, Overall Resource Effectiveness (ORE) extends OEE by incorporating seven dimensions that provide a more comprehensive assessment of manufacturing resource utilization [2]. Previous studies have demonstrated that ORE offers a broader evaluation of manufacturing performance than conventional OEE [2], [3]. In addition, Root Cause Analysis (RCA) supported by Pareto analysis and Fishbone diagrams has proven effective for identifying dominant production losses and their underlying causes [4], [5]. Nevertheless, most studies apply these approaches separately, creating a gap in systematically linking performance measurement with production loss analysis and improvement planning.

Based on this gap, this study systematically applies ORE, loss analysis, Pareto analysis, and RCA to the production of 311 cans to evaluate resource effectiveness, determine dominant losses, and identify root causes as a basis for improvement. The results show an average ORE of 49.31%, with facility availability (76.90%) and performance efficiency (72.52%) being the

lowest factors. Speed reduction, tool and blade changes, and breakdown losses account for approximately 79% of total losses. This approach provides a systematic basis for prioritizing improvements and supporting continuous improvement.

Methodology

This study employs a quantitative case study approach on the 311-can production line to evaluate production resource effectiveness using Overall Resource Effectiveness (ORE). The analysis proceeds with loss measurement, Pareto analysis, and Root Cause Analysis (RCA) using a Fishbone Diagram to identify dominant losses and their root causes. The research stages are illustrated in Figure 1.

The study was conducted on the 311-can production line at a metal packaging manufacturing company. This line was selected because it is a relatively new product line that, since the start of its operations, has experienced recurring technical and non-technical disruptions, such as downtime, machine malfunctions, process instability, and reduced operating speeds. Preliminary company data indicated an average downtime of 31.93%, making the 311-can production line a suitable candidate for evaluation using ORE. Operational data from January to November 2025 were analyzed, excluding May due to a lack of production activity, covering ten monthly production periods. The production system operates on a one- or two-shift basis, with working hours adjusted to meet production requirements. The 311 can line utilizes a single main machine that integrates stamping, trimming, and palletizing processes, supported by a conveyor system. Research data were gathered through company documentation, direct observation, and semi-structured interviews, covering production time, downtime, output, material and labor availability, setup, product quality, and maintenance data used to calculate ORE and losses. The Root Cause Analysis (RCA) was supported by interviews with the Head of the 311 Can Production Machine and the Head of the Production Division; these findings were verified through observation and documentation before being analyzed using a Fishbone Diagram based on the 6M categories.



Fig. 18 Research Methodology

The first stage involved evaluating manufacturing performance using the Overall Resource Effectiveness (ORE) model proposed by Eswaramurthi and Mohanram [2]. ORE assesses manufacturing resource utilization through seven dimensions: readiness, availability of facility, changeover efficiency, availability of material, availability of manpower, performance efficiency, and quality rate, providing a comprehensive evaluation of manufacturing performance.

The ORE calculation is performed monthly based on seven factors, without additional weighting. The ORE value is obtained by multiplying all the factors, as follows:

$$ORE = R \times A_f \times C \times A_m \times A_{mp} \times P \times Q$$

Each factor is calculated based on the ratio of time or actual output. For example, the two most influential factors in this study are calculated as follows:

$$A_f = \frac{\text{Loading Time}}{\frac{\text{Planned Production Time}}{\text{Earned Time}}}$$

$$P = \frac{\text{Earned Time}}{\text{Actual Running Time}}$$

As a calculation example, for January 2025, a planned production time of 22,125 minutes and a loading time of 18,320 minutes result in a facility availability of 82.80%. The same procedure is applied to all factors and production periods to obtain the monthly ORE value.

The calculated ORE values were then used to classify production losses based on the ORE loss categories. Pareto analysis was applied to identify the dominant losses contributing most significantly to manufacturing inefficiency, enabling improvement efforts to focus on the most critical production problems [4].

The dominant losses were further analyzed using Root Cause Analysis (RCA) through Fishbone Diagrams, which examined potential causes from six perspectives: man, machine, method, material, measurement, and environment. This approach supports the systematic identification of root causes and the development of appropriate improvement actions [5], [6].

Based on the analysis results, improvement recommendations were developed to enhance manufacturing resource effectiveness, including preventive maintenance, equipment condition monitoring, standardized operating procedures, tooling life-cycle management, and the implementation of 5S practices.

Result and Discussion

Overall Resource Effectiveness Assessment

The Overall Resource Effectiveness (ORE) assessment showed that the average manufacturing resource effectiveness was 49.31%, indicating that the production resources had not been utilized optimally. Among the seven ORE dimensions, availability of facility (76.90%) and performance efficiency (72.52%) recorded the lowest values, while the remaining dimensions consistently exceeded 92%. These findings indicate that manufacturing performance was primarily affected by equipment-related interruptions and reduced operating speed rather than by material, manpower, or quality issues. The results are consistent with previous studies that identified equipment availability and operational performance as critical factors influencing manufacturing effectiveness [2], [3].

