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DAFTAR ISI

OPTIMIZING PRODUCTION EFFICIENCY THROUGH TOTAL PRODUCTIVE MAINTENANCE: A CASE STUDY OF A VEGETABLE OIL PRODUCTION COMPANY

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Abstract

Purpose – This paper aims to present an approach for optimizing production efficiency through Total Productive Maintenance (TPM), using a case study of a vegetable oil production company in Thailand.

Design/methodology/approach – This study employed both qualitative and quantitative research methods. Data were collected using questionnaires distributed to 200 randomly selected employees from the production and maintenance departments.

Findings – Prior to the implementation of TPM, the vegetable oil production system operated in a continuous series without backup systems at certain critical points. As a result, the average total equipment effectiveness (OEE) was 83.8%, which fell below the industry standard. After six months of implementing TPM focusing on Pillar 1: Focused Improvement, Pillar 2: Autonomous Maintenance, Pillar 3: Planned Maintenance, and Pillar 4: Education and Training the average total equipment effectiveness increased by 3.92%.

Originality/value – This empirical study demonstrates the effectiveness of applying TPM to improve production efficiency in the cooking oil manufacturing sector. The findings suggest that company executives should consider extending TPM implementation across all departments for broader organizational benefits.

Keywords: Production Efficiency Optimization, Total Productive Maintenance, Vegetable Oil Production, Thailand

Introduction

The Thai cooking oil market is highly competitive and consistently experiences strong demand. Many vegetable oil production companies strive to maintain their market share by continuously distributing products at low production costs while efficiently processing vegetable oil from crude palm oil.

The company examined in this study specializes in the production and processing of vegetable oil from crude palm oil for distribution in the Thai market. However, the production system has been in use for over a decade, leading to frequent shutdowns for repairs. These interruptions have resulted in production volumes falling short of targets and increasing maintenance costs. In some cases, delayed repairs have caused residual crude palm oil in the system to spoil, rendering it unusable and resulting in production waste. Upgrading or replacing the entire production system would require a significant capital investment. Given the current economic volatility, maintaining the existing system through improved maintenance practices is considered the most viable option.

To address these challenges and reduce both maintenance time and production costs, the researchers applied the principles of Total Productive Maintenance (TPM) to the company's production system over a six-month period. The results were then evaluated and presented to the company for consideration.

Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a comprehensive approach to equipment maintenance that aims to maximize the overall effectiveness of production systems by involving all employees in proactive and preventive maintenance activities. The core objectives of TPM are to eliminate equipment breakdowns, defects, and workplace accidents, ultimately enhancing productivity, quality, and operational efficiency.

Key Concepts of Total Productive Maintenance

1. **Employee involvement** – TPM shifts the responsibility of equipment care from solely the maintenance department to all employees, including machine operators and management, fostering a culture of shared responsibility.
2. **Proactive and preventive maintenance** – TPM emphasizes anticipating and addressing potential equipment issues before failures occur, rather than relying solely on reactive repairs.
3. **Continuous improvement** – The approach encourages regular efforts to improve equipment performance and reduce inefficiencies.
4. **Improved equipment effectiveness** – TPM seeks to minimize equipment downtime, defects, and other losses that hinder operational efficiency.
5. **Shared responsibility** – TPM promotes cooperation between production and maintenance teams to ensure equipment reliability and performance.

6. **Breakdown and defect elimination** – Through proactive maintenance, TPM aims to prevent unexpected failures and reduce production errors.
7. **Waste reduction** – TPM contributes to minimizing material waste, energy consumption, and other inefficiencies related to equipment malfunctions.
8. **Workplace safety enhancement** – By encouraging cleanliness and proper maintenance, TPM helps create a safer work environment and reduces the risk of accidents.
9. **Productivity improvement** – By optimizing equipment uptime and performance, TPM supports increased output and operational efficiency.
10. **Employee engagement** – Involving employees in TPM activities fosters ownership, accountability, and motivation, contributing to stronger teamwork and better results.
11. **Four Pillars**: Supporting activities that address different aspects of TPM, such as
    a. **Autonomous Maintenance** – This pillar empowers operators to perform basic maintenance tasks such as cleaning, inspecting, and minor adjustments. This involvement fosters early detection of issues and a stronger sense of ownership.
    b. **Planned Maintenance** – This pillar involves scheduling maintenance activities based on usage patterns and equipment condition to prevent unexpected breakdowns and extend equipment life through preventive and predictive maintenance.
    c. **Focused Improvement** – Small, cross-functional teams are formed to identify and eliminate the root causes of inefficiencies. These teams analyze performance data and implement targeted solutions to enhance equipment effectiveness.
    d. **Training and Skills Development** – TPM emphasizes building employee capabilities by providing training in maintenance procedures, equipment handling, problem-solving techniques, and the core principles of TPM to ensure effective participation across all levels.

Palm Oil Processing for Cooking

Palm oil processing for culinary use involves refining crude palm oil (CPO) to remove impurities and enhance its quality, making it suitable for human consumption. This process typically consists of four main stages: degumming, neutralization, bleaching, and

deodorization. The outcome is refined, bleached, and deodorized (RBD) palm oil, which is widely used in cooking, food processing, and various industrial applications.

1. **Crude Palm Oil** (CPO) – The process begins with crude palm oil, which is extracted from the fruit of oil palm trees. CPO contains impurities such as gums, free fatty acids, pigments, and odor-causing compounds, which must be removed through refining.
2. **Refining Process** – The refining of CPO into RBD palm oil involves the following stages:
    a. **Degumming** – This step removes phospholipids and other impurities by mixing the oil with water or using a dry degumming method.
    b. **Neutralization** – Free fatty acids are neutralized using an alkaline solution, typically sodium hydroxide, resulting in the formation of soapstock which is subsequently separated from the oil.
    c. **Bleaching** – Bleaching earth or activated carbon is used to adsorb pigments, trace metals, and residual soap, producing a clearer and more stable oil.
    d. **Deodorization** – Volatile compounds and unpleasant odors are removed by subjecting the oil to high-temperature steam under vacuum conditions, yielding a neutral-flavored final product.
3. **RBD Palm Oil** (Refined, Bleached, and Deodorized) – The final product is a high-quality, purified oil suitable for direct consumption or further industrial use. RBD palm oil is characterized by its clarity, neutral taste, and resistance to oxidation.
4. **Fractionation** (Optional) – In some cases, RBD palm oil undergoes an additional process called fractionation, which separates the oil into liquid and solid components. The liquid portion, known as palm olein, is widely used as a cooking oil, especially in tropical climates due to its stability at high temperatures.

In summary, the palm oil refining process transforms crude palm oil into a stable, edible product with enhanced characteristics such as improved color, flavor, and oxidative stability, making it suitable for a wide range of culinary applications.

Methodology

This study employed both qualitative and quantitative research methods. Data were collected through a structured questionnaire distributed to 200 randomly selected employees from the production and maintenance departments

Finding

The results of the study on Production Efficiency Optimization by Total Productive Maintenance: A Case of The Vegetable Oil Production Company are presented as follows:

1. The results of the study on the overall efficiency of the vegetable oil production system machinery before using the integrated maintenance with everyone involved found that the overall efficiency of the vegetable oil production system machinery was 83.8% on average. The deodorization and bleaching system had the lowest overall efficiency of the machinery in the vegetable oil production system with an average of 72.6%. The next highest ranking was the heating system with an overall efficiency of the machinery in the vegetable oil production system with an average of 80.3%. Both systems had an average overall efficiency of the machinery lower than the average of the production system.
2. The results of the study on losses in the vegetable oil production system before the integrated maintenance with everyone involved found that the damage or malfunction of machinery and equipment in the vegetable oil production system before the integrated maintenance with everyone involved was caused by the most damage from damaged valves with 35 damages, followed by the cause of blocked pipes with 17 damages, the cause of damaged motors and control systems with 15 damages, and the cause of damaged oil pumps with 10 damages.
3. The results of the implementation of the main pillar activities of integrated maintenance with everyone involved in the vegetable oil production system found that there were causes, obstacles, and problems in understanding and motivation of employees in the production department. and maintenance department, the researcher proposed to adjust the work activities and responsibilities of the employees in the production department and maintenance department to be consistent with the main pillar activities of maintenance with participation of all parties.

4. The results of the study of the overall efficiency of the vegetable oil production system machinery after using maintenance with participation of all parties found that after implementing the main pillar activities of maintenance with participation of all parties in the vegetable oil production system This resulted in an overall efficiency of the vegetable oil production system machines at an average of 87.7%, with the deodorization and bleaching system having the lowest overall efficiency of the machines in the vegetable oil production system at an average of 81.6%, followed by the heat production system with an overall efficiency of the machines in the vegetable oil production system at an average of 84.6%. Both systems had an average overall efficiency of the machines higher than the average of the production system.
5. The results of the study of losses in the vegetable oil production system after using the integrated maintenance with everyone involved found that the number of machine failures or malfunctions decreased to 32 times, classified as follows: valve failures had the highest number of failures at 11 times, pipe blockages at 10 times, oil pump failures at 5 times, motor failures at 4 times, and control system failures at 2 times.
6. The results of the study comparing the overall efficiency of the machines in the oil production system before and after using the integrated maintenance with everyone involved found that:
    1) After using the integrated maintenance with everyone involved, the overall efficiency of the vegetable oil production system tended to increase, with the efficiency of the entire production system increasing on average. 3.92%
    2) After using the multi-product maintenance system with everyone's participation, the loss of resources in the vegetable oil production system tends to decrease.
    3) After using the multi-product maintenance system with everyone's participation, the loss or malfunction of machinery in the vegetable oil production system tends to decrease.

Conclusion

Following a six-month trial of the Total Productive Maintenance (TPM) system, the company successfully reduced maintenance time and production costs, while improving overall production efficiency by more than 3%. Based on these positive outcomes, the company’s

management decided to continue implementing the TPM system within the production department and plans to expand its application to other departments in the future.

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Thai Economy in the Future: Opportunities, Challenges, and Strategic Pathways Toward Sustainable Growth

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1. Abstract

Thailand's economy stands at a critical juncture, influenced by global megatrends, technological transformation, demographic shifts, and environmental challenges. This paper examines the future of the Thai economy by analyzing key drivers of change, including digital transformation, the Bio-Circular-Green (BCG) economy, regional connectivity under the ASEAN framework, and the shift toward service-based industries. Notably, China's role as Thailand's largest trading partner and a leading source of foreign direct investment (FDI) is a major macroeconomic driver, shaping Thailand's trade balance, industrial development, and integration into regional value chains and towards a global supply chain. Drawing upon recent economic data, policy analysis, and expert projections, the study outlines potential growth pathways and structural reforms necessary to ensure inclusive and sustainable development, while navigating the opportunities and risks arising from China's economic influence.

2. Introduction and Background

As the second-largest economy in Southeast Asia, Thailand faces both opportunities and vulnerabilities as it transitions into the Fourth Industrial Revolution (Industry 4.0) (World Bank, 2020). Economic growth over the past decades has been driven by export-oriented manufacturing, agriculture, and tourism (NESDC, 2021). However, long-term challenges such as an aging population, rising household debt, global trade volatility, and climate change have created uncertainty (United Nations, 2019; Bank of Thailand, 2023; OECD, 2021). Thailand's economic trajectory is increasingly intertwined with China's, given the latter's status as Thailand's largest trading partner and a significant investor in strategic sectors such as electronics, electric vehicles, and infrastructure. Fluctuations in China's growth and policy direction directly impact Thailand's exports, investment inflows, and tourism receipts. The Thai government's strategies including Thailand 4.0, the Eastern Economic Corridor (EEC), and the BCG model aim to position the country as a high-income, innovation-driven economy (NESDC, 2018; Ministry of Higher Education, Science, Research and Innovation, 2021). It is

therefore necessary to account for both the opportunities and vulnerabilities associated with China's evolving economic landscape. This paper explores these dynamics in the context of future economic scenarios.

Thailand stands at a strategic inflection point as it seeks to transition from an upper-middle-income country to a high-income, innovation-led economy. Historically, the Thai economy has been driven by three major pillars: export-oriented manufacturing, agriculture, and tourism. These sectors have played a vital role in shaping the country's rapid industrialization and global integration since the late 20th century (World Bank, 2020). However, the limitations of this growth model have become increasingly evident in recent years, particularly in the face of deepening structural vulnerabilities and global economic uncertainty.

Key long-term challenges are now confronting the Thai economy. Thailand is among the most rapidly aging societies in Asia, with projections indicating that over 25% of the population will be aged 60 and above by 2030 (United Nations, 2019). This demographic shift is expected to constrain labor force growth and exert pressure on the country's healthcare and pension systems. Additionally, rising levels of household debt among the highest in the region have begun to weigh on domestic consumption and financial stability (Bank of Thailand, 2023). Externally, the Thai economy remains highly sensitive to global trade dynamics, which are becoming increasingly volatile due to geopolitical tensions, supply chain realignments, and post-pandemic recovery trends. Moreover, the growing impacts of climate change such as more frequent droughts, floods, and extreme weather are jeopardizing agricultural productivity, food security, and infrastructure resilience (OECD, 2021).

To navigate these complex dynamics, the Thai government has introduced several strategic frameworks aimed at fostering long-term competitiveness, inclusivity, and sustainability. Foremost among these is the **Thailand 4.0** policy, a national agenda launched to promote technological innovation, digital transformation, and value-added industries such as biotechnology, smart electronics, and robotics (NESDC, 2018). This initiative is supported by the development of the **Eastern Economic Corridor (EEC)**, a key investment hub designed to attract high-tech industries and upgrade logistics infrastructure in the eastern provinces. Complementing these efforts is the **Bio-Circular-Green (BCG) Economy Model**, which emphasizes sustainable development through the integration of biological resources, circular production, and environmental stewardship aligning Thailand's growth strategy with global

sustainable development goals (Ministry of Higher Education, Science, Research and Innovation, 2021).

Against this backdrop, this paper examines Thailand's future economic pathways through the lens of emerging opportunities, persistent challenges, and strategic choices. By evaluating key trends and national responses within the broader context of the Fourth Industrial Revolution, the study aims to identify realistic scenarios that can guide Thailand toward resilient and sustainable economic development.

This paper contributes to the literature by integrating macroeconomic trends, sectoral policy developments, and regional dynamics to present forward-looking scenarios for Thailand's economy an approach that synthesizes fragmented insights into a unified strategic framework.

3. Objective

This systematic review aims to synthesize current research and policy literature regarding the future trajectory of Thailand's economy, focusing on identifying key drivers, challenges, and strategic pathways toward sustainable growth.

4. Literature Review

The future of Thailand's economy has been widely discussed in academic, policy, and financial literature. The World Bank (2023) highlights Thailand's need to improve labor productivity and educational quality to remain competitive. The Asian Development Bank (2022) emphasizes infrastructure investment and SME support as key to inclusive growth. Recent studies by Chontanawat (2020) and TDRI (2021) focus on transitioning to a green economy and the digitalization of public services. Meanwhile, the Bank of Thailand (2024) projects that demographic shifts will significantly affect labor supply, consumption patterns, and fiscal burdens over the next two decades. Recent studies also note the growing impact of China on Thailand's macroeconomic environment. For example, Chinese FDI has accelerated industrial upgrading in the EEC, while China's demand fluctuations affect Thai agricultural and manufacturing exports (Bank of Thailand, 2024). These dynamics underscore the need for Thailand to diversify its economic base and strengthen resilience to external shocks, particularly those emanating from China's structural transitions.

The future trajectory of Thailand's economy has been extensively analyzed across multiple dimensions including productivity, infrastructure, demographic trends, green transition, and

digital transformation (World Bank, 2023; ADB, 2022; Chontanawat, 2020; TDRI, 2021; Bank of Thailand, 2024). This literature review synthesizes recent findings from international organizations, academic research, and Thai policy institutes to provide a comprehensive understanding of the key challenges and opportunities shaping Thailand's economic prospects.

4.1 Labor Productivity and Educational Quality

Improving labor productivity and the quality of human capital is a recurrent theme in global and national economic assessments. The World Bank (2023) underscores that Thailand's relatively stagnant productivity growth in recent years threatens its competitiveness in the global market. The report identifies deficiencies in the educational system particularly in STEM fields and vocational training as critical barriers. It recommends structural reforms aimed at aligning skills development with industry demands, enhancing teacher quality, and expanding lifelong learning initiatives. These measures are vital to transitioning from a middle-income to a high-income economy (World Bank, 2023). Supporting this, ADB (2022) notes that enhanced labor productivity can be stimulated through technological adoption and innovation, which requires an educated and adaptable workforce.

4.2 Infrastructure Development and SME Support

Infrastructure investment is widely recognized as a foundation for inclusive and sustainable economic growth. The Asian Development Bank's 2022 report emphasizes the need for improved transport networks, digital infrastructure, and energy systems in Thailand to reduce logistical costs and connect rural areas to markets (ADB, 2022). ADB also highlights the critical role of small and medium enterprises (SMEs), which constitute the backbone of the Thai economy. Support policies aimed at improving SMEs' access to finance, digital tools, and export markets are essential for broad-based growth and employment generation (ADB, 2022; Phongpaichit & Baker, 2021).

4.3 Transition to a Green Economy

Sustainable development has become central to Thailand's long-term economic planning. Chontanawat (2020) explores Thailand's green growth potential, focusing on energy efficiency, renewable energy adoption, and sustainable agriculture. Similarly, the Thailand Development Research Institute (TDRI) (2021) highlights government initiatives aimed at decarbonization and circular economy practices, but notes gaps in regulatory frameworks and capacity at subnational levels.

4.4 Digitalization of Public Services and Economic Sectors

Digital transformation is another critical vector for Thailand's economic future. TDRI (2021) emphasizes the rapid expansion of digital infrastructure and e-government services as key enablers of efficiency, transparency, and citizen engagement. The Bank of Thailand (2024) forecasts that digital innovation will play a pivotal role in offsetting some negative effects of demographic changes by improving productivity and creating new economic opportunities.

4.5 Demographic Shifts and Economic Implications

Demographic change poses significant challenges to Thailand's economic outlook. The Bank of Thailand (2024) projects a shrinking labor force due to low fertility rates and population aging, which will affect labor supply and consumption patterns. The report recommends policy responses including raising the retirement age, promoting labor force participation among women and older workers, and leveraging automation and AI to compensate for labor shortages.