Production Loss Assessment

Production loss analysis identified a total production time loss of 66,537.77 minutes during the observation period. Pareto analysis revealed that speed reduction loss (35.76%), tool and blade change loss (25.98%), and breakdown loss (17.28%) together accounted for 79.02% of the total

losses. This finding confirms the Pareto principle, where a small number of dominant problems contribute to the majority of manufacturing inefficiencies, providing a clear basis for prioritizing improvement initiatives [4].

The distribution of losses is illustrated via Pareto analysis in Figure 2. Three dominant losses, speed reduction loss (35.76%), tool and blade change loss (25.98%), and breakdown loss (17.28%), cumulatively account for 79.02% of the total time loss and serve as the focus of the RCA.

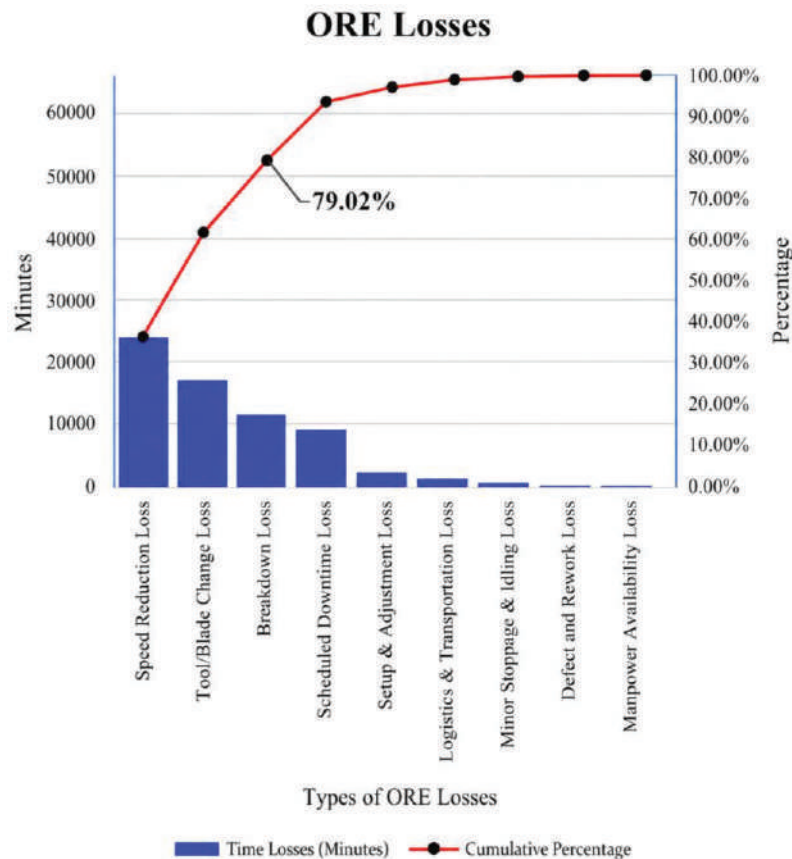


Figure 2. Pareto Chart

Root Cause Analysis and Improvement Opportunities

Root Cause Analysis (RCA) using Fishbone Diagrams identified several major factors contributing to the dominant production losses. The primary issues included the absence of an early condition monitoring system, non-standardized maintenance and blade replacement procedures, deteriorated tooling conditions, and unfavorable environmental conditions. These findings indicate that production losses resulted from the interaction of multiple operational factors rather than a single cause. Similar applications of Fishbone analysis have demonstrated its effectiveness in identifying fundamental causes of manufacturing problems and supporting continuous improvement [5], [6]. Low facility availability is primarily driven by facility downtime, while low performance efficiency indicates that the machinery is unable to maintain optimal production speeds. This situation aligns with the loss analysis results, which identify speed reduction and breakdowns as the two primary sources of loss. Overall, the ORE of 49.31% remains well below the 85% benchmark; consequently, improving availability and performance is a top priority to minimize production time losses and enhance line effectiveness. Low facility availability is primarily driven by facility downtime, while low performance efficiency indicates that the machinery is unable to maintain optimal production speeds. This situation aligns with the loss analysis results, which identify speed reduction and breakdowns as the two primary sources of loss. Overall, the ORE of 49.31% remains well

below the 85% benchmark; consequently, improving availability and performance is a top priority to minimize production time losses and enhance line effectiveness.

Based on the RCA, improvement efforts prioritized the three dominant losses accounting for 79.02% of total time loss. Speed reduction losses were addressed through condition monitoring and preventive maintenance; tool and blade change losses through standardized replacement and tooling lifespan control; and breakdown losses through maintenance checklists, preventive cleaning, and 5S. These improvements are expected to primarily enhance facility availability and performance efficiency. The quantitative impact on ORE has not yet been calculated, as the recommendations have not yet been implemented.

Conclusion and Recommendations

This study sequentially applies ORE, loss analysis, Pareto analysis, and RCA to evaluate the production effectiveness of "311" cans and determine improvement priorities. An average ORE value of 49.31% indicates suboptimal resource utilization, particularly regarding facility availability and performance efficiency. Three dominant losses—speed reduction, tool and blade changes, and breakdowns—account for nearly 80% of total time loss. This approach links performance measurement, loss prioritization, and root cause identification to support targeted improvements, aligning with the application of ORE in evaluating and enhancing manufacturing performance [2], [7], [8], [10].

The study is limited to a single production line, and the recommendations have not yet been implemented; consequently, the resulting ORE improvement remains unvalidated. Proposed improvements focus on preventive maintenance, condition monitoring, procedure standardization, tooling lifespan management, and 5S [11]. Future research should validate this approach through the implementation of improvements, a comparison of pre- and post-implementation ORE, or a comparison with OEE in other manufacturing contexts.

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Determination of Standard Time for Bottleneck Identification in Water Bottle Production Line at Company X

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Abstract— Delays, long cycle times, and increased operating costs can result in bottlenecks with adverse effects to the efficiency of production line. This research provides an investigation of Company X Sdn Bhd (Company X) which handles the water filling and packing of disposable bottles and experienced production inefficiencies from bottlenecks within the production line. Preliminary observations lead to the discovery that the task times were highly unequal between the stations and the work pieces which were distributed unevenly, leading to unbalanced workloads in the future. Since there was no quantifiable and precise data, the company was unable to find the location and reason for these inefficiencies. This research therefore carried out a detailed study of Company X's production line, which consists of 15 production cycles. The cycle time for each process was determined using the assistance of stopwatch time study methods, followed by the calculation of the standard time by considering related allowances. The processes in Company X involved in the standard time determination are Water Filling, Bottle Transfer 1, Bottle Capping, Bottle Transfer 2, and Label Sealing. Since all the mentioned processes are carried out automatically (conveyor) except for Bottle Transfer 2, the related allowances only applied to Bottle Transfer 2. 7% of allowance (5% personal allowance and 2% standing allowance) were included in the calculation of standard time. Individual process standard time showed that Water Filling had the highest standard time of 38.91 seconds, while Bottle Capping was the shortest at 19.98 seconds. The total standard time for the water bottle production line at Company X was 153.02 seconds. Data obtained from this research would be beneficial in identifying production bottleneck, and consequently by utilizing line-balancing method, production efficiency can be improved.

Introduction

Productivity is one of the most important parameters in manufacturing industry. The need to reach the company's Key performance Indicators (KPIs) and fulfil customer's demands was a bit of a challenge for some companies with low production efficiency. Some happen may be due to unexpected or overlooked bottlenecks inside their processes that can cause delays. Improving a company's productivity is crucial because it directly influences profitability, competitiveness and its operational efficiency. Industrial process efficiency is usually measured through cycle time measurement because shorter and more consistent cycle times typically imply smoother operations and more efficient work [1-2]. However, efficiency can be undermined by bottlenecks, wherein delays at specific processes reduce the system's overall output. Therefore, measuring production efficiency is not only a matter of tracking cycle times but also detecting and analyzing bottleneck processes [3-5]. This approach provides full insight into how resources are being used and recommends ways for maximizing throughput and operating performance. These flaws must be identified using time study which enables the accurate time measurements of task in the production line. Balanced working time allows the available work facilities to function optimally. This minimizes idle time and increases work efficiency. The objectives in this study were to identify work, time standard to work which involves manpower in bottlenecks process in Company X which located in Tangkak, Johor and local SMEs which specializing in bottled water production. An important role in production planning, capacity estimation, and performance measurement is time study. General techniques include breaking down manufacturing processes into discrete elements, measuring cycle times

and applying statistical analysis to establish standard times in production line. Time studies require observers with stopwatches, but modern techniques progressively rely on technology. From the previous research, it is shown that the time studies performed well can make production 15-30% more effective in standard manufacturing sector [6]. However, the outdated method, which is time studies, was commonly utilized among manufacturing sectors where limited research focuses on the quantitative bottleneck dynamics in semi-automated SME beverage packaging line whereas automated machinery directly interfaces with manual material supervision. Therefore, this study discusses an observed baseline for allowance distribution in hybrid packaging environment and also demonstrating how minor manual variations impact overall system in production line.

Table 1: Methodological and observational comparison with existing literature

Feature / Dimension	Previous Studies in Literature	Present Work (Company X Study)
Focus Environment	Fully automated lines or fully manual assembly.	Hybrid semi-automated SME beverage line.
Allowance Application	Applied uniformly across all process stations.	Selective allowance assignment (7% to manual transfers; 0% to automated conveyers).
Scope of Work	Theoretical modeling or pure stopwatch studies.	Empirical primary data collected across 15 production cycles with clear task marking (A–F).
Outcome	General efficiency metrics	Precise quantification of standard time vs. normal time variance (151.04s vs. 153.02s) to locate exact bottleneck stations.