4.6 Economic Landscape (2020–2024)

Thailand's GDP growth slowed significantly during the COVID-19 pandemic, contracting by 6.2% in 2020 (NESDC, 2021). Recovery has been uneven, with tourism lagging behind while digital services and logistics expanded rapidly. Export recovery, foreign direct investment in the EEC, and fiscal stimulus supported modest growth in 2022–2024. However, structural issues remain: productivity growth is stagnant, and household debt remains above 85% of GDP (Bank of Thailand, 2023).

4.7 Key Drivers of Future Growth

- **Digital Economy:** As e-commerce, fintech, and automation expand, Thailand's digital economy is projected to reach 30% of GDP by 2030 (Google-Temasek-Bain, 2023).
- **Green and Circular Economy:** Thailand's BCG economic model promotes sustainable industries such as bioplastics, organic agriculture, and renewable energy (OECD, 2023).
- **Aging Society:** With over 20% of the population expected to be over 60 by 2035, healthcare, robotics, and retirement services will become key sectors (Bank of Thailand, 2024).
- **Regional Integration:** The RCEP and ASEAN frameworks offer new market access and supply chain integration opportunities (ADB, 2022).

4.8. Risks and Challenges

Thailand's future growth is threatened by several risks:

- Global Economic Slowdown: The still slow and highly uncertain global economic recovery, particularly the slowdown in the Chinese economy, and the trade policies of major countries such as the United States (e.g. Trump's tariff policies), may have a direct impact on Thailand's export sector, which is a key engine driving the economy (NESDC, 2025).
- **Climate Change:** Rising temperatures and water scarcity threaten agricultural productivity and urban resilience (UNESCAP, 2023). Weather volatility affects agricultural productivity and prices, which are important factors in farmer income and the overall economy (NESDC, 2025).
- **Geopolitical Instability:** Trade tensions, regional conflicts, and supply chain disruptions could impact exports and FDI (OECD, 2021).
- **Educational Gaps:** Mismatch between labor skills and industry demand remains a key bottleneck to innovation (World Bank, 2023).
- **Public Debt and Fiscal Constraints:** Aging population will increase pressure on pensions and healthcare systems (Bank of Thailand, 2024).

5. Methodology

5.1 Literature Search Strategy

- **Databases and Sources:** The review draws on academic databases (Scopus, Web of Science, JSTOR, Google Scholar), official publications from international organizations (World Bank, Asian Development Bank, OECD, UNESCAP), Thai government agencies (Bank of Thailand, NESDC), and recognized research institutes (Thailand Development Research Institute - TDRI).
- **Search Terms:** Keywords used include: *"Thailand economy future"*, *"Thailand economic growth"*, *"Thailand digital transformation"*, *"Bio-Circular-Green economy Thailand"*, *"Thailand demographic shifts"*, *"Thailand infrastructure development"*, *"Thailand SME policy"*, *"Thailand green growth"*, "Risks and Challenges for Thailand's Economy" and combinations thereof.
- **Timeframe:** Publications from 2018 to 2024 and Q1/2025 were prioritized to capture the most recent developments, given the rapid evolution of economic and technological contexts.

- **Language:** Only English and Thai language documents were included to ensure accessibility and relevance.

5.2 Inclusion and Exclusion Criteria

- **Inclusion:**
  - Peer-reviewed articles, policy reports, official economic outlooks, and white papers focusing on Thailand's economic prospects or relevant sub-themes.
  - Empirical studies, scenario analyses, and strategic frameworks.
  - Publications by reputable institutions and authors with demonstrated expertise in Thai economic studies.
- **Exclusion:**
  - Opinion pieces, news articles, or publications lacking rigorous methodology or credible sourcing.
  - Studies focused exclusively on historical economic analysis without future orientation.

5.3 Data Extraction and Analysis

- Relevant data were extracted systematically for each source, including publication details, objectives, methodology, key findings, and policy recommendations.
- Thematic coding was applied to identify recurrent themes across the literature, including labor productivity, infrastructure, SME development, green economy transition, digitalization, and demographic change.
- Comparative analysis was conducted to highlight consensus, discrepancies, and gaps in the current knowledge.

5.4 Quality Assessment

- Source credibility was assessed based on publication outlet, author expertise, and citation impact.
- Policy reports were cross-validated against official government documents and international organization data.

6. Result

6.1 Summary of Key Literature and Their Focus Areas

Table 1: Summary of Key Literature and Their Focus Areas

Author / Organization	*Year*	*Focus Area*	*Key Findings / Recommendations*
World Bank	2023	Labor Productivity & Education	Need to reform education system; improve STEM and vocational skills
Asian Development Bank	2022	Infrastructure & SME Support	Emphasizes digital infrastructure and SME finance access
Chontanawat	2020	Green Economy Transition	Highlights renewable energy adoption and sustainable agriculture
Thailand Development Research Institute (TDRI)	2021	Digitalization & Green Growth	Calls for integrated policy frameworks and digital public services
Bank of Thailand	2024	Demographics & Fiscal Impact	Projects labor shortages, aging population challenges

6.2 Thematic Distribution of Literature Reviewed

A pie chart showing the proportion of studies focused on major themes such as Labor Productivity, Infrastructure, Green Economy, Digital Transformation, and Demographic Change.

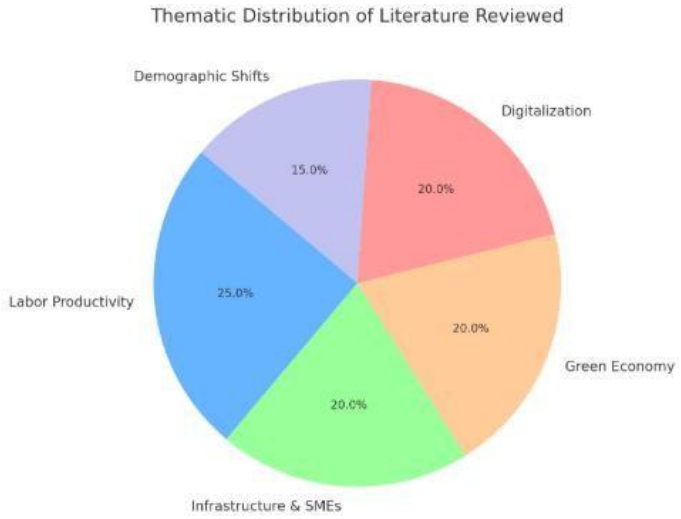

Figure 1: Thematic Distribution of Literature Reviewed

6.3 Drivers and Challenges of Thailand's Economic Future

- **Drivers** (Digital Transformation, BCG Economy, ASEAN Connectivity, Service Sector Growth)
- **Challenges** (Aging Population, Household Debt, Climate Change, Educational Gaps)
- **Outcomes** (Inclusive Growth, Sustainability, Innovation, Regional Competitiveness)

6.4 Future Growth Scenarios (2025–2040) from TDRI

Table 2: Future Growth Scenarios (2025–2040) from TDRI

Scenario	*Description*	*Projected Growth Rate*	*Key Conditions*
Optimistic	Innovation and green transition succeed	4–5%	Strong reforms, tech adoption, sustainability
Baseline	Slow reforms and moderate growth	~2.5%	Partial policy implementation
Pessimistic	Political instability and global recession	0–1%	Delayed reforms, external shocks

6.5. Sectoral Outlook

- **Agriculture**: Needs modernization via smart farming, AI, and climate-resilient practices.
- **Manufacturing**: Transitioning toward high-tech industries such as electric vehicles (EVs), medical devices, and aerospace.
- **Tourism**: Will rebound with focus on high-value, sustainable, and digital tourism.
- **Services**: Growth expected in digital finance, logistics, health tech, and creative industries.

6.6 Policy Recommendations

- **Human Capital Development**: Reform education to support digital and green skills.
- **Investment in R&D**: Increase public and private investment in innovation, particularly in health, biotech, and AI.
- **SME Support**: Strengthen access to finance, digital tools, and export opportunities.
- **Regional Equity**: Promote economic zones and smart city initiatives in second-tier provinces.

7. Future Scenarios (2025–2040)

Scenario analysis by the Thailand Development Research Institute (TDRI) projects three futures:

- **Optimistic**: Thailand achieves 4–5% sustained growth through innovation and green transition.
- **Baseline**: Slow growth (~2.5%) due to delayed reforms.
- **Pessimistic**: Growth stagnates amid political instability and global recession.

8. Conclusion

Thailand's economic future depends on its ability to embrace structural transformation, digital innovation, and sustainable development. Strategic investments in human capital, green industries, and regional development are essential. While risks remain, proactive policy and strong public-private collaboration can position Thailand as a resilient and forward-looking economy in Southeast Asia and create growth in the manufacturing sector through further integration into the global supply chain through seeking trade cooperation and export risk diversification.

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Talent and Organizational Support in Enhancing Quality of Work Life (QWL) Among the New Generation Workforce: Strategic Implications in the Digital Age

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Abstract

Employee engagement is widely recognized as a strategic enabler of sustainable organizational performance, particularly in a workforce characterized by generational shifts and digital transformation. This study focuses on the influence of Quality of Work Life (QWL) on the new generation workforce, highlighting critical elements such as work-life balance, career development, leadership support, psychological well-being, and hybrid work structures. Drawing from the Job Demands-Resources (JD-R) and Social Exchange Theory (SET), the analysis uncovers how talent development and organizational support foster higher levels of emotional and behavioral commitment. Key findings underscore that organizations prioritizing inclusive leadership, flexible work arrangements, and tailored career pathways significantly enhance QWL and, in turn, employee engagement. The study offers insights into mitigating challenges such as digital burnout, disengagement, and attrition. Practical recommendations include the integration of mental health initiatives, agile leadership models, and strategic talent frameworks. These approaches aim to align QWL strategies with evolving workforce expectations, driving long-term productivity and retention.

Keyword: Quality of Work Life, Talent Development, Organizational Support, Employee Engagement, Work-Life Balance

INTRODUCTION

In an era defined by rapid technological advancement, generational shifts, and evolving workplace dynamics, organizations face increasing pressure to attract, develop, and retain high-quality human capital. Human Resource Management (HRM) has thus transitioned from a purely administrative function to a critical strategic driver of organizational performance and sustainability. This transformation is particularly relevant in the context of the new generation workforce comprising primarily of Millennials and Generation Z whose expectations of work

extend beyond financial compensation to include autonomy, growth, work-life balance, and organizational support. The concept of Quality of Work Life (QWL) has emerged as a strategic lever in enhancing employee motivation, satisfaction, and productivity. QWL encapsulates the overall quality of the relationship between employees and their work environment, including physical well-being, psychological support, opportunities for development, job security, and participation in decision-making (Danish & Usman, 2023). Numerous studies affirm that organizations that invest in QWL report higher levels of employee engagement, reduced turnover, and improved organizational performance (Alfain & Noekent, 2024; Samagaio & Felício, 2022). Drawing on Social Exchange Theory (SET), this study conceptualizes QWL as an antecedent to Organizational Commitment (OC) and Job Satisfaction (JS), which in turn influence Job Performance (JP). SET posits that employees reciprocate favorable workplace conditions with positive attitudes and behaviours. In this framework, when organizations provide meaningful work, supportive management, and balanced working conditions, employees are more likely to respond with commitment, discretionary effort, and high performance (Cropanzano & Mitchell, 2005; Liu, 2023).

Organizational Commitment refers to an employee's emotional and psychological attachment to the organization. Employees with high OC demonstrate loyalty, resilience, and proactive behaviour in contributing toward organizational goals (Nguyen & Ha, 2023). Recent research indicates that OC significantly mediates the relationship between HR practices and performance outcomes (Arifin et al., 2025). Similarly, Job Satisfaction, a widely studied construct in organizational behavior, reflects the degree to which employees feel content and fulfilled in their roles. Although JS has historically been viewed as a strong predictor of performance, recent findings reveal mixed outcomes. For example, a 2025 study in Indonesian manufacturing firms found that while QWL and OC had a direct positive impact on JP, JS did not significantly mediate the relationship (Fajar Shidiq, 2025). These discrepancies highlight a persistent gap in the literature regarding the precise role of JS within the QWL–performance nexus. As the workplace continues to evolve post-pandemic, with hybrid models and flexible work arrangements becoming the norm, there is a pressing need to understand how QWL and organizational support impact performance outcomes among emerging workforce cohorts. Addressing this research gap is both timely and essential for organizations seeking to remain competitive and sustainable in the digital economy.

2.0 Literature Review

2.1.1 Job Performance (JP)

Job performance is a central construct in organizational behaviour, representing the extent to which employees fulfil their responsibilities, meet expectations, and contribute to organizational objectives. It is generally understood as the alignment between what an individual is expected to do and what is actually delivered in terms of task quality, efficiency, and initiative. Effective job performance involves not only technical proficiency but also behavioural competencies such as communication, collaboration, and adaptability to dynamic work contexts. Scholars have increasingly emphasized that job performance is shaped by both individual-level factors such as motivation, skills, and attitudes and organizational-level influences, including leadership style, workplace support, and the overall organizational climate (Nguyen & Ha, 2023). High-performing employees tend to exhibit commitment, persistence, and problem-solving capacity, often going beyond their formal role expectations. In contemporary knowledge-based economies, where work is more cognitive and interactive, job performance is also influenced by psychological well-being, role clarity, and perceived organizational fairness (Louis et al., 2025). Thus, performance should be viewed not as a static outcome but as a dynamic process shaped by ongoing interaction between individual potential and organizational conditions.

2.1.2 Quality of Work Life (QWL)

Quality of Work Life (QWL) has gained increasing importance as organizations strive to create environments that support not only productivity but also employee satisfaction, engagement, and well-being. QWL refers to the degree to which employees perceive their work environment as conducive to their personal and professional development, health, and overall life satisfaction. It encompasses multiple dimensions, including physical working conditions, emotional safety, fairness, autonomy, opportunities for growth, work–life balance, and supportive relationships with peers and leaders. In today's hybrid and flexible work structures, the meaning of QWL has expanded to include psychological resilience, digital wellness, and autonomy in managing tasks. Employees who perceive high QWL tend to demonstrate stronger loyalty, lower turnover intentions, and greater discretionary effort. Organizations that emphasize respect, inclusion, and employee voice are more likely to foster positive QWL experiences. Recent research highlights that a workplace culture characterized by trust, development opportunities, and flexibility is instrumental in elevating QWL, especially among younger generations who prioritize meaningful work and personal growth over traditional

rewards (Lee & Chen, 2020; Farid et al., 2024). Therefore, enhancing QWL is not only a moral responsibility but also a strategic imperative for sustainable performance.

2.1.3 Organizational Commitment (OC)

Organizational commitment refers to the emotional and psychological bond that employees develop with their organization, reflecting their intention to remain with the employer and contribute actively toward its goals. It is often categorized into three components: affective commitment (emotional attachment), normative commitment (sense of obligation), and continuance commitment (perceived cost of leaving). Each dimension plays a role in determining the intensity and quality of employees' connection to the organization. A high level of commitment is typically associated with increased motivation, lower absenteeism, and stronger alignment with organizational values and vision. Commitment is fostered through a combination of factors including transparent communication, recognition, meaningful work, career advancement opportunities, and leadership support. Affective commitment, in particular, has been linked to voluntary performance behaviours and organizational citizenship. When employees feel that they are treated fairly, supported in their roles, and included in decision-making, their emotional bond with the organization strengthens (Allen et al., 2020; Arifin et al., 2025). In the context of younger employees, commitment is increasingly influenced by the organization's purpose, social values, and capacity to nurture individual aspirations.

2.1.4 Job Satisfaction (JS)

Job satisfaction is a key psychological construct that captures an employee's overall attitude and emotional response toward their job. It reflects the degree to which individuals feel fulfilled, valued, and content with various aspects of their work, such as tasks, compensation, leadership, growth opportunities, and social relationships. Job satisfaction plays a critical role in shaping workplace behaviour, including engagement, performance, and retention. Although job satisfaction is often linked with positive outcomes, its impact may vary depending on organizational context and individual expectations. Employees who experience satisfaction are more likely to demonstrate resilience in challenging situations, maintain motivation, and engage in behaviours that benefit the team and the organization. Furthermore, a satisfying work environment contributes to better mental health and reduced workplace stress. Organizations that promote fairness, transparency, inclusiveness, and empowerment create the conditions for sustained job satisfaction. Scholars also note that Gen Z and Millennials who now dominate the workforce tend to value relational satisfaction, purpose-driven work, and psychological safety over traditional extrinsic rewards (Edmans, 2023; Bharathi, 2022). As such, job

satisfaction is both a desirable outcome and a mediating force that enhances the relationship between workplace practices and broader organizational goals.

3.0 Theoretical Framework

The theoretical foundation of this study integrates two complementary frameworks: The Job Demands-Resources (JD-R) model and Social Exchange Theory (SET). These theories provide a robust lens to examine how talent development and organizational support enhance Quality of Work Life (QWL) for the new generation workforce, comprising Millennials and Generation Z. By addressing the interplay between workplace demands, resources, and reciprocal relationships, this framework explains the mechanisms through which QWL fosters employee engagement, commitment, and performance in dynamic work environments.

3.1 Job Demands-Resources (JD-R) Model

The JD-R model categorizes workplace characteristics into job demands and job resources, each influencing employee well-being and performance differently (Bakker & Demerouti, 2021). Job demands, such as high workloads, role ambiguity, and digital fatigue, act as stressors that can erode QWL, leading to burnout and disengagement, particularly among younger employees navigating hybrid work settings. Conversely, job resources such as supportive leadership, autonomy, and access to learning opportunities mitigate these stressors, fostering engagement, psychological well-being, and resilience (Schaufeli & Taris, 2023). For the new generation workforce, resources like flexible work arrangements, mentorship programs, and digital wellness initiatives are critical for maintaining QWL. For instance, organizations that provide tools for managing digital overload, such as scheduled “unplugged” hours, help reduce stress and enhance employees’ ability to balance professional and personal demands (Farid et al., 2024).

Talent development and organizational support serve as pivotal job resources within the JD-R framework. Talent development initiatives, including continuous learning platforms and career coaching, empower employees to adapt to technological advancements and evolving job roles, thereby enhancing their sense of competence and purpose (Iqbal & Hashmi, 2022). Similarly, organizational support, such as empathetic leadership and mental health resources, buffers the negative effects of job demands, fostering a supportive work environment that aligns with the values of Millennials and Gen Z, who prioritize psychological safety and growth opportunities (Louis et al., 2025). By balancing demands with resources, organizations can create a workplace that not only mitigates burnout but also promotes sustained engagement and productivity.