Data Collection Method and Process Evaluation and Verification

For the current research, the time study technique discussed in [7] was employed, which significantly applied in industrial engineering for the measurement of task performance and calculation of standard times. By site visit, observation has been done to see the production line under normal operating conditions, pay attention to the order of tasks, the role of machines, and the way operators interacted with the equipment. By combining measured data with such first-hand information, the study can determine the cycle time, normal time, and standard time reflect the true conditions at Company X. The production activities were carefully noted in an effort to learn the order of the activities, inputs used, and possible causes of delay during the visit. In order to make sure that the data collection became systematic, a check sheet was recommended as the main instrument for documentation. This allowed task times, process flow, and worker actions to be recorded in a clear and uniform manner. From the site visit, a check sheet was developed to facilitate structured data collection. Upon designing the check sheet, considerations such as the appropriate sample size and the type of data to be recorded were considered to ensure accuracy and representativeness. A template was then prepared to standardize the recording of observations across different cycles. During the data collection phase, device calibration and verification were conducted to ensure measurement reliability.

Data Analysis dan Data Calculation

Development of standard time is important in work measurement studies as it provides a solid ground for productivity efficiency estimation and identification of potential bottlenecks. Standard time is the expected time of job completion in normal condition and is computed by adding allowances and rating of performance. These factors ensure that computer calculated time will reflect not only the technical requirements of the job, but also miscellaneous human performance and workday conditions. The first step was to determine the average observed time, which represents the mean cycle time obtained from multiple observations of the same task. This value helps to minimize random variations that occur between individual observations and provides a more reliable basis for further analysis.

$$\text{Average observed time, } \bar{t} = \frac{\sum t_i}{n} \quad (1)$$

The second step was to calculate the normal time (NT). In this step, a rating factor (RF) was applied to the average observed time in order to adjust the recorded performance to a standard level. This ensured that differences in worker speed, whether faster or slower than normal, were normalized;

$$\text{Normal time, } NT = \bar{t} \times \text{Rating Factor (RF)} \quad (2)$$

The third step was to calculate the standard time (ST). To make the time value more realistic for actual working conditions, an allowance factor (AF) was introduced. This allowance accounts for unavoidable interruptions, such as fatigue, personal needs, and small delays.

$$\text{Standard time, } ST = \frac{\text{Total normal time}}{1 - \text{Allowance Factor}} \quad (3)$$

The final step was to determine the total standard time, which was obtained by summing the standard times of all tasks in the production process. This overall value represents the complete cycle time for producing one unit under normal working conditions.

$$\text{Total standard time, } \sum ST_i \quad (4)$$

Results and Discussions

During the data collection phase, device calibration and verification were conducted to ensure measurement reliability. In addition, a clear marking method was defined using codes A, B, C, D, E and F to classify different tasks or process elements consistently. This systematic approach minimized recording errors and enhanced the clarity of the data, thereby strengthening the reliability of the subsequent analysis. The illustration and division of the process during data collection as shown in Fig. 1.

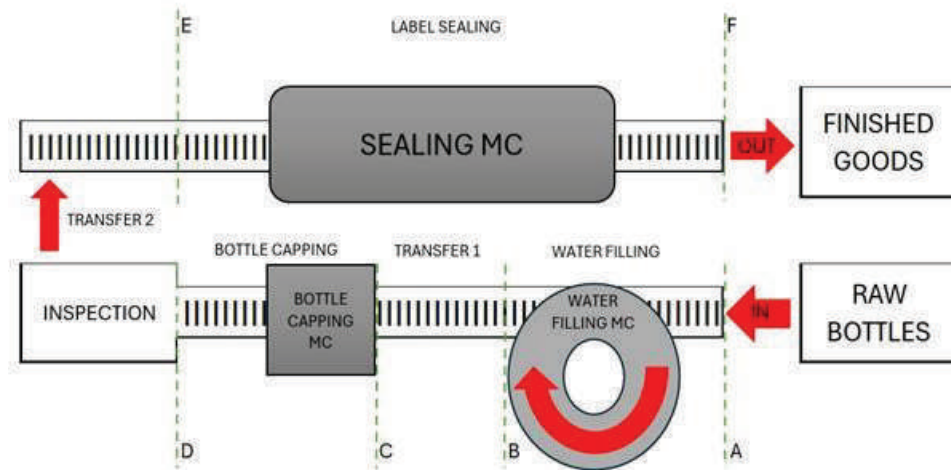


Fig. 1 The Illustration and Division of the process during data collection

This sub-section documented outcomes from the time study and bottleneck analysis. The outcomes were based on observed cycle times of 15 production cycles, which were then applied to calculate both standard and normal times for each of the processes. The analysis noted discrepancies between tasks, particularly where manual operations led to delays, and their overall effect on combined cycle time. These results formed the foundation for establishing major bottlenecks and coming up with ways to maximize production efficiency. Based on primary data collection that was carried out directly from the industrial visit, the obtained data as Water filling (38.91 seconds) and label sealing (36.02 seconds) are the two most time-

consuming tasks, indicating potential bottlenecks in the process. Meanwhile, bottle capping (19.98 seconds) was widely regarded as the shortest element. This made sure that the differences in speed between workers were balanced, so the time calculated would represent the effort of an average worker. Allowances were added to make the time more realistic for actual working conditions. In this study, only two allowances were considered. Since most of the processes in Company X's production line were automated using a conveyor, allowances were only applied to the bottle transfer process, which was the only task that needed direct human effort. The mean observed times over 15 production cycles were used to calculate normal and standard times. Additionally, Bottle Transfer 2 was done manually by the operator, which added more variation with human effort, fatigue, and minor delay. Hence, 7% allowance was applied. Standard time for Bottle Transfer 2 increased to 28.48 seconds (standard) from 26.49 seconds (normal) after the adjustment.

Table 3: Standard Time for Mineral Water production line

Process code	Process	Mean Cycle Time Per Unit (sec)	Rating (%)	Allowance (%)	Normal Time (sec)	Standard Time (sec)
A-B	Water Filling	38.91	100	0	38.91	38.91
B-C	Bottle Transfer 1	29.63	100	0	29.63	29.63
C-D	Bottle Capping	19.98	100	0	19.98	19.98
D-E	Bottle Transfer 2	26.49	100	7	26.49	28.48
E-F	Label Sealing	36.02	100	0	36.02	36.02
	Total					153.02

Conclusions

Overall, the establishment of normal and standard times for 15 production cycles revealed minor variations for most processes as operations were performed at a standard rate with a 100% rating factor and without allowances. Bottle Transfer 2 had more variation due to manual handling, fatigue of the operator, and minor delays, which necessitated the introduction of a 7% allowance. This adjustment took the task time from 26.49 seconds (normal) to 28.48 seconds (standard), which took the overall standard cycle time to 153.02 seconds from a normal cycle time of 151.04 seconds. These findings highlight how significant an impact manual operation has on cycle time reliability and how important it is to include allowances while analyzing processes influenced by human labor.

Acknowledgement

This work was supported by Ministry of Higher Education (MOHE) through the *Industry Matching Program (IMaP)* Grant (A199) and Universiti Tun Hussein Onn Malaysia (UTHM) through Geran Penyelidikan Pasca Siswazah (GPPS) (Vot J082)

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IoT-Enabled Fertigation Monitoring and Control in Smallholder Agriculture: Assessment in Johor and Melaka, Malaysia

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Abstract — Fertigation couples irrigation with nutrient delivery, yet conventional dosing in smallholder farms remains labour-intensive, imprecise, and blind to real-time crop and soil conditions. This study investigated the current state of fertigation practice, the barriers to IoT adoption, and the suitability of commercially available sensors for monitoring soil moisture, temperature, and nutrient levels for Malaysian smallholders' farms. A mixed-methods design was employed, combining a questionnaire survey of 15 fertigation farms in Johor and Melaka, structured field observations and owner interviews at three representative farms, and a systematic analysis of nine commercial sensor product families. Results revealed a universal reliance on basic drip fertigation with timer-based pumping: none of the surveyed farms had adopted IoT technology, and all respondents identified initial investment cost as the decisive barrier, compounded by infrastructure, connectivity, and skills gaps. Sensor analysis identified capacitance-type soil moisture probes, LoRaWAN- and Bluetooth-based communication modules, and multiparameter EC/pH probes as technically viable, low-power options; however, calibration accuracy and rural power supply remain practical concerns. The study contributes a region-specific empirical baseline for IoT-enabled fertigation and outlines the cost-benefit analysis, farmer training, and scalable architecture requirements needed to move smallholders toward precision nutrient and water management.

Introduction

Freshwater is the most heavily extracted natural resource on the planet, and agriculture accounts for roughly 70% of global withdrawal volume [1]. With climate change intensifying drought frequency and an expanding global population raising food demand, agricultural water security has become a recognised constraint on food production in many regions [2]. Fertigation is widely regarded as a practical response to this dual pressure, since it delivers water and nutrients simultaneously and precisely to the root zone. Drip fertigation, in particular, has been shown in meta-analytic work to improve yields and water productivity relative to conventional broadcast fertilisation and surface irrigation [3]. These results illustrate the central principle that fertigation returns are governed by the precision with which water and nitrogen are co-delivered, not by input volume alone [4].

The fourth industrial revolution has begun to reshape agriculture through the Internet of Things, defined as networks of interconnected, data-exchanging devices embedded with sensors and actuators [5, 6]. IoT-enabled systems gather real-time data on soil moisture, temperature, humidity, and nutrient status, transmit it wirelessly, and support automated decisions on irrigation and fertilisation [7, 8]. Recent surveys of smart irrigation report a rapid shift from expensive proprietary equipment toward low-cost sensors and wireless network nodes that make automated monitoring accessible to smaller farms [9]. Machine learning has further extended this capability, with models trained on sensor and weather data now used to forecast crop water requirements and schedule irrigation [10]. Trials of IoT-based fertigation systems show measurable benefits: an ESP32-based automated fertigation platform achieved consistent electrical conductivity control at lower cost than commercial products [11], and an IoT-controlled vertical hydroponic system increased basil yield by 19% and water-use efficiency by 18% relative to manual fertigation [12]. Collectively these studies demonstrate technical feasibility and measurable agronomic gains but nearly all were validated on prototype scales, and none addresses the question of why working farms in developing regions have not yet incorporated such systems.