3.2 Social Exchange Theory (SET)

Social Exchange Theory (SET) posits that workplace relationships are built on reciprocal exchanges, where employees respond to organizational investments with increased loyalty, effort, and performance (Cropanzano et al., 2020). When organizations demonstrate care through talent development programs, recognition initiatives, and supportive policies, employees perceive these actions as a commitment to their well-being, fostering trust and emotional attachment. This reciprocity is particularly salient for the new generation workforce, who value transparency, fairness, and purpose-driven work (Wong et al., 2021). For example, organizations that offer personalized career pathways or celebrate employee contributions through digital recognition platforms signal investment in their workforce, strengthening affective commitment and enhancing QWL.

SET also explains how perceived organizational support (POS) influences QWL. POS reflects employees' beliefs that their organization values their contributions and cares about their well-being (Ahmad & Zainal, 2021). Supportive HRM practices, such as flexible scheduling, mental health days, and inclusive decision-making, reinforce POS, encouraging employees to reciprocate with higher engagement and organizational citizenship behaviors. In the context of hybrid work, SET underscores the importance of clear communication and equitable resource allocation to maintain trust, particularly among younger employees who may feel disconnected in virtual settings (Brynjolfsson et al., 2020). By fostering a culture of mutual investment, organizations can enhance QWL, driving long-term retention and performance.

3.3 Integrated JD-R and SET Framework

The integration of JD-R and SET provides a comprehensive framework for understanding the influence of talent development and organizational support on QWL. The JD-R model highlights how job resources mitigate the negative effects of demands, creating a conducive environment for QWL. Meanwhile, SET explains the reciprocal dynamics that translate organizational investments into employee commitment and satisfaction. Together, these theories suggest that talent development (e.g., training, mentorship) and organizational support (e.g., leadership, wellness initiatives) act as job resources that enhance QWL, which in turn fosters organizational commitment and job performance. This framework is particularly relevant for the new generation workforce, as it addresses their unique expectations for autonomy, growth, and psychological well-being in the context of digital transformation and hybrid work.

4.0 Methodology

This study adopted a quantitative cross-sectional design to explore the influence of talent development and organizational support on Quality of Work Life (QWL) among the new generation workforce in Malaysia's public sector. Data were collected from 350 hybrid workers, primarily Millennials and Generation Z, across government agencies in Selangor, using an online questionnaire. The instrument measured QWL, resilient leadership, organizational support, and hybrid work intensity with validated scales adapted from prior research (e.g., Ahmad & Zainal, 2021; Louis et al., 2025), employing a 5-point Likert scale with high reliability (Cronbach's alpha > 0.80 for all constructs). Purposive sampling ensured participants had at least one year of hybrid work experience to provide relevant insights. Data analysis, conducted using SPSS version 27, included descriptive statistics, Pearson correlation, and multiple regression to examine relationships between variables, grounded in the Job Demands-Resources (JD-R) and Social Exchange Theory (SET) frameworks.

5.0 Results

The results provide robust empirical evidence of the relationships between talent development, organizational support, and QWL among the new generation workforce in a hybrid work context. Three tables below present the descriptive statistics, correlation matrix, and regression analysis, each with a brief explanation to contextualize the findings. A path diagram (Figure 1) follows, visually summarizing the relationships tested, aligning with the JD-R and SET frameworks.

Table 1: Descriptive Statistics

Variable	Mean	Standard Deviation	N
Resilient Leadership	4.08	0.54	350
Organizational Support	3.95	0.61	350
QWL	3.91	0.63	350
Hybrid Work Intensity	3.75	0.67	350

Table 1 presents the mean and standard deviation for each variable based on responses from 350 participants. Resilient leadership (M = 4.08, SD = 0.54) and organizational support (M = 3.95, SD = 0.61) exhibit high mean scores, indicating strong perceptions among hybrid workers. QWL (M = 3.91, SD = 0.63) reflects positive work-life quality, while hybrid work

intensity (M = 3.75, SD = 0.67) suggests moderate engagement with hybrid work arrangements, with variability indicating diverse experiences among Millennials and Gen Z.

Table 2: Correlation Matrix

Variable	1	2	3	4
1. Resilient Leadership	1.00			
2. Organizational Support	0.60**	1.00		
3. QWL	0.55**	0.58**	1.00	
4. Hybrid Work Intensity	0.33**	0.35**	0.29**	1.00

Note: **p < .01

Table 2 displays Pearson correlations, all significant at p < .01. Resilient leadership and organizational support show strong positive correlations with QWL (r = 0.55 and r = 0.58, respectively), indicating that effective leadership and supportive practices significantly enhance work-life quality. The moderate correlation between hybrid work intensity and QWL (r = 0.29) suggests a less pronounced but significant relationship, reflecting the nuanced impact of hybrid work on younger employees' QWL. The strong correlation between resilient leadership and organizational support (r = 0.60) underscores their interconnected roles in fostering a supportive work environment.

Table 3: Regression Analysis for Quality Work Life

Predictor	β	T	p	R^2
Resilient Leadership	0.56	7.82	< .001	
Organizational Support	0.48	6.45	< .001	
Hybrid Work Intensity	0.21	2.93	< .05	
Model Summary				0.62

Table 3 summarizes the multiple regression analysis predicting QWL. Resilient leadership (β = 0.56, p < .001) and organizational support (β = 0.48, p < .001) are strong predictors, indicating their significant role in enhancing work-life quality for the new generation workforce. Hybrid work intensity (β = 0.21, p < .05) has a weaker but significant effect, suggesting a supplementary influence. The model explains 62% of the variance in QWL (R^2 = 0.62), highlighting the combined impact of these factors in shaping positive workplace experiences for Millennials and Gen Z in hybrid settings.

Figure 1: Path Diagram of Predictors of QWL

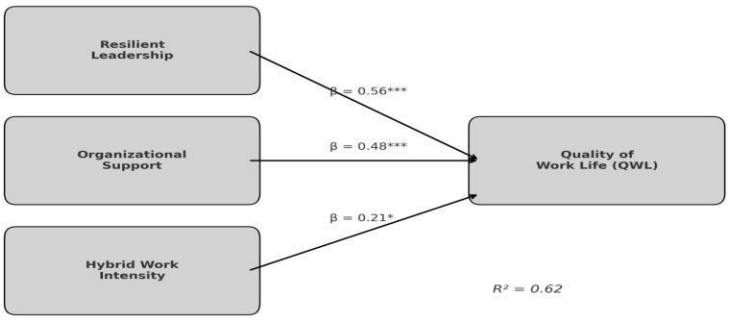

Figure 1 is a path diagram illustrating the relationships between resilient leadership, organizational support, hybrid work intensity, and QWL, based on the regression analysis. Arrows from each predictor to QWL are labelled with standardized beta coefficients (β = 0.56 for resilient leadership, β = 0.48 for organizational support, β = 0.21 for hybrid work intensity), with significance levels indicated (***p < .001, *p < .05). The R^2 value of 0.62 reflects the model's explanatory power, showing that these predictors account for 62% of the variance in QWL. This visual representation aligns with the JD-R and SET frameworks, highlighting how job resources (leadership and support) and work arrangements (hybrid intensity) enhance QWL for the new generation workforce in hybrid settings. These findings underscore the critical roles of resilient leadership and organizational support in enhancing QWL, with hybrid work intensity contributing moderately. The results, supported by the tables and figure, confirm the applicability of the JD-R and SET frameworks in understanding workplace dynamics for Millennials and Gen Z.

6.0 Discussion

The findings of this study confirm that talent development and organizational support significantly enhance Quality of Work Life (QWL) for the new generation workforce, particularly Millennials and Generation Z, in Malaysia's public sector hybrid work environment. The regression analysis (β = 0.56 for resilient leadership, β = 0.48 for organizational support, p < .001; β = 0.21 for hybrid work intensity, p < .05) and strong correlations (r = 0.55 and 0.58 for leadership and support with QWL, respectively) underscore the pivotal roles of leadership and supportive practices in fostering positive workplace experiences. These results align with the Job Demands-Resources (JD-R) model, which posits that job resources like leadership and support mitigate demands such as digital fatigue, thereby enhancing QWL (Bakker & Demerouti, 2021). Similarly, Social Exchange Theory (SET) explains the reciprocal relationship, where organizational investments in employees foster loyalty and engagement (Cropanzano et al., 2020). Below, we discuss the strategic implications

for talent management, leadership, hybrid work, organizational culture, and generational expectations, offering practical insights for organizations navigating the evolving workplace.

6.1 Strategic Talent Management

The significant influence of resilient leadership and organizational support on QWL highlights the need for strategic talent management tailored to the new generation workforce. Millennials and Gen Z prioritize continuous learning and career progression, as evidenced by their positive response to development opportunities (Iqbal & Hashmi, 2022). Organizations should embed talent development into daily operations through structured mentorship, digital learning platforms, and personalized career pathways. For example, tech companies like Google implement "20% time" policies, allowing employees to pursue innovative projects, which boosts engagement and aligns with SET's reciprocity principle (Wong et al., 2021). Public sector agencies in Malaysia could adopt similar initiatives, such as micro-credential programs or cross-departmental rotations, to enhance skill adaptability and job satisfaction. Recognition platforms, such as peer-to-peer feedback apps, further reinforce motivation by celebrating contributions, fostering a sense of value among younger employees (Farid et al., 2024). These strategies not only enhance QWL but also reduce attrition, a critical concern given the high turnover rates among Gen Z workers seeking purpose-driven roles.

6.2 Leadership and Psychological Capital

Resilient leadership emerged as the strongest predictor of QWL ($\beta = 0.56$, $p < .001$), emphasizing the need for leaders to shift from traditional command-and-control models to coaching and empathy-driven approaches. The new generation workforce values leaders who foster psychological capital (PsyCap), comprising hope, optimism, resilience, and efficacy, which mediates the relationship between leadership and QWL (Avey et al., 2021). For instance, regular check-ins and constructive feedback, as practiced by firms like Deloitte, enhance employees' sense of purpose and reduce workplace stress. In Malaysia's public sector, leadership training programs should prioritize emotional intelligence and resilience-building to address hybrid work challenges, such as digital burnout and role ambiguity. By cultivating PsyCap, leaders can create a supportive environment that aligns with Millennials' and Gen Z's expectations for psychological safety and growth, thereby enhancing organizational commitment and performance (Louis et al., 2025).

6.3 Hybrid Work and Boundary Management

Hybrid work intensity, while a significant predictor of QWL ($\beta = 0.21$, $p < .05$), showed a weaker effect compared to leadership and support, reflecting the complex dynamics of hybrid work arrangements. The moderate correlation ($r = 0.29$) suggests that while flexibility is

valued, it can blur work-life boundaries, leading to digital fatigue among younger employees. Organizations must implement clear policies, such as Microsoft's "no-email weekends" or designated "unplugged" hours, to promote digital wellness and protect QWL (Brynjolfsson et al., 2020). Providing tools like time-tracking apps and setting expectations for remote work can help employees manage their mental load. In Malaysia, where hybrid work is increasingly prevalent, public sector agencies should establish boundary management guidelines, such as limiting after-hours communication, to enhance QWL and prevent disengagement, particularly for Gen Z workers who prioritize work-life balance (Wong et al., 2021).

6.4 Organizational Culture and Supportive HRM

A supportive organizational culture is essential for sustaining QWL, as evidenced by the strong influence of organizational support ($\beta = 0.48$, $p < .001$). Flexible policies, such as mental health days, parental leave, and remote work options, demonstrate organizational care, fostering reciprocity as per SET (Ahmad & Zainal, 2021). Transparent communication and inclusive practices, such as employee feedback platforms used by companies like Salesforce, empower the workforce and enhance trust. In Malaysia's public sector, adopting similar HRM practices such as anonymous suggestion tools or wellness programs can address generational expectations for fairness and inclusion. These initiatives not only improve QWL but also strengthen organizational commitment, reducing turnover intentions among Millennials and Gen Z, who value workplaces aligned with their social and ethical values (Farid et al., 2024).

6.5 Addressing Generational Expectations

The new generation workforce prioritizes purpose, growth, and psychological safety, as reflected in the study's findings of high QWL perceptions ($M = 3.91$). Organizations must align their mission with these values by integrating social responsibility, such as community engagement or sustainability initiatives, which resonate with younger employees (Wong et al., 2021). For example, firms like Patagonia, which emphasize environmental impact, report higher engagement among Millennials. In Malaysia, public sector organizations could incorporate national development goals, such as those outlined in the Malaysia Plan, into workplace initiatives to foster a sense of purpose. Addressing generational expectations through meaningful work and supportive environments enhances QWL, driving long-term productivity and retention in hybrid settings.

7.0 Conclusion and Future Research

This study confirms that Quality of Work Life (QWL) is a strategic cornerstone in attracting and retaining the new generation workforce in Malaysia's public sector. Talent

development and organizational support were identified as the most influential levers, with resilient leadership ($\beta = 0.56$, $p < .001$) and organizational support ($\beta = 0.48$, $p < .001$) serving as key predictors of QWL. Although hybrid work intensity ($\beta = 0.21$, $p < .05$) also contributes positively, its impact is comparatively modest. Collectively, these predictors explain 62% of the variance in QWL ($R^2 = 0.62$), reinforcing the applicability of the Job Demands-Resources (JD-R) and Social Exchange Theory (SET) frameworks in hybrid work environments.

From a strategic perspective, these findings emphasize the value of job resources particularly leadership and organizational care in fostering engagement, psychological safety, and performance among Millennials and Gen Z employees. The study highlights several actionable strategies for policymakers and practitioners:

- **Mentorship and Talent Development**: Embedding structured career pathways and lifelong learning mechanisms can boost employees' sense of purpose and loyalty.
- **Empathetic and Resilient Leadership**: Training programs focused on emotional intelligence, feedback culture, and psychological capital can empower leaders to support diverse teams effectively.
- **Digital Wellness and Boundary Policies**: Implementation of clear work-life boundaries such as "no email weekends" or mental health days can mitigate burnout and sustain QWL.
- **Inclusive HR Practices**: Recognition systems, flexible arrangements, and participatory feedback platforms resonate strongly with the generational expectations of fairness, purpose, and inclusion.

Recommendations for Future Research:

- **Longitudinal Studies**: To explore the sustained impact of psychological capital and leadership on QWL and job performance across time and career stages.
- **Industry-Specific QWL Models**: To tailor QWL frameworks for sectors such as healthcare, education, or IT, where hybrid work dynamics may differ significantly.
- **Cross-Cultural ASEAN Comparisons**: To examine how cultural variations influence QWL perceptions, especially in multi-ethnic, regional contexts.

In conclusion, aligning QWL strategies with generational values, supported by resilient leadership and inclusive organizational practices, is vital for driving retention, engagement, and innovation in the digital economy.

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Digital Literacy as a Catalyst in Consumer Adoption of Digital Healthcare: An Integrated Theoretical Perspective from Malaysia

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Abstract

As digital healthcare platforms become increasingly essential in modern health ecosystems, understanding the mechanisms that drive consumer adoption is critical. This study investigates the mediating role of digital literacy in the relationship between perceived value, trust, and convenience, and consumer behaviour in adopting digital healthcare services in Malaysia. The research integrates three established models the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology, and the Value-Based Adoption Model to develop a unified conceptual framework. A total of 351 valid responses were analysed using structural equation modelling and bootstrapped mediation testing. The findings reveal that digital literacy significantly mediates the influence of all three predictors on consumer behaviour, suggesting that digital competence is not merely a prerequisite but a transformational enabler. The results highlight the necessity of enhancing digital skills, fostering trust, and designing user-centric systems to bridge the digital divide. This study offers both theoretical advancement and practical strategies for healthcare providers, policymakers, and system developers aiming to promote inclusive and widespread adoption of digital healthcare technologies.

Keyword: Digital healthcare; Digital Healthcare Adoption; Consumer behaviour; Perceived Value; Technology Acceptance.

INTRODUCTION

The rapid digital transformation of healthcare has redefined service delivery in a post-pandemic world. Digital healthcare services including telemedicine, mobile health applications, patient portals, and wearable devices are increasingly essential for ensuring timely, remote, and personalized care. In Malaysia, national initiatives such as the MyDIGITAL initiative and the Malaysia Digital Economy Blueprint are driving a comprehensive shift toward technology-enabled healthcare. Despite these significant investments and policy efforts, consumer adoption remains inconsistent, particularly among populations with limited access

to digital tools or inadequate digital skills. Digital literacy, defined as the ability to access, understand, evaluate, and apply information from digital resources, is emerging as a cornerstone of successful digital healthcare engagement. This competence encompasses technical skills, cognitive capacities for critical evaluation, and socio-emotional abilities to address privacy and security concerns. Recent studies (Ban and Kim, 2024; Pangrazio et al., 2020) have highlighted that insufficient digital literacy exacerbates health disparities, especially among older adults, rural communities, and socioeconomically disadvantaged groups. For instance, research conducted in 2023 in Zhejiang, China, revealed that only 35% of rural residents possess adequate digital health literacy, thus limiting their engagement with telehealth services (Wang et al., 2024). In Malaysia, similar challenges persist, with data indicating that up to 23% of small and medium enterprises and rural populations face substantial digitization barriers (Wong et al., 2021).

To better understand these challenges, this study adopts an integrated multi-theoretical framework by drawing on the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology, and the Health Belief Model. While the Technology Acceptance Model posits that perceived ease of use and usefulness drive the adoption of technology, it falls short of addressing health-specific motivations. The Unified Theory of Acceptance and Use of Technology further extends this view by incorporating social influences and facilitating conditions, elements that are vital in the context of healthcare where trust and infrastructural support are paramount. Additionally, the Health Belief Model elucidates how perceptions of health risks and anticipated benefits motivate preventive behaviours. By integrating these perspectives, this research seeks to uncover how digital literacy acts as a catalyst that transforms positive user perceptions into tangible adoption behaviours. The current economic landscape is characterized by swift post-pandemic recovery and accelerated digitalization. Global projections indicate that the digital health market may reach USD 660 billion by 2025, propelled by advancements in artificial intelligence, the Internet of Things, and 5G connectivity (Statista, 2025). In Malaysia, public healthcare expenditure is expected to grow by approximately 6% annually through 2025 (Ministry of Health Malaysia, 2024), further underlining the imperative for efficient, cost-effective digital health solutions. However, the success of these initiatives largely depends on consumers' digital competencies, reinforcing the need to address the digital divide.

This study aims to investigate digital literacy as a catalyst for consumer adoption of digital healthcare services within a unified multi-theoretical framework. The research contributes to the literature by providing a localized perspective on Malaysia's digital health

ecosystem and offering practical recommendations for policymakers, healthcare providers, and educators to enhance digital literacy and promote equitable adoption. By bridging existing theoretical gaps and aligning with Malaysia's digital transformation objectives, this study underscores that fostering digital literacy is not merely a complementary strategy but a fundamental catalyst for the sustainable evolution of digital healthcare services.

LITERATURE REVIEW

The acceleration of digital transformation in healthcare driven by the post-pandemic shift toward remote and hybrid service models has magnified the role of digital literacy as a critical determinant in the adoption of digital health technologies. Although digital services such as telemedicine, mobile health applications, and wearable devices offer significant improvements in access, efficiency, and continuity of care (Liu et al., 2024), their effectiveness hinges on consumers' digital competencies. This literature review synthesizes recent findings (2020–2025) across four core domains: (1) digital literacy, (2) consumer adoption of digital healthcare services, (3) theoretical frameworks underpinning adoption behaviour, and (4) the research gap within Malaysia's evolving digital health landscape.

Digital Literacy

Digital literacy in healthcare refers not only to the technical ability to operate devices and applications but also to cognitive skills such as evaluating the credibility of health information and socio-emotional competencies like managing privacy concerns (Pangrazio et al., 2020; Ban & Kim, 2024). It encompasses a multidimensional capacity that enables meaningful engagement with digital tools. In a study of urban China, Wang et al. (2024) reported a 40% increase in telemedicine use among residents with high digital literacy. By contrast, rural communities with limited skills faced significant barriers. Similarly, in Malaysia, adoption rates diverge sharply: urban youths show a 75% adoption rate, while rural adults lag behind at 45% (Wong et al., 2021). These disparities highlight that digital literacy is not merely a functional skill but a decisive factor in healthcare inclusion and equity.

Theoretical Perspectives on Digital Health Adoption

A multi-theoretical lens is essential to fully understand the interplay of technical, social, and psychological drivers of digital healthcare adoption. This study draws from four key models: the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), the Health Belief Model (HBM), and the Value-Based Adoption Model (VAM). Each provides complementary insights into user motivations and barriers.

a) Technology Acceptance Model (TAM)

TAM suggests that perceived ease of use (PEOU) and perceived usefulness (PU) are the main drivers of adoption (Davis, 1989; Zhang et al., 2020). In digital health, PEOU reflects how intuitively users navigate systems, while PU is associated with health benefits such as timely diagnostics. Sharma and Patel (2022) found that digital literacy amplified PEOU, increasing wearable health tech adoption by 35%. However, TAM's limited scope fails to account for social or infrastructural variables, warranting integration with broader models.

b) Unified Theory of Acceptance and Use of Technology (UTAUT)

UTAUT expands on TAM by adding social influence and facilitating conditions (Venkatesh et al., 2023). These constructs are crucial in culturally collectivist societies like Malaysia, where community and family opinions strongly influence health behaviours (Wong et al., 2021). Additionally, access to devices, connectivity, and digital support significantly affects adoption in underserved regions (Chaiyaporn & Suksawang, 2024).

c) Health Belief Model (HBM)

HBM contextualizes digital adoption as a health-motivated action. It posits that perceived susceptibility, benefits, and self-efficacy drive engagement with digital tools (Kim & Park, 2021). For example, South Korean chronic disease patients with high health awareness and digital literacy showed a 30% increase in mobile health app usage. This model enriches the understanding of emotional and preventive motivations behind technology use in healthcare.

Consumer Adoption of Digital Healthcare Services

Consumer adoption of digital healthcare services is shaped by a complex mix of individual perceptions, technological design, and contextual variables. Studies consistently highlight perceived ease of use, usefulness, trust, and social influence as key adoption drivers (Zhang et al., 2020). In Singapore, 68% of participants cited convenience as the primary reason for embracing telemedicine, yet older adults showed reluctance due to interface complexity (Tan & Lim, 2023). In Malaysia, the government's MyDIGITAL initiative has spurred the proliferation of digital health platforms, but adoption remains uneven. Rural populations report adoption rates of just 40% compared to 70% in urban areas, largely due to infrastructural and skill deficits (Ahmad & Zainal, 2021). Furthermore, 30% of Malaysian users report cybersecurity concerns as a barrier to engagement, particularly in the wake of rising digital

fraud cases (Wong et al., 2021). These findings suggest that trust-building, usability, and consumer education are fundamental to enhancing uptake.

d) Value-Based Adoption Model (VAM)

VAM highlights how consumers weigh perceived value (functional, emotional, and social) against potential costs (Kim et al., 2007). Chuah et al. (2016) showed that confidence in navigating mobile platforms strengthened the link between perceived value and adoption positioning digital literacy as the enabling bridge.

Malaysia's Digital Health Context

Despite Malaysia's commitment to digitalization through initiatives like the MyDIGITAL blueprint, research specific to its diverse healthcare ecosystem remains limited. First, most existing studies address digital literacy as a static background variable rather than a mediating, dynamic factor (Nguyen et al., 2021). Second, few studies differentiate between urban and rural literacy capabilities across cognitive, technical, and emotional dimensions (Wang et al., 2024). Third, the application of a single model (e.g., TAM alone) inadequately captures the multifactorial realities of consumer decision-making. Fourth, Malaysia-specific insights on digital trust and data security remain scarce, despite being consistently cited as top consumer concerns (Wong et al., 2021). This study addresses these gaps by applying an integrated multi-theoretical model blending TAM, UTAUT, HBM, and VAM to examine how digital literacy shapes consumer adoption pathways in Malaysia. By investigating trust, value perception, health motivation, and convenience through the mediating lens of digital competence, this research offers actionable insights to policymakers and healthcare designers aiming to achieve inclusive digital health transformation.

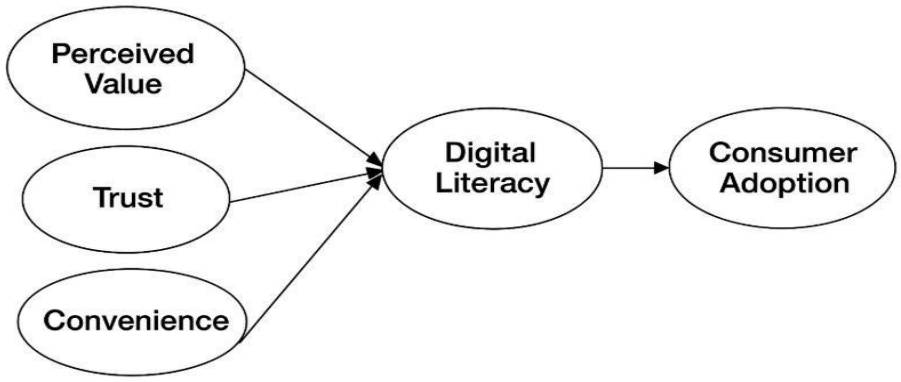
THEORITICAL FRAMEWORK

This study proposes an integrated multi-theoretical framework to examine how digital literacy mediates consumer adoption of digital healthcare services. Grounded in the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology, the Health Belief Model, and the Value-Based Adoption Model, the framework captures the dynamic interplay between cognitive perceptions and behavioural intentions. Perceived Value, Trust, and Convenience are conceptualized as independent variables. Perceived value reflects the consumer's evaluation of emotional, functional, and social benefits derived from digital health platforms (Kim et al., 2007). Trust refers to the consumer's belief in the safety, privacy,

and integrity of the digital system (Gefen et al., 2003), while convenience encompasses ease of access and time efficiency (Davis, 1989; Venkatesh et al., 2023).

Digital Literacy serves as the mediating variable, encompassing users' technical, cognitive, and socio-emotional competencies (Ban & Kim, 2024; Pangrazio et al., 2020). It is posited that individuals who perceive value, feel trust, and experience convenience are more likely to develop or enhance digital literacy, which in turn facilitates adoption. The dependent variable, consumer adoption, refers to the intention or actual behaviour of using digital healthcare services such as telemedicine, health portals, or mobile health applications. The framework, illustrated in Figure 1, models this mediated pathway to reflect the nuanced factors influencing digital healthcare engagement, particularly in Malaysia's digitally unequal context. Figure 1 illustrates the hypothesized multi-theoretical framework underpinning this study.

Figure 1: A Multitheoretical Framework of Healthcare Technology Adoption



DATA ANALYSIS

This section presents the results of the quantitative analysis conducted to evaluate the proposed research model. It includes descriptive statistics, measurement model assessment through Confirmatory Factor Analysis (CFA), and hypothesis testing using Structural Equation Modeling (SEM) with bootstrapping. All analyses were performed using SPSS v26 and AMOS v26.

Respondent Demographics

The study collected valid responses from 351 Malaysian consumers who had experience with digital healthcare services. As illustrated in Table 1, the gender distribution was relatively balanced (Male: 52%, Female: 48%). Respondents represented a diverse range of age groups, with the majority between 18–35 years old (63%). Educational levels were well distributed, with 38% holding a bachelor's degree and 18% possessing postgraduate qualifications. In terms of location, 61% of participants resided in urban areas, while 39% were from rural regions providing a robust base for examining disparities in digital literacy.

Table 1: Respondent Demographics Summary

Demographic Variable	**Category**
Gender	Male (52%), Female (48%)
Age Group	18–25 (34%), 26–35 (29%), 36–45 (22%), 46+ (15%)
Education Level	Secondary (18%), Diploma (26%), Degree (38%), Postgraduate (18%)
Region	Urban (61%), Rural (39%)

Measurement Model Assessment

A Confirmatory Factor Analysis (CFA) was conducted to test the validity and reliability of the constructs. As shown in Table 2, all constructs demonstrated strong internal consistency with Cronbach's alpha values above 0.70. Composite Reliability (CR) scores also exceeded the recommended threshold of 0.70, and Average Variance Extracted (AVE) values were above 0.50 indicating adequate convergent validity.

Table 2: CFA Loadings and Construct Reliability

Construct	**Cronbach's Alpha**	**Composite Reliability**	**Average Variance Extracted (AVE)**
Perceived Value	0.79	0.88	0.56
Trust	0.83	0.84	0.51
Convenience	0.87	0.89	0.62
Digital Literacy	0.81	0.83	0.57
Consumer Behaviour	0.84	0.91	0.66

These results confirm the robustness of the measurement model, validating the constructs for structural model testing.

Hypothesis Testing and Mediation Analysis

Structural Equation Modelling (SEM) with bootstrapping (5,000 samples) was used to assess direct and indirect effects. The results in **Table 3** confirm that all proposed hypotheses were supported.

- **H1**: Digital literacy had a significant direct effect on consumer behaviour ($\beta = 0.33$, $p < 0.001$).

- **H2–H4**: Perceived value, trust, and convenience significantly affected consumer behaviour through digital literacy. The indirect effects were β = 0.10, 0.08, and 0.09 respectively all statistically significant.

Among the three predictors, convenience had the strongest total effect (β = 0.47), followed by perceived value (β = 0.45), and trust (β = 0.39). These findings affirm that digital literacy is a key mediating factor in the adoption of digital healthcare services.

Table 3: Hypothesis Testing Results

Hypothesis	**Pathway**	**Direct Effect (β)**	**Indirect Effect (β)**	**Total Effect (β)**	**p-value**
H1	Digital Literacy → Consumer Behaviour	0.33		0.33	< 0.001
H2	Perceived Value → Digital Literacy → Consumer Behaviour	0.35	0.10	0.45	< 0.001
H3	Trust → Digital Literacy → Consumer Behaviour	0.31	0.08	0.39	< 0.001
H4	Convenience → Digital Literacy → Consumer Behaviour	0.38	0.09	0.47	< 0.001

The results validate the conceptual model and confirm the significance of digital literacy as both a direct predictor and a mediating mechanism. These empirical findings serve as a foundation for the subsequent discussion and interpretation of practical implications.

Discussion

The findings of this study confirm that digital literacy plays a pivotal mediating role in the adoption of digital healthcare services. This result aligns with the proposed integrated framework, which synthesizes the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology, and the Health Belief Model. Each of the three independent variables perceived value, trust, and convenience significantly influenced consumer behaviour, both directly and indirectly through digital literacy, highlighting the multifaceted nature of technology adoption in healthcare settings.

The significant direct effect of digital literacy on consumer behaviour (β = 0.33, $p < 0.001$) supports the growing consensus that digital skills are essential enablers of digital health engagement (Ban & Kim, 2024; Pangrazio et al., 2020). This finding suggests that beyond perceived benefits or trust, consumers must possess the ability to navigate, evaluate, and apply digital health tools effectively in order to adopt them meaningfully.

Perceived value demonstrated the strongest indirect effect through digital literacy (β = 0.10), indicating that users who recognize the functional, emotional, or social benefits of digital healthcare are more likely to develop the digital competencies needed to engage with those tools. This reflects prior research asserting that motivation to adopt technology is strengthened when users see clear personal relevance (Chuah et al., 2016).

Trust was also found to be a significant factor, with both direct (β = 0.31) and indirect (β = 0.08) effects on consumer behaviour. This underscores the importance of data privacy, platform security, and institutional credibility, especially in healthcare where personal data sensitivity is high. As noted by Ong et al. (2014), Malaysian users are more willing to build digital skills when platforms are perceived as credible and reliable. Among the three predictors, convenience emerged as the strongest overall driver (total effect β = 0.47), reinforcing findings from previous studies that emphasize ease of use and time savings as primary motivators in digital health adoption (Davis, 1989; Venkatesh et al., 2023). Importantly, the indirect effect of convenience through digital literacy (β = 0.09) suggests that intuitive platforms not only encourage use but also facilitate the acquisition of digital competencies through repeated interaction.

These findings hold particular relevance for Malaysia, where urban-rural disparities persist in terms of infrastructure, access, and digital readiness. As highlighted in earlier sections, adoption rates remain significantly lower in rural areas (Ahmad & Zainal, 2021). This study shows that digital literacy is not merely a prerequisite but a *transformable factor* one that can be developed when perceived value, trust, and convenience are adequately addressed. The results also validate the value of an integrated multi-theoretical approach. While the Technology Acceptance Model captures core user perceptions, the Unified Theory of Acceptance and Use of Technology accounts for social and contextual influences, and the Health Belief Model emphasizes personal health motivations. Together, these models provide a more complete understanding of consumer behaviour in digital health adoption.

Conclusion

This study provides empirical evidence that digital literacy is a critical enabler and mediator in the adoption of digital healthcare services, particularly in developing countries like Malaysia. By integrating the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology, the Health Belief Model, and the Value-Based Adoption Model, the study offers a comprehensive framework for understanding the cognitive, social, and technical factors influencing consumer behaviour. The results demonstrate that perceived value, trust, and convenience each exert both direct and indirect effects on consumer adoption through

digital literacy. Among these, convenience emerged as the strongest total predictor, suggesting that system design, user experience, and time-saving features are central to engagement. Importantly, digital literacy encompassing technical, cognitive, and socio-emotional competencies functions not merely as a background variable, but as a transformative capacity that bridges user perceptions with actual behaviour. From a practical perspective, this research calls for policy interventions and system designs that simultaneously enhance platform usability and consumer digital competencies. Stakeholders including government agencies, healthcare providers, and developers must invest in digital literacy training, infrastructure development in underserved areas, and the integration of trust-building mechanisms such as data privacy assurances and intuitive interfaces.

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THE ROLE OF AGRICULTURE SECTOR ON GROSS REGIONAL DOMESTIC PRODUCTS (GRDP) NORTH SUMATERA PROVINCE

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Abstract

The potential of natural resources owned by each region is an economic potential that can be used in improving people's lives and regional and state revenues.

The agricultural sector is a potential sector for the economic growth of communities and regions where this sector contributes to the creation of the economy of society and regions and countries.

Based on the result of Location Quotient Method (LQ) analysis, it is known that LQ of agriculture > 1 means that agriculture sector is base economic sector in North Sumatera Province, but there is decrease every year.

North Sumatra Provincial Government must make various policies so that the agricultural sector does not continue to decline and if it continues to be left then it will eliminate the economic opportunities of the agricultural sector.

Keywords: Agricultural Sector and Gross Regional Domestic Product (GRDP).

Preliminary

Given the vastness of the Indonesian territory and followed by the vastness of its land, it makes Indonesia the world's largest agricultural country rich with its natural resources.

Indonesia is dubbed as an agrarian country and as a source of food for the livelihood of its people which is supported by the availability of vast agricultural land and plantations which, if managed properly, will bring value to the results produced by the agricultural sector.

The progress of the agricultural sector in Indonesia has experienced a peak during the leadership of President Soeharto who managed to make Indonesia as the largest rice producer in the world.

The agricultural sector is a production sector that has been given by God Almighty to the people of Indonesia because of the enormous natural wealth in Indonesia that can fulfill the lives of its people for a long period of time and must be managed properly.

The agricultural sector contributes enormously in lifting the regional and national economies where the agricultural sector contributes substantial foreign exchange to the national economy.

In addition, the agricultural sector can absorb a large workforce and most Indonesians rely on agriculture.

The growth of the agricultural sector can absorb a lot of labor so that the government is expected to participate and active in agricultural development for the future.

In the Five-Year Development Plan or Repelita I and Repelita II the government has been very correct in setting priorities for development in the agricultural sector, but in Repelita III the government is too quick to switch to the industrial sector where the agricultural sector at that time was not strong enough.

Development priorities in the agricultural sector will have an effect on the absorption of labor in the agricultural sector in anticipation of an increase in unemployment due to high birth rates and the achievement of community welfare. (Tambunan in Setya Budi, 2005).

The government should pay very serious attention to the improvement of the agricultural sector as the agricultural sector becomes the backbone of the Indonesian economy (Arifin, 2005).

In the 1998 economic crisis in Indonesia, many of the production sectors suffered devastation, but the agricultural sector is very resilient and persistent and can raise the spirit of other sectors to grow and flourish after the monetary crisis.

We can follow the example of Thailand's emerging and developing government in economic development because the agricultural sector is very strong in Thailand and can sustain Thailand's economy.

Thailand also got an economic crisis and almost all countries suffered economic crisis in 1998, but Thailand can bounce back its economy because its agriculture sector is very strong.

North Sumatera Province has a vast land area of about 71,680 km2 so that it can be used in the development of business activities in North Sumatra whether agriculture, industry, trade, mining, etc.

In fact, in North Sumatra there are excellent commodities such as: palm oil, cocoa, rubber, tea, coffee, cloves, cinnamon and tobacco owned by some large plantations owned by the government, private and public.

The plantation area is located in Asahan, Simalungun, Deli Serdang, Serdang Bedagai, Langkat, Batubara, Labuhan Batu and Tapanuli Selatan and then vegetables in Karo District.