What remains poorly understood is the specific situation of fertigation-based smallholders: their current system configurations, the operational limitations they experience with manual dosing, their perceptions of IoT, and whether commercially available sensing hardware actually matches their crop, infrastructure, and budget constraints. Empirical, farm-level studies that connect these elements are largely absent from the Malaysian literature, and international reviews tend to emphasise either agronomic outcomes or hardware design rather than the adoption-readiness interface between them.

This study addresses that gap through three objectives: (i) to characterise the current state of fertigation systems and the limitations of traditional methods among smallholder farms in Johor and Melaka; (ii) to explore the perceived potential of IoT for fertigation monitoring and control in this population; and (iii) to analyse the types of commercial IoT sensors available for soil moisture, temperature, and nutrient monitoring and their suitability for smallholder deployment [13]. The study's novelty lies in its triangulated design: a regional survey, structured case observations at three operating farms, and a technical reading of nine commercial sensor families are combined for the first time in the Malaysian smallholder context. Rather than testing a single prototype, the work maps the full adoption decision space in terms of agronomic practice, economic constraint, and technological readiness so that subsequent engineering efforts target the barriers that govern uptake.

Methodology

A mixed-methods design was adopted, combining quantitative survey data with qualitative case observations and technical product analysis [14,15]. This structure follows established practice in farmer-adoption research, where quantitative descriptive approaches are increasingly paired with qualitative methods to capture context. The survey instrument comprised eight sections: respondent general information, farming background, current fertigation systems, IoT technology perceptions, limitations of traditional fertigation methods, future considerations, adoption and investment attitudes, and additional comments. Pre-testing principles drawn from survey literature were applied during instrument development to clarify question wording and response options [16]. A total of 15 completed questionnaires were returned from Muar, Tangkak, Batu Pahat, Jasin, Alor Gajah, and Melaka Tengah, yielding a 37.5% response rate.

To gather detailed qualitative context, structured field observations and semi-structured interviews were conducted at three farms representing contrasting scales and system configurations: D'Impian Agro Farm (Muar, Johor), Ace Natural Farm (Batu Pahat, Johor), and Rockmelon Farm @ Laman Azalea (Melaka) [17]. Observations were recorded against a standardised checklist covering infrastructure, equipment, crop condition, and operational routines. Finally, the technical parameters, wireless connectivity, and power requirements of nine commercial sensor products were compiled and analysed to evaluate their suitability for smallholder deployment [18].

Findings and Arguments

The findings reveal a sector characterized by high satisfaction with existing manual drip fertigation but a complete absence of IoT adoption. Despite experiencing severe operational limitations with traditional manual dosing such as uneven distribution, high labour intensity, and imprecise nutrient adjustment smallholders remain locked into basic timer-based configurations due to key barriers.

Respondent and Farm Profile

Table 1 outlines the demographic and operational profiles of the 15 surveyed farms. Farming experience was concentrated in the 1-5-year band (10 respondents), and drip irrigation was the near-universal fertigation method (12 respondents). Importantly, while all respondents reported high satisfaction (ratings of 3-5) with their current timer-based drip systems, IoT adoption was 0.0% (0 respondents).

Table 5: Respondent and Farm Profile
Baseline (n = 15)

Dimension	Category	Count (n=15)
Farming Experience	< 1 Year	3
Farming Experience	1-5 Years	10
Farming Experience	5-10 Years	1
Farming Experience	> 10 Years	1
Current Fertigation Use	Yes	14
Current Fertigation Use	No (Hydroponic)	1
Fertigation Method	Drip Irrigation	12
Fertigation Method	Not Specified	3
IoT Technology Adoption	Yes (0.0% adoption)	0

Farming Experience Distribution of Respondents (n = 15)

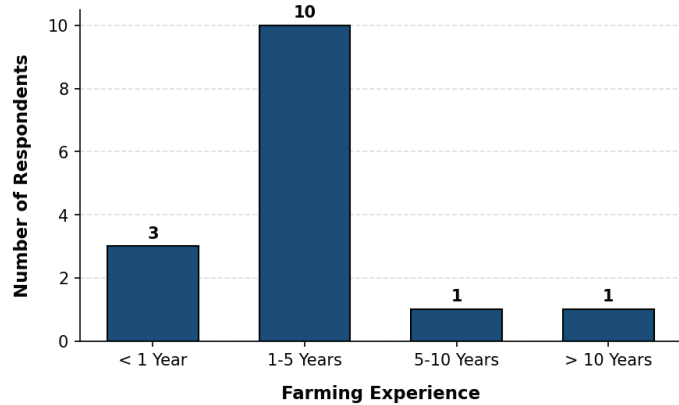


Figure 1: Distribution of Farming Experience among Surveyed Smallholders

Limitations of Traditional Fertigation

Of the 13 respondents who previously managed crops using traditional, non-precision methods, every single operator identified significant drawbacks. Referring to Table 2, the labour intensity and uneven nutrient distribution were reported as the most severe issues, as traditional dosing and clock-based timing rely heavily on frequent physical monitoring and arbitrary manual adjustments.