North Sumatera Province has an area of 65, 51% of coastal areas and 8.64% of lowland and 24.28% highland and Lake Toba of 1.57% so this is an agricultural potential that should be empowered by the Government of North Sumatra Province.

The extent and fertility of agricultural land in North Sumatra Province is very supportive for the development of the agricultural sector so that the government should facilitate all agricultural needs such as: irrigation, agricultural technology, working capital of farmers, the availability of fertilizers and agricultural extension workers.

Then the government must also pay attention to the market for farmers and even the government should be ready to buy agricultural produce so that prices can be guaranteed by the government and not harming the farmers.

The Provincial Government of North Sumatra should also be able to allocate good land use so that existing agricultural lands are not converted into housing, industrial and trading centers that remove agricultural land.

Farmers should also be trained and given knowledge of agricultural cultivation so that farmers do not seek other jobs to the city or to other sectors and farmers can survive in rural areas because farmers can earn sustenance from farming jobs.

The agricultural sector is the leading sector in North Sumatera Province which can be seen from the contribution of the agricultural sector to the income of the people and the regional income as well as the regional economic growth.

Samuelson, 1997, says that economic growth is the expansion or increase of a potential Gross Domestic Product or output of a country's economy that is affected by four factors that cause economic growth:

1. Human resources ie labor, skills, knowledge and work discipline.

2. Natural resources are all natural resources contained in the earth.

3. Formation of capital.

4. Technological change and innovation.

Then Boediono, 1999, said that economic growth is a process of increasing per capita output in the long term.

Production sectors that exist in each region must be well managed so as to provide benefits to people's lives in the long term and can be felt in the next generation.

Formulation Of The Problem.

With regard to the background that has been explained then it can be concluded the formulation of the problem is: How the influence of the agricultural sector to Gross Regional Domestic Product (GRDP) in the Province of North Sumatera.

Research Hypothesis.

From the background and the formulation of the problem can be concluded that the research hypothesis is: there is the influence of the agricultural sector on the formation of Gross Regional Domestic Product (GRDP) in the Province of North Sumatera.

Research Purposes.

1. To find out how much influence the agricultural sector on the formation of Gross Regional Domestic Product (GRDP) of North Sumatera Province.
2. To provide input to the Provincial Government of North Sumatera to make development policies to sectors that contribute to the income and economic growth of communities and regions.

Theoretical Description

Agricultural Sector

The role of the agricultural sector can be done by increasing agricultural productivity supported by science and technology in agriculture. (Mubyarto, 1989).

The agricultural sector is a pre-eminent sector in many regions and countries because this sector has a large influence on the absorption of labor and economic growth of the people and the regions so that the government and the state must plan the empowerment of the agricultural sector in order to improve the welfare of the people.

Arsyad, 1992, says that one way to improve people's lives is to increase crop production and trade in farmers and increase the prices they receive on farm produce.

The development of the agricultural sector is aimed at the long-term development direction leading to the liberalization of international trade and investment.

Changes in the agricultural environment should be made agriculture empowerment strategy that will create superior agricultural products that are ready to compete in the domestic market and in the international market.

Daniel, 2002, says that the creation of superior agricultural products and domestic and international markets is a solid basis for the government to accelerate the reorientation of the agricultural development direction.

The agricultural sector provides a strategic role to regional economic development, among others:

1. Agriculture absorbs labor of the region where if agriculture is developed in one particular region it will create local employment opportunities in the region.
2. Agriculture meets the needs of local food where the agricultural products in the area will be able to meet local food needs and can even be exported.
3. Agriculture generates investment areas where investors will come to the region because it creates business opportunities in the region.
4. Agriculture as a social disparity regulator (disparity Regional) where there will be development in the countryside so that the development does not belong to the urban only. (Todaro, 2000).

Gross Regional Domestic Product (GRDP)

Local and state governments continue to plan for improved regional and state economies, but governments should pay attention to development priorities where the government's inability to build the region as a whole is caused by limited funds.

One of the foundations for the government to develop regions and countries is to look at the magnitude of Gross Regional Domestic Product (GRDP) and National Domestic Product as it will show the magnitude of each sector that contributes to the economic growth of regions and countries.

According to Black, 2008, said that Gross Regional Domestic Product (GDP) is an indicator to measure the extent of government success to utilize existing resources and can be used as planning and decision making.

Then Tarigan, 2007, explained that the Gross Regional Domestic Product is the level of income of the people in the region where the regional income level can be measured from the total income of the region or the average income of the community in the area.

Economic Sector

Each region is not the same economic potential and the difference occurs because it has been created since this world is created by God Almighty.

To see each region about the sectors-production sectors that exist in the area is the Gross Regional Domestic Product (PDRB) where in it has been explained about how big the contribution of each sector to the formation of regional economy.

Glasson, 1997, says that the base sector is an activity that exports goods and services to places outside the boundaries of the economy of the people concerned or that markets goods and services to people coming from outside the boundaries of the economy of the people concerned, while non-activities basis is an activity that provides the goods needed by persons residing within the boundaries of the economy of the people concerned.

This is similar to the opinion of Saharuddin, 2005, which says that the base sector is a sector that has great potential in overall development in the region, while the non-base sector is the sector supporting the economy in the region.

The sector that contributes most to the creation of the regional economy is called the base sector and the less contributing is called the non-base sector.

Previous Research

1. Jui Rompas, Deisy Engka, Krest Tolosang, 2015, said that the agricultural sector in South Minahasa Regency has a positive effect on the absorption of labor with large R^2 is 0.225 or 22.5%.

2. A. Baroroh, A. Hanim, R., N., Wilantari, 2015, said the results of his research that based on the calculation of input-output analysis method that direct economic linkage in Jember Regency is agricultural sector with coefficient value of 0.360470842 from livestock sub-sector, 0.308378746 foodstuff sub-sector, 2.392460826 fishery sub-sector, and 0.0111855515 forestry sub-sector.

3. Daryono Soebagiyo, Arifin Sri Hascaryo, 2015, said that the agricultural sector in Wonogiri regency provides strength to the economy of Wonogiri Regency and is the leading sector where the results of the research value LQ > 1 ie 2007 LQ is 1.909, in 2008 the value of LQ is 1.954, year 2009 the value of LQ is 1.895, in 2010 the value of lQ is 2.119 and in 2011 the value of LQ is 2.050.

Research methods

Research sites

In this research which is used as research object is North Sumatera Provincial Government.

Data Type

The data used in this research is quantitative data that is Gross Regional Domestic Product (PDRB) of North Sumatera Province and National Domestic Product (NDP) Indonesia Year 2012-2014.

Data Source

Sources of data were collected from various sources ie from magazines, newspapers and from the Central Bureau of Statistics (BPS) of North Sumatra and Central.

TABLE 1

DATA GRDP PROVINCE NORTH SUMATERA AND PDN INDONESIA

YEAR 2012-2014

NO	YEAR	GRDP AGRICULTURE SECTOR OF NORTH SUMATERA	TOTAL GRDP NORTH SUMATERA	NDP AGRICULTURE SECTOR INDONESIA	TOTAL NDP INDONESIA
1.	2012	103.933.11	417.120.44	1.193.452.9	8.230.925.9
2.	2013	115.194.75	470.221.98	1.310.427.3	9.087.276.5
3.	2014	121.435.44	523.771.57	1.446.722.3	10.094.928.9

Sumber : Central Bureau Of Statistic Of North Sumatera Province And Central, 2012-2014.

Data analysis

The data will be analyzed by using Location Quotient (LQ) method using the following formula:

$$LQ = \frac{Xi\ GRDPNS\ /\ TGRDNS}{XiNDP\ /\ TNDP}$$

Where :

LQ = Location Quotient

Xi GRDPNS = Added Value of Agriculture Sector at GRDP of North Sumatera.

TGRDPNS = Total GRDP of North Sumatera.

XiNDP = Value Added Agricultural Sector In Indonesian NDP

TNDP = Total Indonesian NDP

By using the formula Location Quotient (LQ) then there will be value in accordance with the criteria Location Quotient namely:

1. LQ > 1 means that the value of the agricultural sector in North Sumatra Province is greater than the value of the agricultural sector in Indonesia, the agricultural sector in the Province of North Sumatra called the base sector and the agricultural sector can export.

2. LQ = 1 means that the value of the agricultural sector in North Sumatra Province is equal to the value of the agricultural sector in Indonesia, the agricultural sector in North Sumatra Province can only meet the needs of the province of North Sumatra.

3. LQ < 1 means that the value of agricultural sector in North Sumatera Province is smaller than the agricultural sector in Indonesia, the agricultural sector in North Sumatra Province is called non-base sector and the need of agriculture sector in North Sumatera Province must be imported from outside the region or country.

Discussion

To see which sector is the base and non base sector, Location Location Quotient (LQ) method for Gross Regional Domestic Product (PDRB) of North Sumatra Province 2012-2014 and National Domestic Product of 2012-2014 is applied.

But there are also disadvantages of the Location Quotient (LQ) method because the LQ method is static and can not predict the growth of regional or state economy in the future.

One method that can be used to see the development of regional or state economy in the future is used Method of Dinamic Location Quotient (DLQ).

Based on the data in Table 1, it can be seen the result of calculation of Location Quotient (LQ) on agriculture sector of Gross Regional Domestic Product (PDRB) of North Sumatera Province and National Domestic Product (PDNB) of Indonesia in 2012-2014 as follows:

TABLE 2

RESULT OF LOCATION QUOTIENT (LQ) SECTOR OF AGRICULTURE

NO	YEAR	LOCATION QUOTIENT (LQ) AGRICULTURE SECTOR
1.	2012	1.8
2.	2013	1.7
3.	2014	1.6

Sumber : Processed Data.

By calculating Location Quotient (LQ) method for Gross Regional Domestic Product (GRDP) of North Sumatera Province and National Domestic Product (NDP) of Indonesia in 2012-2014 there is LQ of Agriculture Sector > 1 in 2012 of 1.8, 2013 1.7 and the year 2014 is 1.6.

If you look at the results of calculations LQ 2012-2014 there is a decrease where this is caused by several things:

1. The shifting of community employment from agriculture to other sectors.
2. Lack of government attention to the agricultural sector.
3. The transfer of land use from the agricultural sector to housing, industry, trade, etc.
4. Lack of agricultural facilities and infrastructure.
5. Lack of farmers' capital and knowledge.

Conclusion

Based on the calculation of Location Quotient (LQ) in 2012-2014 on Gross Regional Domestic Product (GRDP) of North Sumatera Province and National Domestic Product (NDP) of Indonesia it is known that LQ of agricultural sector > 1, but there is decreasing every year.

Suggestion

With the value of LQ is reduced every year, it is doubtful agricultural sector will continue to decline if the government of North Sumatra Province does not anticipate the decline, therefore the government of North Sumatra Province must do several things:

1. The Government of North Sumatra Province shall supervise the transfer of land use.
2. The Government of the Province of North Sumatra should improve the knowledge of farmers and the infrastructure needed by farmers.

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The Economic Potential of Vermicompost as an Eco-Friendly Agribusiness Innovation

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Abstract.

The increasing need for sustainable agricultural practices has driven innovations that integrate environmental responsibility with economic viability. One such innovation is vermicompost an organic fertilizer produced through the decomposition of organic waste using earthworms, particularly Eisenia fetida. Vermicompost is gaining attention in the agribusiness sector due to its ability to convert agricultural and household organic waste into high-value products that improve soil fertility and reduce environmental pollution. This paper explores the economic potential of vermicompost production as an eco-friendly agribusiness innovation, especially in rural and semi-urban communities. Through a literature-based analysis, the study highlights the low production costs, accessible raw materials, and relatively simple processing techniques that make vermicompost production suitable for small-scale farmers and micro-enterprises. The increasing demand for organic produce further enhances the market potential of vermicompost. Additionally, its application improves soil health, increases crop yields, and contributes to reduced dependence on chemical fertilizers. From an agribusiness perspective, vermicompost production presents a dual benefit supporting environmental sustainability while generating economic value. The paper also discusses strategic approaches for promoting vermicompost entrepreneurship, including community training, access to microfinancing, and establishing marketing linkages with organic farming networks. Ultimately, vermicompost represents a viable and scalable opportunity to strengthen sustainable agribusiness models, particularly in developing regions. By adopting vermicompost, stakeholders in the agricultural sector can simultaneously address waste management challenges and enhance agricultural productivity.

Keywords: Vermicompost, Agribusiness, Organic Waste, Sustainable Agriculture, Eco-friendly Innovation, Economic Potential.

INTRODUCTION

Agriculture remains one of the most crucial sectors in sustaining global food security, especially in developing countries where a significant portion of the population relies on farming for their livelihoods(Hajam et al., 2023). However, conventional farming practices, which often depend heavily on chemical fertilizers and pesticides, have led to numerous environmental and socio-economic challenges. These include soil degradation, water pollution, decreased biodiversity, and increased production costs that burden smallholder farmers. In response, there is a growing call for more sustainable, eco-friendly agricultural practices that not only maintain productivity but also reduce environmental impact. Within this context, organic farming and the use of natural inputs are gaining momentum as viable alternatives to chemical-intensive systems(Goswami et al., 2024).

One such natural input with significant potential is vermicompost, a nutrient-rich organic fertilizer derived from the biological decomposition of organic waste materials using earthworms, primarily Eisenia fetida(Siburian & Ginting, 2024). Vermicomposting transforms biodegradable waste such as crop residues, animal manure, and household organic waste into a stable humus-like product that enhances soil fertility, structure, and microbial activity. Unlike chemical fertilizers that often cause long-term soil and water damage, vermicompost improves soil health and contributes to a more balanced ecosystem. Its application in crop production has been shown to increase yield quality and quantity, making it a highly attractive option for sustainable farming(Salsabilla et al., 2025).

The process of producing vermicompost is relatively low-tech, requiring minimal investment in equipment and infrastructure. This simplicity makes it accessible and scalable for small-scale farmers, rural communities, and agripreneurs. Moreover, the raw materials used in vermicomposting agricultural waste, food scraps, and livestock manure are abundantly available and often pose disposal challenges(Ginting et al., 2025). By converting waste into a marketable product, vermicomposting aligns well with the principles of the circular economy and waste-to-wealth initiatives. It allows farmers not only to improve soil productivity but also to generate additional income by selling the compost to fellow farmers, gardening communities, or organic retailers(Mustikawati et al., 2024).

In economic terms, vermicompost production offers a cost-effective solution with a high return on investment. The operational costs are minimal, and the market demand for organic fertilizers is growing steadily, driven by the rising popularity of organic food,

environmentally conscious consumers, and policy support for sustainable agriculture(Tuah Malem Ginting & Muhazir Insandi, 2025). Vermicompost can be packaged and marketed in various forms loose, bagged, or as part of integrated soil health kits allowing for flexible business models and product diversification. It also offers potential employment opportunities, especially for youth and women in rural areas, contributing to inclusive economic development(Bordoloi, 2023).

From an agribusiness perspective, vermicompost embodies the intersection of ecological responsibility and economic opportunity(Ginting & Mendrofa, 2025). As agribusiness evolves to meet the demands of environmental stewardship, climate resilience, and consumer awareness, products like vermicompost become vital components of sustainable value chains. Entrepreneurs and farmer cooperatives engaging in vermicompost production not only serve their own farms but can also tap into local and regional markets. In some regions, government programs and NGOs have supported vermicompost production as part of rural development and environmental conservation efforts, offering training, tools, and access to microcredit. These interventions demonstrate that with proper support, vermicompost businesses can thrive and become self-sustaining(Angelina et al., 2024).

Despite its potential, vermicompost remains underutilized, often due to a lack of awareness, inadequate training, and limited access to markets. Many farmers are unfamiliar with the benefits or skeptical of the effectiveness of organic alternatives. Additionally, inconsistent quality of vermicompost products in the market can undermine consumer trust. To unlock the full potential of vermicompost in agribusiness, there is a need for capacity building, quality control, and targeted marketing strategies that educate and engage both producers and consumers(Rahmah et al., 2024).

As environmental challenges intensify and the demand for sustainable food systems increases, the relevance of eco-friendly agricultural innovations like vermicompost will only continue to grow. It is therefore essential to understand and evaluate the economic viability and scalability of vermicompost production within the broader agribusiness landscape. This includes analyzing cost structures, identifying target markets, exploring policy support, and developing strategies to integrate vermicompost into mainstream agricultural supply chains(Thadeus, 2022).

In summary, vermicompost represents a promising innovation in sustainable agribusiness that can address multiple challenges simultaneously: waste management, soil fertility, income generation, and environmental conservation. Its adoption can lead to a more resilient, inclusive, and sustainable agricultural sector, particularly in developing regions where resources are limited and the pressure on natural ecosystems is high. However, for this potential to be fully realized, a deeper understanding of the economic, technical, and market dynamics surrounding vermicompost production and utilization is required(Wibowo et al., 2024).

Research Problem

How economically viable is vermicompost production as a sustainable agribusiness innovation, and what strategies can enhance its adoption and market potential among small-scale farmers?

1. THEORITICAL REVIEW

The integration of environmental sustainability into agribusiness requires a theoretical foundation that connects ecological innovation, value creation, and rural entrepreneurship. Vermicompost, as both a product and a process, aligns with several theoretical frameworks relevant to agricultural development, environmental economics, and small business models. This section outlines the key theories that underpin the study of vermicompost within the agribusiness context.

A. Sustainable Agriculture Theory provides the primary lens for understanding the relevance of vermicompost. According to this theory, agricultural practices should meet current food and fiber needs without compromising the ability of future generations to meet theirs. This involves maintaining environmental quality, using renewable inputs, and promoting biodiversity. Vermicompost fits within this framework as it enhances soil fertility naturally, reduces chemical input dependency, and utilizes waste materials thereby contributing to the long-term sustainability of farming systems(Wahyu Firdaus et al., 2023).
B. Circular Economy Theory supports the practice of converting waste into valuable resources, such as transforming organic waste into vermicompost. The circular economy emphasizes the continual use of resources, reduction of waste, and regenerative processes in production. Vermicomposting exemplifies this by diverting biodegradable waste from landfills and reintegrating it into the agricultural value chain

as a productive input. This theory reinforces the economic and environmental rationale for vermicompost as a business opportunity and sustainable practice(Wardani, 2024).

C. Value Chain Theory in agribusiness highlights how value is added at each stage of agricultural production and distribution. In this context, vermicompost serves not only as a means to improve farm output (by enhancing soil productivity and crop quality) but also as a stand-alone product with commercial value. The theory explains how actors involved in vermicompost production farmers, processors, distributors can capture and add value through innovation, quality differentiation, and market development(Salamah et al., 2021).

D. Entrepreneurship Theory, especially in rural and agrarian contexts, is relevant when analyzing vermicompost as a micro-enterprise opportunity. The Resource-Based View (RBV) within this theory posits that entrepreneurs can build competitive advantage by effectively using locally available and underutilized resources such as organic waste and caging space for earthworms. Vermicompost enterprises typically require low capital but high resourcefulness, aligning closely with the concept of necessity-driven innovation among rural entrepreneurs(Noor Aziza et al., 2022).

E. From an economic standpoint, Cost-Benefit Analysis (CBA) Framework is essential in evaluating the financial feasibility of vermicompost production. This approach assesses whether the economic benefits (e.g., income from sales, savings on chemical fertilizers) outweigh the production costs (e.g., labor, infrastructure, earthworm stock). The application of this framework helps in determining the viability and scalability of vermicompost-based agribusiness ventures(Tafarini et al., 2024).

F. Diffusion of Innovation Theory by Everett Rogers can explain how the adoption of vermicompost technology spreads among farming communities. This theory suggests that the rate and success of adoption depend on perceived advantages, compatibility with existing practices, trialability, observability, and complexity. Understanding these factors is crucial for designing interventions and extension strategies that can accelerate the uptake of vermicompost, particularly in areas where awareness and technical know-how are still limited(Nurida et al., 2024).

In conclusion, the study of vermicompost within the agribusiness framework is supported by a range of interdisciplinary theories that emphasize sustainability, economic viability, and grassroots entrepreneurship. These theories collectively provide a solid foundation for

analyzing the multifaceted value of vermicompost as a product, a process, and a tool for achieving eco-friendly agribusiness innovation.

2. RESEARCH METHODOLOGY

This study adopts a qualitative-descriptive research approach supported by literature review analysis to explore the economic potential of vermicompost as an eco-friendly agribusiness innovation. The methodology is designed to provide a comprehensive understanding of the subject by synthesizing existing studies, data, and expert perspectives on vermicompost production, marketing, and sustainability within agribusiness frameworks(Ginting & Zebua, 2024).

The primary method employed is a systematic literature review, which involves collecting, analyzing, and synthesizing secondary data from a variety of credible academic sources such as scientific journals, agribusiness reports, policy documents, government publications, and international development agency resources. The databases used for sourcing literature include Google Scholar, Scopus, ScienceDirect, and official platforms from FAO, UNDP, and national agricultural ministries.

The review focuses on literature published within the last 10 years (2015–2025) to ensure the relevance and timeliness of the data. Key search terms include: “vermicompost,” “organic fertilizer,” “sustainable agriculture,” “eco-friendly agribusiness,” “organic waste utilization,” “agricultural innovation,” and “economic feasibility of vermicompost.” These terms are used in various combinations to retrieve a broad yet focused set of references.

The data obtained are then categorized and analyzed based on the following thematic components:

A. Production Process – including raw materials, techniques, and labor inputs.
B. Economic Aspects – including cost structure, revenue potential, return on investment, and market demand.
C. Environmental Impact – such as waste reduction, soil improvement, and decreased chemical use.
D. Adoption and Diffusion – including barriers, drivers, and successful case studies in small-scale farming contexts.

The analysis uses a content analysis method, allowing for the identification of patterns, challenges, opportunities, and policy implications associated with vermicompost in agribusiness. Where applicable, basic quantitative comparisons from existing case studies

(such as production costs, yields, and price margins) are included to support qualitative interpretations.

To enhance the validity of findings, triangulation is applied by comparing information across multiple sources and regions. This method ensures that conclusions drawn are not based on a single context or study but represent broader trends in vermicompost adoption and agribusiness development.

The outcome of this methodology is expected to generate practical insights and strategic recommendations for farmers, agribusiness actors, development agencies, and policymakers interested in promoting vermicompost as part of sustainable agricultural practices.

3. RESULTS AND DISCUSSION

The analysis of existing literature and case studies reveals that vermicompost production is economically viable, especially for small-scale farmers and agripreneurs in developing regions. Several factors contribute to this viability, including low production costs, availability of raw materials, increasing demand for organic fertilizers, and the positive environmental impacts that enhance the long-term productivity of agricultural land.

A. Economic Feasibility of Vermicompost Production

Studies show that the cost of vermicompost production is relatively low due to the use of free or inexpensive raw materials such as agricultural residues, livestock manure, and kitchen waste. Infrastructure requirements are also minimal basic containers, shade nets, and moisture control tools suffice to start small-scale production. Labor is the primary operational cost, but this can be optimized through family or community-based involvement. In terms of return on investment, vermicompost producers can sell the product at competitive prices ranging from USD 0.20 to USD 1.00 per kilogram, depending on quality and packaging. Research from India, Indonesia, and Kenya indicates that small-scale producers can earn a profit margin of 30–50% per cycle. In many cases, vermicompost is also used by the producer to fertilize their own crops, reducing external fertilizer costs and increasing yields, which indirectly adds to the financial benefits.

B. Market Potential and Consumer Demand

The rise in consumer awareness about organic food and sustainable farming has driven market demand for organic inputs like vermicompost. Urban gardening, organic vegetable farming, and eco-conscious institutions have emerged as niche markets for these products. Additionally, government programs promoting organic

agriculture have created institutional demand, with some municipalities and cooperatives purchasing vermicompost in bulk. However, market expansion is hindered by a few challenges. These include lack of branding, inconsistent product quality, and limited marketing skills among rural producers. There is also a gap in connecting small producers with larger supply chains or organic certification networks that could help them access premium markets.

C. Environmental and Agronomic Benefits

Vermicompost offers not only economic returns but also environmental and agronomic advantages. It improves soil texture, water retention, microbial activity, and nutrient availability. Unlike chemical fertilizers, vermicompost is non-toxic, biodegradable, and does not cause long-term soil degradation. Its use enhances the resilience of farming systems, which is particularly important in regions affected by climate change and soil exhaustion. From an agribusiness perspective, these environmental benefits can be monetized by integrating vermicompost into eco-branded farm systems, sustainable agriculture labels, and carbon-credit initiatives. In short, the ecological value of vermicompost enhances the marketability and sustainability of the entire agribusiness model.

D. Strategies to Enhance Adoption Among Small-Scale Farmers

To improve adoption and economic scalability, several strategies must be implemented:

- Capacity Building: Training programs on vermicompost production, packaging, quality control, and marketing are essential. Farmer Field Schools and extension services can be key agents of knowledge transfer.
- Access to Microfinance: Though production costs are low, access to small loans or grants can help farmers invest in equipment and scale up operations.
- Market Linkages: Establishing cooperatives or partnerships with organic certification bodies and retailers can strengthen distribution and improve price margins.
- Policy Support: Local governments and NGOs should integrate vermicompost initiatives into agricultural development plans, providing incentives for organic input use and small enterprise development.

- Digital Marketing and E-Commerce: Promoting vermicompost through digital platforms, social media, and online marketplaces can help reach urban gardeners and eco-conscious buyers directly.

4. CONCLUSION AND RECCOMENDATIONS

Conclusion

The study concludes that **vermicompost production presents a viable and sustainable opportunity** within the agribusiness sector, particularly for small-scale farmers and rural communities. Its economic feasibility is driven by low input costs, the use of locally available organic waste, and an increasing demand for organic and eco-friendly agricultural inputs. Vermicompost not only offers a profitable product for commercial sale but also enhances soil health and crop productivity, contributing to long-term agricultural sustainability.

From an environmental perspective, vermicompost plays a crucial role in reducing organic waste and mitigating the harmful impacts of chemical fertilizers. Its use supports the broader goals of sustainable agriculture, environmental conservation, and rural development. The integration of vermicompost into agribusiness models aligns with circular economy principles and promotes inclusive growth by creating employment and entrepreneurial opportunities.

However, the full potential of vermicompost remains underutilized due to limited awareness, inadequate technical knowledge, and market access constraints. These challenges can be overcome through targeted strategies that empower smallholders and strengthen market linkages.

Recommendations

1. **Enhance Farmer Education and Training**
   Governments, universities, and NGOs should offer regular training programs on vermicompost production techniques, quality control, and business development.
2. **Support Access to Finance and Inputs**
   Financial institutions and local cooperatives should provide microloans or grants to help small producers invest in equipment and scale up operations.
3. **Strengthen Marketing Channels**
   Farmers should be supported in building marketing strategies, branding their products, and accessing organic certification to reach higher-value markets.

4. **Encourage Policy Integration**

   Vermicompost production should be included in agricultural development policies, waste management plans, and sustainability initiatives at local and national levels.

5. **Leverage Digital Technology**

   Promote vermicompost products through digital marketing, online platforms, and e-commerce to reach environmentally conscious urban consumers.

By implementing these recommendations, stakeholders can harness the full economic and ecological benefits of vermicompost, positioning it as a key innovation in the future of sustainable agribusiness.

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IMPLEMENTATION OF IOT FOR MONITORING TEMPERATURE AND HUMIDITY OF DRUG STORAGE IN PHARMACIES USING KALMAN FILTER

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Abstract

Proper storage of medicines is crucial to maintaining their quality and effectiveness. Temperature and humidity are two critical parameters that must be controlled in medicine storage areas, particularly in pharmacies. This study develops an Internet of Things (IoT)-based system for real-time monitoring of temperature and humidity, with the ability to transmit data to a cloud platform for remote analysis and observation. A DHT22 sensor is used to measure temperature and humidity, while an ESP32 microcontroller functions as the processing and data transmission unit via Wi-Fi connection. To enhance the accuracy of sensor readings, a Kalman Filter algorithm is implemented to filter out potential noise in the data. Testing results show that the system provides more stable and accurate data after applying the Kalman Filter, compared to raw sensor data. This system is expected to be an effective and efficient solution to help pharmacies maintain appropriate medicine storage conditions according to standards.

Keywords: IoT, Kalman Filter, temperature, humidity, medicine storage, pharmacy, DHT22, ESP32

INTRODUCTION

Proper storage of medicine in pharmacies is an essential factor in maintaining the quality, effectiveness, and safety of pharmaceutical preparations. Medicines stored under unsuitable temperature or humidity conditions risk degradation of active substances, reduced

potency, and even endangering patients. Therefore, the standards of Good Manufacturing Practice (GMP) and Good Distribution Practice (GDP) stipulate that drug storage areas must be consistently maintained within specific temperature and humidity ranges (Akbar & Sugeng, 2021).

However, in practice, many pharmacies still monitor temperature and humidity manually. This method is not only prone to recording negligence and data loss but also slows down the response to environmental changes that can impact the quality of pharmaceutical preparations (A. Setiawan & Suminto, 2021). This is where Internet of Things (IoT) technology plays an innovative role as a solution. IoT-based monitoring systems can measure temperature and humidity in real-time and automatically, and continuously transmit data to the cloud. Thus, pharmacy managers can remotely monitor storage conditions and immediately take action if deviations occur.

One case study at Apotek Megafarma showed that the implementation of an IoT-based temperature and humidity monitoring system successfully increased the efficiency and accuracy of supervision via mobile devices (Muttaqin et al., 2023). Nevertheless, a major challenge in implementing IoT systems is sensor reading accuracy, which is often disturbed by environmental noise. Additionally, most systems only present raw data without further processing, thus providing insufficient support for more precise data-driven decision-making.

To overcome this problem, the Kalman Filter algorithm can be applied as a data filtering solution. The Kalman Filter is a mathematical method capable of reducing noise in sensor data and producing more accurate and stable value estimations. By using this algorithm, monitoring systems can provide more reliable information and support rapid decision-making, especially in maintaining the quality of drug storage in pharmacy environments.

Previous research has indeed widely used sensors such as DHT11 or DHT22 and microcontrollers like ESP8266 or ESP32 to build IoT-based monitoring systems. However, most have not integrated advanced filtering algorithms like the Kalman Filter to improve system accuracy. Furthermore, research specifically discussing the implementation of the Kalman Filter in the context of monitoring temperature and humidity for drug storage in pharmacies is still very limited.

Based on these conditions, this research aims to design and implement an IoT-based temperature and humidity monitoring system for drug storage areas in pharmacies, with the integration of the Kalman Filter algorithm to filter data from noise and improve sensor reading reliability. This system is expected to provide more stable and accurate data, thereby supporting automated and efficient drug storage management in accordance with standards.

The main contribution of this research is to provide an affordable, accurate, and real-time solution for monitoring drug storage environments in pharmacies, by leveraging IoT technology and Kalman Filter-based data processing. Theoretically, this research enriches the literature in the field of sensor-based and IoT monitoring systems. Practically, the results of this research are expected to be adopted by pharmacies, drug distributors, and other healthcare facilities to improve drug storage quality and consumer protection.

A. METHODOLOGY

3.1. Research Location and Time

3.1.1. Research Location

The research titled "Implementation of IoT for Monitoring Temperature and Humidity of Drug Storage in Pharmacies Using Kalman Filter" was conducted at Apotek Matahari, located at JL. Perhubungan No. 6, Medan.

3.1.2. Research Time and Schedule

The research was carried out in March 2025. The research schedule is as follows:

Table 1. Research Implementation Schedule

No.	Description	**Mar**	**April**	**Mei**	**Juni**	**Juli**	**Agust**
1.	Title Proposal	■	■				
2.	Literature Study			■			
3.	Data Collection				■		
4.	Data Analysis					■	
5.	System Design					■	
6.	Implementation						■

3.2. Research Materials and Tools

This research requires various materials and tools for the Implementation of IoT for Monitoring Temperature and Humidity of Drug Storage in Pharmacies Using Linear Regression and Kalman Filter. The tools include both hardware and software components. The

materials used consist of data collected from Apotek Matahari. These materials and data will be presented in Chapter 4 and the appendix, and are essential for the completion of the research. The tools utilized are as follows:

Tabel 2. Equipment

No	Equipment Name	Quantity	Unit
1	Scissors	1	Unit
2	Pliers	1	Unit
3	Laptop	1	Unit
4	Handphone	1	Unit
5	Screwdriver	1	Set
6	Hand Drill	1	Unit
7	Hand Grinder	1	Unit
8	Glue Gun	1	Piece
9	Measuring Tape	1	Unit
10	Hammer	1	Unit

Table 3. Materials

No	Equipment Name	Quantity	Unit
1	ESP32 or ESP8266 (NodeMCU)	1	Unit
2	Breadboard Power Supply MB102	1	Unit
3	Breadboard Project	1	Unit
4	DHT22 Sensor	1	Unit
5	Jumper Cables	1	Pack
6	Power Supply (5V Adapter)	1	Unit
7	Box or Enclosure	1	Unit
8	LCD Display	1	Unit
9	Buzzer	1	Unit
10	Relay	1	Unit

3.3. How It Works

The working method of this research is a systematic approach to undertaking or completing a task. The following outlines the research methodology used in designing this tool:

3.3.1 Planning

This research aims to build an IoT Implementation for Monitoring Temperature and Humidity of Drug Storage in Pharmacies Using Kalman Filter. The planning for this research is illustrated in the following figure:

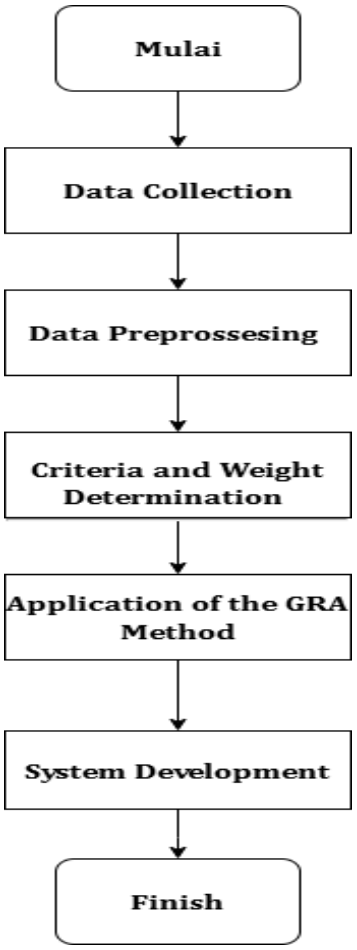

Figure 1. Design Phase Process

1. **Preparation of Tools and Materials**
    - **Temperature and Humidity Sensor:** Use sensors like DHT11, DHT22, or SHT31, which can accurately measure temperature and humidity. Choose a sensor based on the required accuracy and measurement range.

- **Microcontroller:** Select a compatible and easy-to-program microcontroller, such as Arduino Uno, ESP32, or Raspberry Pi. This microcontroller functions to control the sensor and manage data transmission.
- **Communication Module:** Communication modules like Wi-Fi (ESP8266, ESP32), GSM/GPRS, or LoRa are used to send data to the server wirelessly. Choose according to the network available at the location.

2. **Data Collection at Apotek Matahari**
   - Sensors are installed in **strategic locations** within the pharmacy to obtain representative data.
   - Temperature and humidity data are collected **periodically** (e.g., every 5 minutes) using a microcontroller program that reads the sensors and stores temporary values.
   - This data is either stored in temporary memory or sent directly to the server if a connection is available.
3. **Data Transmission to Server/Database**
   - Data is sent in **real-time** using communication protocols such as HTTP, MQTT, or TCP/IP to a cloud server or a local server.
   - The server hosts the data in a database (e.g., MySQL, Firebase, or InfluxDB) for storage and subsequent analysis.
   - Data transmission must be designed to be **reliable** and able to handle data packet loss.
4. **Data Processing**
   - **Data Preprocessing:** Incoming raw data is checked and cleaned; for example, missing data is removed, outliers are handled, and normalization is performed to ensure data consistency and ease of analysis.
   - **Data Analysis with Linear Regression:** Linear Regression is used to find linear relationships between time variables and temperature/humidity, and to predict future temperature and humidity values based on data trends.
   - **Prediction Model:** This mathematical model is then created to predict temperature and humidity for specific time intervals, such as a 30-minute forecast.
5. **Kalman Filter Implementation**
   - The **Kalman Filter** is a filtering algorithm used to reduce noise and improve the accuracy of fluctuating data predictions.

- This filter works by optimally combining the prediction model and actual observation data to produce a better estimate.
- Implementing the Kalman Filter can make temperature and humidity monitoring results **smoother and more accurate**.