Table 6: Limitations of Traditional Fertigation Methods (n = 13)

Reported Limitation	Description & Farm-Level Implications	Count (n)
Under-fertilisation	Zones furthest from the pump receive lower concentrations, depressing marketable yields.	7
Over-fertilisation	Imprecise calibrations or manual errors exceed exact crop tolerances, leading to salinity issues.	8
Runoff and Over-application	Water/nutrients applied beyond absorption limits overflow, causing waterlogging and nutrient wastage.	9
Imprecise Dosing Adjustment	Standard injectors lack the precision needed to micro-adjust EC and pH as growth stages shift.	10
Uneven Water and Nutrient	Terrain, wind, and piping inefficiencies cause non-uniform delivery across the field layouts.	11
High Labour Intensity	Starting, stopping, mixing, and adjusting pumps require continuous physical farmer intervention.	12

Case Observations at Representative Farms

Structured field observations highlighted diverse scales and economic contexts. At D'Impian Agro Farm, approximately 3,000 golden melon plants are managed across UV plastic rain shelters (500 plants per shelter). Dosing is regulated on basic clock-based timers connected to a 2 hp pump. Golden Melon fruits mature to a golden-yellow colour at 1.5–2.0 kg, with one fruit manually selected per plant [17]. Rainy season disease pressure requires twice-daily pesticide sprayings. D'Impian's crop batch economics are recorded as: seeds (RM1,300), pesticides (RM1,100), foliar spray (RM300), and media

treatment (RM600), leading to a total batch cost of approximately RM5,344 [17]. The farm operator highlighted the need for solar panels to reduce high electricity costs and shorten planting hours.

Ace Natural Farm represents a larger 4-acre operation cultivating watermelon and melon without pesticides. In contrast to D'Impian's mixed water-fertiliser tank, Ace Natural uses separate tanks with independent valves. Laman Azalea operates on a smaller footprint (0.25 acres) but features a highly capital-intensive iron greenhouse (costing approximately RM70,000). These profiles demonstrate that while capital investment varies, timer-based clock dosing is the standard across all operational scales, with none using automated sensors [17].

Sensor Technology Assessment

Technical product characterization reveals that mature sensing options exist. For soil moisture, dielectric impedance and capacitance probes like the Decagon GS3 and METER TEROS 12 provide high accuracy [18]. However, they rely on SDI-12 communication protocols that require local dataloggers. The Sensoterra Wireless offers native LoRaWAN connectivity and multi-year battery life, bypassing the need for expensive logging hardware [18].

For nutrient quality, compact multiparameter Bluetooth/Wi-Fi probes such as the Sensorex SAM-1 and Bluelab Pulse Meter measure pH, EC, and temperature, enabling rapid real-time data logging on mobile devices [18]. While these sensing solutions are technically mature, their success in Malaysian cocopeat substrate depends on two factors: (i) substrate-specific calibration, as standard factory calibrations can have error margins of 5 vol.% [16, 18], and (ii) energy harvesting, as remote smallholder fields require solar panels to sustain node operation over crop cycles [19].

Conclusions

This study establishes a region-specific baseline for fertigation practice among smallholders in Johor and Melaka. Although drip fertigation is widely adopted and satisfies farmers, actual IoT adoption is non-existent. The primary barriers preventing smart farming adoption are high initial startup costs, rural connectivity gaps, and a critical absence of farm-level cost-benefit evidence.

To bridge this adoption gap, three interventions are proposed. First, agricultural extension services must publish accessible ROI analyses that demonstrate precision fertigation profitability to smallholders. Second, sensor vendors must provide pre-calibrated probes tailored for organic cocopeat media rather than mineral soils. Finally, public funding should subsidise solar-powered LoRaWAN communication gateways to support resilient, long-term rural wireless networks.

Acknowledgement

The authors thank the Faculty of Industrial and Manufacturing Technology and Engineering at Universiti Teknikal Malaysia Melaka for supporting this research and providing access to farm-level facilities in Johor and Melaka.

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Reducing Document Approval Rejection in an ISO 9001 Paperless Manufacturing Document Management System

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Abstract— This extended abstract presents a paper extracted from a thesis on improving document approval performance in a paperless manufacturing document management system. The selected topic is the reduction of document rejection in approval workflows for process and statistical process control documents under an ISO 9001-based quality management system. Historical approval data showed that process documents contributed the highest rejection share, followed by general documents and statistical process control documents. The study therefore proposed two complementary interventions: a verification stage in the Document Management System (DMS) before formal approval routing and an E-Certification platform to certify document writers before they submit process-critical documents. The approach links document control requirements, competence management, workflow monitoring, and system validation. The contribution of this work is a practical framework for reducing avoidable document rejection, improving approval readiness, and supporting timely manufacturing recipe and parameter updates.

Introduction

ISO 9001:2015 requires organizations to control documented information so that documents are properly identified, reviewed, approved, available for use, protected, and controlled when revised. In a manufacturing environment, document control is not only an administrative requirement but also an operational control because manufacturing specifications, process recipes, and statistical process control parameters are linked to production execution. Delays in approval or rework caused by rejected documents can affect product delivery, customer communication, and manufacturing responsiveness.