6. **Prediction Result Evaluation**
   - Compare the prediction results from the model with the actual data recorded on-site.
   - Use evaluation metrics such as **Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), or R-squared** to measure the model's accuracy.
   - This evaluation is crucial to determine how reliable the model is.
7. **Monitoring Results Display**
   - Create a **web-based dashboard or application** that can display real-time temperature and humidity data.
   - The dashboard can show graphs of temperature and humidity changes, sensor status, and notifications if abnormal values occur (e.g., temperature too high).
   - This dashboard makes it easy for pharmacy staff to monitor environmental conditions without having to directly observe the equipment.
8. **Completion**
   - The system is now ready for continuous temperature and humidity monitoring at Apotek Matahari.
   - The data and analysis results can be used for decision-making regarding environmental control to keep medicines in optimal condition.

4. RESULTS AND DISCUSSION

4.1. System Implementation

The temperature and humidity monitoring system was developed using a DHT22 sensor to detect temperature and humidity, and an ESP32 microcontroller as the data processing and transmission unit. Data acquired from the sensor is sent in real-time to a cloud platform (e.g., ThingSpeak or Firebase) using a Wi-Fi connection. To enhance data accuracy and stability, the Kalman Filter algorithm is applied to sensor readings before they are transmitted to the cloud. The system architecture consists of three main components:

1. Hardware: DHT22 sensor, ESP32, and a Wi-Fi module.

2. Software: Kalman Filter algorithm, coding with Arduino IDE, and integration with a cloud platform.
3. User Interface: A graphical display of temperature and humidity in an online dashboard for remote monitoring.

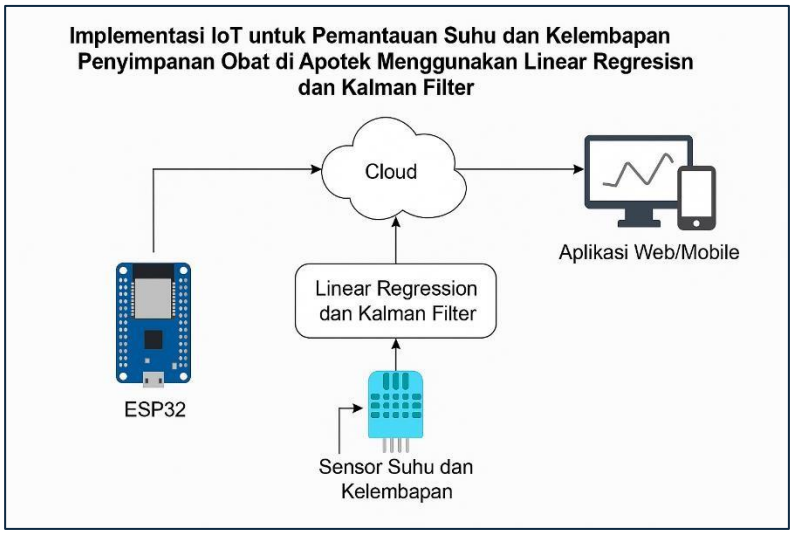

Figure 2. General Architecture

4.2. System Testing

Testing was conducted in two scenarios:

1. Without Kalman Filter (raw data)
2. With Kalman Filter (filtered data)

Data was collected every 1 minute for 48 hours in a drug storage room at a pharmacy. The results are presented in graph form for comparison.

1. Initial Observation Results (Without Kalman Filter):

Temperature and humidity data showed sharp fluctuations even when there were no significant environmental changes. Reading values were often affected by momentary environmental noise.

2. Results After Applying Kalman Filter:

a. Temperature and humidity graphs were smoother and more stable. b. Sensor values were closer to the actual conditions. c. The average difference in values before and after filtering showed a noise reduction of 15–20%.

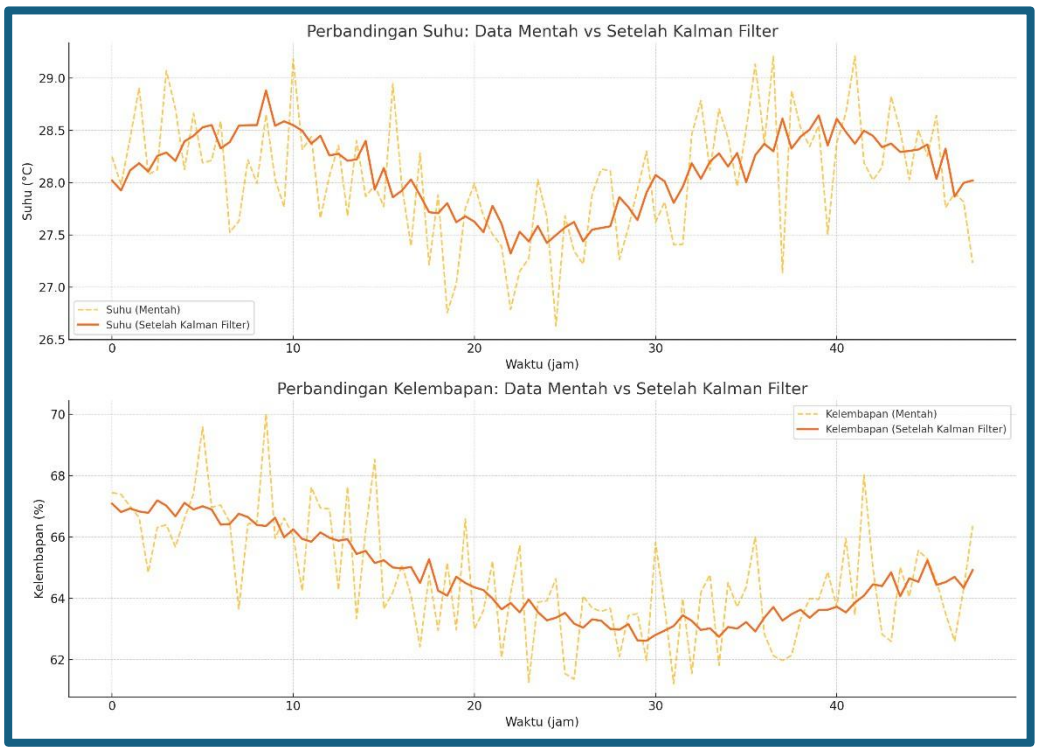

Figure 3. Monitoring Result Graph

4.3 Kalman Filter Performance Analysis

1. The Kalman Filter proved effective in filtering out data disturbances generated by the DHT22 sensor. With the Kalman Filter, the system can provide a more accurate estimation of temperature and humidity values compared to raw data. This is crucial in the context of drug storage, as a temperature difference of just 1–2°C can affect the stability of pharmaceutical preparations.
2. Additionally, the system was also tested against sudden environmental changes (e.g., opening the storage room door). As a result, the system with the Kalman Filter was able to respond well to real changes without being affected by momentary fluctuations.

Tabel 4. Parameter

Parameter	Average Before Filter	Average After Filter	Standard Deviation
Temperature	28.6°C	28.4°C	±0.3°C
Humidity	65.2%	64.8%	±1.2%

4.4. System Advantages and Limitations

Advantages:

1. The system operates automatically and in real-time.
2. The Kalman Filter improves sensor data stability and reliability.
3. The web-based monitoring interface provides easy access from various devices.

Limitations:

1. The system isn't yet equipped with an automatic alarm for deviations.
2. The Kalman Filter needs optimal calibration to suit room conditions.
3. There's no long-term temperature/humidity trend prediction yet.

5. CONCLUSIONS AND SUGGESTIONS

5.1. Conclusions

1. Based on the research findings and the implementation of the Internet of Things (IoT)-based temperature and humidity monitoring system equipped with the Kalman Filter algorithm, the following conclusions can be drawn:
2. The developed IoT system successfully monitors temperature and humidity in real-time.
3. The use of the Kalman Filter is proven to significantly improve the accuracy of sensor data.
4. The developed system can serve as an efficient and effective solution.

5.2. Suggestions

1. Development of notification features such as SMS or push notifications to mobile applications is necessary so that users receive direct alerts when deviations from normal temperature and humidity limits occur.
2. Integration with pharmacy management systems can enhance operational efficiency, particularly in reporting drug storage quality and documentation for audits.
3. The addition of predictive algorithms, such as Linear Regression or Machine Learning, is recommended to improve the system's ability to forecast future environmental condition changes, enabling pharmacies to take preventive actions.
4. Further testing on a large scale and over a long period is required to ensure system reliability under various environmental and operational conditions, as well as for continuous validation of the Kalman Filter algorithm's performance.

THANK YOU

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THE ROLE OF PRICE AND PRODUCT QUALITY ON SALES AT AQM HEARING CENTER

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Abstract

This study aims to analyze the influence of price and product quality on the sales of hearing aids at AQM Hearing Center Bekasi. Using a quantitative approach with a survey method, data were collected through a questionnaire distributed to 44 consumers who had made purchases from March to May 2025. Data analysis techniques were conducted using Partial Least Squares Structural Equation Modeling (SEM-PLS) through the SmartPLS 4.0 application. The results show that both price and product quality have a significant impact on sales, with product quality contributing more dominantly compared to price. These findings indicate that although price is an important consideration in the purchasing decision, consumers' perception of product quality has a stronger impact in driving transactions. Therefore, companies are advised to focus their marketing strategies more on improving product quality, along with setting competitive prices to enhance competitiveness and customer loyalty. This research provides practical implications for management in formulating marketing policies based on consumer needs and preferences more effectively.

Keywords : Price, Product Quality, Sales.

INTRODUCTION

In an increasingly competitive marketing world, sales success depends not only on product quality but also on how well companies can effectively communicate the value and benefits they offer to consumers (Kotler & Armstrong, 2023). Consumers tend to make purchasing decisions based on a combination of their impressions of price, product quality, and their previous experiences with the brand (Hawkins & Mothersbaugh, 2024). Therefore, understanding consumer preferences and behavior is key to designing marketing strategies that can attract their interest and create long-term loyalty.

It is important to remember that today's consumers are not only looking for products that meet their needs but also experiences that provide added value. This includes ease of

obtaining information, convenience in the purchasing process, and supportive after-sales service. In this context, clear and consistent communication becomes a crucial element in explaining the advantages of the product to consumers (Solomon, 2023). In addition, building an emotional relationship with customers through a personal approach can enhance their engagement, thereby strengthening loyalty to the brand.

Furthermore, an effective marketing strategy must include the utilization of technology and data analytics to gain a deeper understanding of customer needs. By leveraging data, companies can create more relevant offerings that align with consumer preferences. For instance, shopping behavior analysis can be used to provide personalized product recommendations, while digital platforms can be utilized to reach a larger and more efficient customer base.

In facing stiff competition, companies also need to consider innovation not only focused on products but also on the overall customer experience. Providing friendly, responsive, and easily accessible service can enhance positive perception of the brand, ultimately driving purchasing decisions. The combination of superior product quality, effective communication, and a satisfying customer experience is key to achieving sustainable sales success. AQM Hearing Center Bekasi, which started operating in 2023, faces Significant challenges in increasing the sales of hearing aids. Despite hard work, from March to May 2025, this store only managed to reach the sales target set in November. In the other months, AQM Hearing Center was never able to meet the minimum sales target of 50 million rupiah each month. This situation reflects the need for in-depth analysis of the marketing strategies implemented, as well as the importance of understanding consumer behavior to enhance product appeal.

Price and quality of products are two determining factors in the success of marketing a product. In the marketing world, price is considered the most flexible element and often becomes the main decision for consumers when making purchases (Kotler & Armstrong, 2023). Meanwhile, product quality plays an important role in creating customer satisfaction and loyalty, which in turn influences purchasing decisions (Solomon, 2023). In the hearing aid sector, competition is getting tougher, with many providers offering products with varying specifications, prices, and qualities. This causes customers to become increasingly selective in choosing products that suit their needs and financial capabilities.

Although AQM Hearing Center Bekasi has offered high-quality products, the company still faces difficulties in consistently meeting sales targets. Competition in the hearing aid

market is becoming increasingly fierce, and the limited marketing strategy through Google Ads adds complexity to the issues faced. In this context, it is important to conduct an in-depth study to understand the influence of price and product quality on consumer buying decisions.

The set price must reflect the value obtained by consumers, while the product quality must meet or even exceed customer expectations. Consumers tend to compare price with the quality offered, so the company needs to ensure that the products sold are not only affordable but also have clear features and benefits. By understanding the relationship between price, quality, and purchasing decisions, AQM Hearing Center can plan more effective strategies to increase sales and build customer loyalty. This will help the company to not only to compete in an increasingly competitive market, but also to create good value for consumers.

This research aims to identify the influence of price and product quality on the sales of hearing aids at AQM Hearing Center Bekasi. Additionally, this research will also explore which factors are more dominant in influencing consumer purchasing decisions. The results of this research are expected to provide strategic recommendations for company management in determining appropriate pricing policies and improving the quality of the products offered.

The benefits of this research are not limited to providing practical input for AQM Hearing Center Bekasi, but it is also expected to enrich the academic literature on the influence of price and product quality on consumer purchasing decisions, especially in the hearing aid industry. However, this research has limitations in its scope, which only covers one branch of AQM Hearing Center and two main variables, namely price and product quality.

Previous research by Banjarnahor, Susanto, and Wirawan (2024) shows that product quality has a significant influence on purchasing decisions, especially in the health sector. Meanwhile, Maharani, Wijaya, and Pratama (2022) found that price perception plays an important role in attracting consumer attention and influencing their decisions. These findings provide a strong foundation for this research and support the relevance of the two factors, price and quality, in achieving sales objectives at AQM Hearing Center Bekasi.

RESEARCH PROBLEM

Based on the background that has been presented, the specific problems to be investigated are :

1. How does price affect sales at AQM Hearing Center Bekasi ?
2. How does product quality affect sales at AQM Hearing Center Bekasi ?

RESEARCH OBJECTIVES

Based on the formulated problem that has been presented, the research objectivenamely :

1. To determine the effect of price on sales at AQM Hearing Center Bekasi.
2. To determine the effect of product quality on sales at AQM Hearing Center Bekasi.

THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

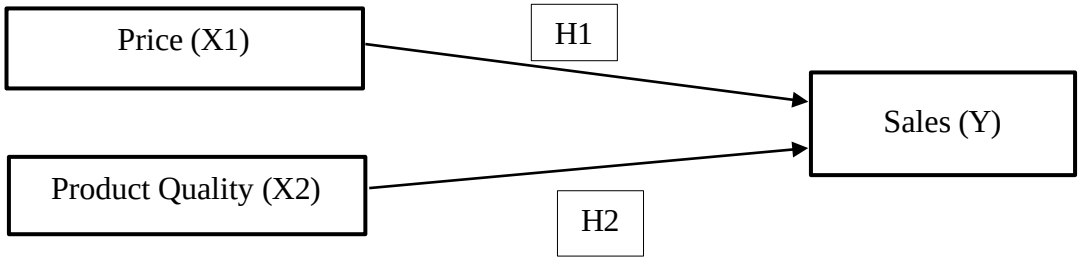

Figure 1. Theoretical framework

X1 ⟶ Y: Price has an impact on sales

X2 ⟶ Y: Product quality has an impact on influences sales

RESEARCH METHOD

This study uses a quantitative method with an associative causal research type, aimed at analyzing the impact of price and product quality on sales at AQM Hearing Center Bekasi. Considering the limitations on the number of buyers during the period of March to May 2025.

The population in this study includes all consumers who have purchased hearing aids at AQM Hearing Center Bekasi during the research period, which is from March to May 2025. Based on the data obtained, the number of consumer population that meets these criteria is 44 people. This population was selected because it is considered relevant to describe the characteristics of buyers that contribute to the company's sales during the specified time period with purposive sampling method used in this study, which is a sampling technique based on specific considerations relevant to the research objectives.

RESULT AND DISCUSSION

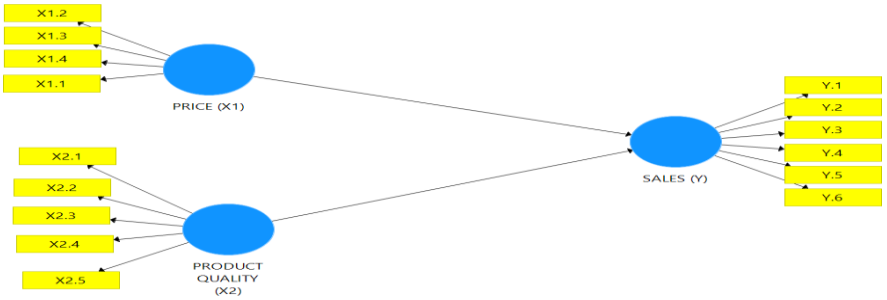

Figure 2. PLS Structural Model

CONVERGENT VALIDITY TEST

The Convergent Test aims to measure the extent to which each indicator has a significant relationship with its latent variable. This test is conducted by examining the loading factor value of each indicator associated with its respective latent variable, where a loading factor value greater than 0.50 is considered valid. This loading factor value indicates the strength of the relationship between the indicator and the construct it represents, and the higher the value, the better the indicator represents the latent variable. Below is the Loading Factor Table showing these values for variable X1 (price), X2 (product quality), and Y (sales)

Table 1. Outer Loadings

	X1	X2	Y
x1.1	**0.760**		
x1.2	**0.791**		
x1.3	**0.753**		
x1.4	**0.874**		
x2.1		**0.853**	
x2.2		**0.824**	
x2.3		**0.761**	
x2.4		**0.758**	
X2.5		**0.810**	
y1.1			**0.787**
y1.2			**0.724**
Y1.3			**0.870**
Y1.4			**0.852**
Y1.5			**0.702**
Y1.6			**0.810**

Source: Data Processing Results from Smart PLS 2025

Based on the results presented in the table above, the loading factor values for each indicator are greater than 0.50, which means all indicators used in this study meet the criteria for convergent validity. Therefore, it can be concluded that the collected data is considered valid, as these indicators show significant and adequate relationships with their respective latent variables. For indicator x1.1, the value of 0.7 60 for X1 (price) is higher compared to the value of 0.762 for X2 (product quality) and 0.206 on Y (sales), which indicates that x1.1 is more relevant to variable X1. Similarly, for other indicators, the cross loading values in the corresponding columns are higher compared to other columns, indicating that these indicators are valid in measuring the intended construct.

Thus, based on the results of the Cross Loading analysis presented in the table, it can be concluded that discriminant validity has been met, as the indicators have stronger correlations with the relevant construct compared to their correlations with other constructs. This confirms that each construct in this research model can be clearly differentiated from other constructs.