The topic selected for this paper is document approval rejection reduction in a paperless ISO 9001 document management workflow. The problem addressed is that revised documents submitted for approval are sometimes rejected due to wrong technical details, wrong document format, or insufficient revision justification. These avoidable rejection causes require document writers to revise and resubmit documents, thereby prolonging approval flow and delaying updates to related manufacturing systems.

Methodology

The research used a case-based improvement methodology in a semiconductor manufacturing document control environment. Approval history data from January to June 2016 were reviewed and segregated by document category: general, process, and statistical process control. Rejection factors were then classified to distinguish business-driven changes from preventable submission errors. The improvement scope focused on preventable causes related to documentation accuracy and readiness before approval routing.

Two interventions were designed. First, the existing DMS was enhanced by adding a verification stage before document control initiated the approval workflow. This stage required designated verifiers to check document content, process recipe naming, tool parameter format, and alignment between document changes and the Engineering Change Notice summary. Second, an E-Certification application was introduced to train and certify document writers. Certification levels were aligned with document categories so that users could only submit documents appropriate to their certification status. Verification and validation were conducted in a development environment before release to avoid disruption to production document control activities.

Table 1: Summary of document rejection by category from January to June 2016

Document category	Total rejected	Percentage of rejection	Owner / verifier
General	173	35.4%	Document Control
Process	238	48.8%	Manufacturing Execution System group
Statistical Process Control (SPC)	77	15.8%	Statistical Process Control group
Total	488	100%	

Findings and Arguments

The analysis indicated that process and statistical process control documents represented 64.6% of total rejected documents. These two categories are critical because errors in recipes, process steps, pathnames, or tool parameters can prevent linked systems from updating correctly. Although further changes requested by external or business-driven needs were difficult to control, wrong technical details, wrong document format, and wrong revision justification were preventable through structured verification and competence control.

The proposed verification stage improves approval readiness by shifting error detection earlier in the workflow. Documents that fail verification are returned to the writer before they enter formal approval routing; therefore, the measured approval cycle time is protected from avoidable rework. The E-Certification platform complements this control by ensuring that document writers understand DMS navigation, standard document format, Engineering Change Notice requirements, process specification rules, and statistical process control writing requirements before they are allowed to submit relevant documents.

Table 2: Proposed improvement controls

Control	Purpose	Expected effect
DMS verification stage	Check document format, technical content, recipe or pathname rules, and ECN alignment before approval routing	Reduce preventable rejection during formal approval
E-Certification Level 1	Certify writers on basic DMS use and general document submission requirements	Improve standard submission quality
E-Certification Level 2	Certify writers on process specification and recipe-related requirements	Reduce process document errors
E-Certification Level 3	Certify writers on statistical process control (SPC) document requirements	Reduce SPC document errors

Table 3: Data on documents rejected based on categories

Period	No. of documents for approval	Documents rejected (%)	Process-step rejection (%)	SPC rejection (%)
Before E-Certification (Jan–Jun 2016)	5,660	11.0	48.8	15.8
After E-Certification (Jan–Jun 2017)	7,835	7.9	40.5	10.2

After E-Cert implementation, rejected documents decreased to 619, or 7.9% of total submissions. Process-step and SPC-related rejections also fell to 40.5% and 10.2%, respectively. This reduction helped shorten approval time, as certified document writers were better prepared to produce accurate process documents. The online certification system allowed employees to complete training at their own pace and encouraged them to understand the requirements before submitting documents. Details of rejection rate for both process-step and SPC-related document submissions are listed in Table 4.

Table 4: Details of rejection rate for both process and SPC categories

Document category	Further changes required (%)	Wrong technical details (%)	Wrong format (%)	Wrong revision justification (%)
Process	7.8	6.3	85.9	0.0
SPC	7.1	4.8	85.7	2.4

Table 4 shows that wrong format and incorrect process-recipe steps remained the main rejection reasons. Further discussion identified the following causes:

- a. New engineers required more time to learn document-writing requirements.
- b. Periodic changes to parameters and naming conventions required writers to stay updated.
- c. MES and SPC verification was often high-level, so some errors were found only during checks with interlinked systems.

Conclusion

This paper demonstrates that document approval rejection in a paperless ISO 9001 manufacturing environment can be addressed through a combined process-control and competence-control framework. The DMS verification stage provides a preventive review before documents enter approval routing, while E-Certification ensures that document writers possess the required competence for each document category. The framework is especially relevant for process and statistical process control documents because these documents directly support manufacturing recipe and parameter updates. Future work should include post-implementation rejection-rate monitoring, cycle-time comparison before and after deployment, and periodic review of certification content to ensure continued relevance to process changes.

Acknowledgement

The author acknowledges SilTerra Malaysia Sdn. Bhd. for providing the industrial context for the document management improvement study.

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PROCEEDINGS OF INTERNATIONAL INNOVATIVE RESEARCH AND INDUSTRIAL DIALOGUE 2026

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