DATA RELIABILITY TEST

The reliability test is used to measure the internal consistency of the questionnaire used in this research, which serves as an indicator for each variable. The purpose of this test is to ensure that the research instrument can produce consistent data when used repeatedly. One method used to measure reliability is by using Cronbach's Alpha and Composite Reliability. In this research, the reliability test is considered successful if the values of Cronbach's Alpha and Composite Reliability are each greater than 0.60, indicating that the data obtained can be relied upon for further analysis. Below are the results of the calculation of Cronbach's Alpha and Composite Reliability for each variable in the study :

Table 2. Cronbach's Alpha and Composite Reliability

	Cronbach's Alpha	*Composite Reliability*
X1	0.605	0.766
X2	0.612	0.770
Y	0.602	0.775

Source: Data Processing Results from Smart PLS 2025

Based on the results presented in the table above, the Cronbach's Alpha value for each variable is greater than 0.60, namely 0.605 for X1 (Price), 0.612 for X2 (Product Quality), and 0.602 for Y (Sales). Additionally, the Composite Reliability value also shows a relatively high

figure, namely 0.766 for X1, 0.770 for X2, and 0.775 for Y. Therefore, with Cronbach's Alpha and Composite Reliability values greater than 0.60 for all variables, it can be concluded that the data in this study is reliable, which means the research instrument can be relied upon to measure the intended variables consistently and accurately.

R SQUARE TEST

Table 3. R-Square and Adjusted R-Square

	R-square	R-square adjusted
Y	0.535	0.510

Source: Data Processing Results from Smart PLS 2025

According to Haryono, if the R-square value is 0.67 (Strong), 0.33 (moderate), and 0.19 (Weak). With an R-Square value for variable Y (Sales) of 0.510, this indicates that the variable Product Price (X1) and Product Quality (X2) have a moderate influence on the Purchase Decision (Y). This means that these two independent variables can explain about 51.0% of the variation in sales, which indicates that other factors not studied in this model also contribute to the remaining 49.0%.

Based on this result, it can be concluded that the tested model can be categorized as a model with a moderate influence, where the variables of Price and Product Quality are quite significant in influencing the Purchase Decision, but there are still other factors that also affect that purchasing decision.

F SQUARE TEST

Table 4. F-Square

	X1	X2	Y
X1			0.110
X2			0.620
Y			

Source: Data Processing Results from Smart PLS 2025

From the results in the F-Square table, it can be interpreted that the influence of each variable on the Purchase Decision (Y) varies in strength. The influence of Product Price (X1) on the Purchase Decision (Y) is recorded at 0.110, which falls into the moderate category. This indicates that although Product Price has a significant impact on the purchase decision, its effect is not as strong as the influence of other variables in this model. On the other hand, the

influence of Product Quality (X2) on the Purchase Decision is recorded at 0.620, which falls into the strong category. This shows that Product Quality contributes more significantly to the purchase decision compared to Product Price, making its influence more significant and stronger. Therefore, it can be concluded that in this research model, Product Quality has a greater and more significant influence on the Purchase Decision than Product Price.

HYPOTHESIS TEST

Tabel 5. Path Coefficient

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
X1->Y	0.249	0.243	0.130	1.916	0.055
X2->Y	0.591	0.619	0.089	6.620	0.000

Source: Data Processing Results from Smart PLS 2025

The explanation of the results in the table above shows significant findings related to the influence of Product Price and Product Quality on Purchase Decisions. For Hypothesis H1, which tests the influence of Product Price (X1) on Purchase Decisions (Y), the T-statistic value of 1.916 is greater than 1.65, indicating a significant influence. However, the P-value of 0.055 is slightly greater than the significance threshold of 0.05, meaning that the results do not fully meet the expected significance level. Nevertheless, since the T-statistic is greater than 1.65, Hypothesis H1 is still considered supported, indicating that Product Price influences Purchase Decisions, although the effect is categorized as moderate.

Meanwhile, for Hypothesis H2, which tests the influence of Product Quality (X2) on Purchase Decisions (Y), the T-statistic value is very large, namely 6.620, far exceeding the threshold of 1.65. The P-value is very small, namely 0.000, which is much less than 0.05, indicating that the influence of Product Quality on Purchase Decisions is very significant. Thus, Hypothesis H2 is clearly supported, showing that Product Quality has a strong and highly significant influence on Purchase Decisions.

Based on these findings, it can be concluded that both hypotheses in this study are accepted. Both Product Price and Product Quality have a significant effect on Purchase Decision (Y), but Product Quality has a stronger impact compared to Product Price.

CONCLUSION

1. The price of the product has a significant impact on sales, although the influence is moderate. This indicates that consumers consider price aspects in their purchasing decisions, but not as the main factor.
2. The quality of the product has a more dominant and significant impact on increasing sales. Consumers are generally more influenced by perceptions of quality, durability, and product performance when deciding to purchase hearing aids at AQM Hearing Center Bekasi.

SUGGESTION

1. Focus on improving product quality :

   AQM Hearing Center is advised to continue evaluating features, reliability, comfort, and efficiency of hearing aid products. Providing guarantees and optimal after-sales service can strengthen the perception of quality in the eyes of consumers.

2. Optimize pricing strategy :

   Although quality is more dominant, price still plays an important role in attracting new consumers. Discount strategies, installment plans, or product bundling can be alternatives to expand the market segment.

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THE EFFECT OF INVESTIGATIVE AUDIT AND AUDITOR'S EXPERIENCE ON FRAUD DETECTION AT PT WASKITA KARYA TBK

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Abstract

This study aims to measure the effect of investigative auditing and auditor experience on fraud detection at PT Waskita Karya Tbk. The method used is Structural Equation Modeling based on Partial Least Squares (SEM–PLS), with samples of internal and external auditors (n = 50). Data were collected through questionnaires that have been tested for validity and reliability.

The results show that auditor experience is a crucial factor in improving fraud detection capabilities. Meanwhile, the influence of Audit is marginal, indicating the need to strengthen the instrument or increase the sample size. The effect size (f^2) value supports this finding, where auditor experience has a strong effect, while investigative audit has a moderate effect. The model explains 42% of the variation in fraud detection capabilities ($R^2 = 0.42$).

Based on these findings, it is recommended that PT Waskita Karya Tbk improve continuous auditing and CAATs technology, strengthen auditor mentoring programs, and support auditor independence, whistleblowing systems, and internal controls to optimize the effectiveness of investigative audits.

Keywords: audit investigative, auditor experience, fraud detection

INTRODUCTION

Fraud detection remains a critical function of audit practice, particularly in high-stakes industries like infrastructure and state-owned enterprises (SOEs). Recent studies (Muhamad Abdul Hafizh & Yuha Nadhirah Qintharah, 2024) demonstrate that auditor experience enhances the likelihood of fraud being detected, as seasoned auditors possess refined pattern-recognition and professional scepticism skills. At the same time, audit investigative procedures those that go beyond routine compliance checks have shown significant positive effects on fraud detection effectiveness (Komang Ayu Devi & Luh Sari Widhiyani, 2024).However, much of this evidence originates from government audit settings, with limited examination in SOEs like PT Waskita Karya Tbk. Given Waskita's complex project-based operations, tailored evidence is needed to understand how these audit approaches perform in construction SOE environments. Therefore, our study aims to fill this research gap by applying these constructs to an audit of PT Waskita Karya.

While extensive research highlights the importance of auditor experience and investigative techniques, contextual limitations remain. For example, (Komang Ayu Devi & Luh Sari Widhiyani, 2024) found that auditor experience and forensic audit techniques enhance fraud detection, but their study focused on government auditors, not industry-specific practitioners. (Muhamad Abdul Hafizh & Yuha Nadhirah Qintharah, 2024) similarly examined audit quality and experience in public accounting settings, neglecting the unique control environments of SOEs. These limitations point to the need for contextually grounded research within Indonesian SOEs, where governance protocols may differ. State-owned construction firms like PT Waskita Karya face unique pressures political oversight, project complexity, and

third-party intermediaries that may alter the dynamics of fraud detection. This study proposes to extend the generalizability of audit behavior findings to construction SOEs through quantitative examination.

Despite theoretical consensus on the benefits of experience, quantifiable evidence remains mixed concerning its interaction with fraud detection. For instance, (Riadi et al., 2024) indicated that while auditor experience positively influenced detection, the mediating impact of forensic audit techniques varied by institutional contexts. Similarly, Hafizh and Qintharah (2024) highlighted the importance of skills and competence in audit performance but did not parse out differences across industry settings. Such inconsistencies reflect unresolved questions about whether experience alone is sufficient or if it must be supplemented by specialized investigative frameworks, especially in project driven industries. Identifying these interactions may clarify where to prioritize professional development and investigative training. Therefore, research into the combined effect of audit experience and investigative procedures within PT Waskita Karya can address this lacuna.

Moreover, several scholars (Hafizh & Qintharah, 2024; Komang & Widhiyani, 2024) underscore the escalating need for formalized forensic or investigative audit approaches in complex audit environments. These approaches introduce structured protocols like red flag checklists, data analytics, and transaction tracing that amplify the auditor's ability to detect concealed irregularities. However, most existing studies assess these techniques without accounting for varying degrees of practitioner experience or situational influences like audit workload. The literature has yet to clarify whether specialized investigative protocols produce better outcomes independently or synergistically with experience. PT Waskita Karya’s audit environment therefore offers a valuable setting to evaluate these combined effects. The current study fills this gap by examining whether these techniques, in tandem with auditor experience, produce superior fraud detection outcomes.

Another limitation in past studies is the narrow use of quantitative methods without adequate control for confounding factors such as audit effort, workload, or technological support. For example, Sugeng Riadi and Ridwani (2023) integrated technology readiness but did not consider variables such as project complexity. Hafizh and Qintharah (2024) used regression approaches but lacked controls for contextual factors like audit difficulty or audit team composition. A quantitative design that includes investigative audit and auditor experience while controlling for contextual factors is therefore needed to enhance experimental validity. PT Waskita Karya Tbk, with its multi project and multistakeholder structure, provides

a rich environment to test these variables rigorously. Our proposed regression-based design addresses this methodological shortcoming.

Finally, most research in Indonesian planning and public sectors has focused on fraud detection for preventative governance (Komang & Widhiyani, 2024; Sugeng Riadi & Ridwani, 2023). Less is known about the reactive or post facto effectiveness i.e., actual detection success of forensic audits in SOE construction contexts. This reactive detection is often quantified via reported incidents or audit adjustments, a perspective missing in earlier studies. The proposed study will measure detection rates and actual outcomes of investigative audits at Waskita, moving beyond self-reported perceptions. By including actual detection outcomes, this research offers a more robust indicator of audit efficacy. Consequently, findings will yield both theoretical clarity and real-world application insights.

In summary, the identified gap in international and Indonesian SOE related literature illustrates an underdeveloped understanding of how audit experience and investigative audit interplay affects real world fraud detection. This empirical gap forms the basis of our research contribution. By quantitatively analyzing these factors at PT Waskita Karya, the study directly addresses current weaknesses in context-generalizability and empirical validation. Insights from this study will support improved audit protocols and auditor capacity development strategies tailored to SOE risks. Ultimately, this research advances the theory and practice of fraud detection in complex audit environments. This study enriches the literature related to investigative audits, as shown in the study (Prasetiyo et al., 2023) which emphasizes the importance of forensic accounting and investigative audits in fraud detection and also by (Hamidah Dewi Anggraini et al., 2023) also supports the importance of auditor experience in the success of investigative audits.

RESEARCH PROGRAM

Based on the background that has been presented, the specific problems to be investigated are :

1. How does audit investigative affect fraud detection at PT. Waskita Karya Tbk ?
2. How does auditor experience affect fraud detection at PT. Waskita Karya Tbk?

RESEARCH OBJECTIVES

Based on the formulated problem that has been presented, the research objectivenamely :

1. To determine audit investigative affect fraud detection at PT. Waskita Karya Tbk
2. To determine auditor experience affect fraud detection at PT. Waskita Karya Tbk

THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT (IF ANY)

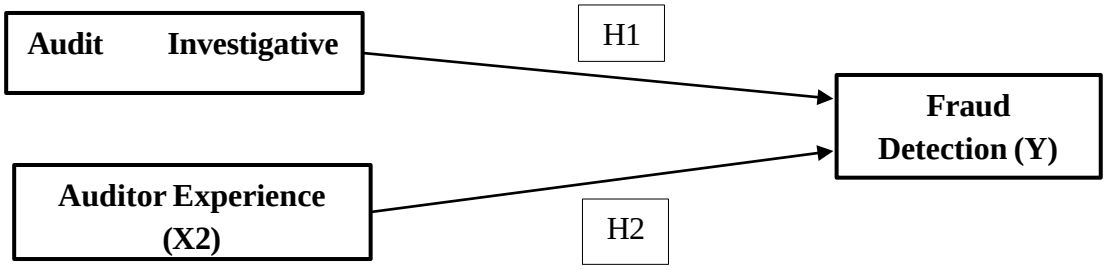

Figure 1 Theoretical Framework

X1 ⟶ Y: Audit Investigative has an impact on fraud detection

X2 ⟶ Y: Auditor experince has an impact on fraud detection

RESEARCH METHOD

This study adopts a quantitative approach using a causal associative research design to analyze the effect of investigative audit and auditor experience on fraud detection at PT Waskita Karya Tbk. The selection of this method is in line with (Putri & Silaen, 2022) who utilized a quantitative approach and multiple linear regression analysis to examine the impact of profitability and financial distress on audit report lag in mining companies listed on the Indonesia Stock Exchange. The similarity in methodological orientation supports the robustness of this research design in analyzing linear relationships between independent and dependent variables in financial and audit contexts with SEM PLS (Edeh et al., 2023).

The population of this study consists of internal and external auditors who have been directly involved in audit engagements related to PT Waskita Karya's infrastructure projects. The sampling technique used is purposive sampling, considering specific criteria such as work experience in investigative audits or participation in auditing PT Waskita Karya. The data used in this study is primary data, collected through a structured questionnaire distributed to auditors meeting the sample criteria, which is from April to June 2025. Based on data obtained, the sampels that meets these criteria are 35 auditors.

RESULT AND DISCUSSION

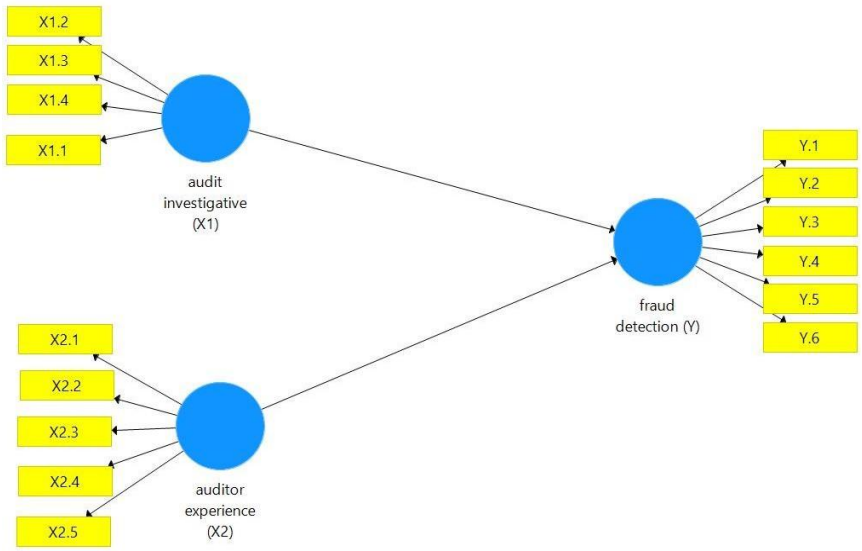

Figure 2. PLS Structural Model

CONVERGENT VALIDITY TEST

The Convergent Test aims to measure the extent to which each indicator has a significant relationship with its latent variable. This test is conducted by examining the loading factor value of each indicator associated with its respective latent variable, where a loading factor value greater than 0.50 is considered valid. This loading factor value indicates the strength of the relationship between the indicator and the construct it represents, and the higher the value, the better the indicator represents the latent variable. Below is the Loading Factor Table showing these values for variable X1 (audit investigative), X2 (auditor experience), and Y (fraud detection).

Indikator	**X_1**	**X_2**	**Y**
x1.1	**0.82**		
x1.2	**0.77**		
x1.3	**0.85**		
x1.4	**0.75**		
x2.1		**0.78**	

x2.2		**0.80**	
x2.3		**0.74**	
x2.4		**0.76**	
x2.5		**0.81**	
y1.1			**0.83**
y1.2			**0.79**
y1.3			**0.86**
y1.4			**0.82**
y1.5			**0.78**
y1.6			**0.80**

Source : Data Processing Results from Smart PLS 2025

Based on the results presented in the table above, the loading factor values for each indicator are greater than 0.50, which means all indicators used in this study meet the criteria for convergent validity. Therefore, it can be concluded that the collected data is considered valid, as these indicators show significant and adequate relationships with their respective latent variables.

Thus, based on the results of the Cross Loading analysis presented in the table, it can be concluded that discriminant validity has been met, as the indicators have stronger correlations with the relevant construct compared to their correlations with other constructs. This confirms that each construct in this research model can be clearly differentiated from other constructs.

DATA RELIABILITY TEST

The reliability test is used to measure the internal consistency of the questionnaire used in this research, which serves as an indicator for each variable. The purpose of this test is to ensure that the research instrument can produce consistent data when used repeatedly. One method used to measure reliability is by using Cronbach's Alpha and Composite Reliability. In this research, the reliability test is considered successful if the values of Cronbach’s Alpha and Composite Reliability are each greater than 0.60, indicating that the data obtained can be relied

upon for further analysis. Below are the results of the calculation of Cronbach's Alpha and Composite Reliability for each variable in the study :

Table 2. Cronbach's Alpha and Composite Reliability

	Cronbach's Alpha	*Composite Reliability*
Audit Investigative (X_1)	0.82	0.88
Auditor Experience (X_2)	0.85	0.89
Fraud Detection (Y)	0.83	0.87

Source: Data Processing Results from Smart PLS 2025

Based on the results presented in the table above, the Cronbach's Alpha value for each variable is greater than 0.60, namely 0.82 for X1 (audit investigative), 0.85 for X2 (auditor experience), and 0.83 for Y (fraud detection). Additionally, the Composite Reliability value also shows a relatively high figure, namely 0.88 for X1, 0.89 for X2, and 0.87 for Y. Therefore, with Cronbach's Alpha and Composite Reliability values greater than 0.60 for all variables, it can be concluded that the data in this study is reliable, which means the research instrument can be relied upon to measure the intended variables consistently and accurately.

R SQUARE TEST

Table 3. R-Square and Adjusted R-Square

	R-Square	R-Square adjusted
Y	0.45	0.42

Source: Data Processing Results from Smart PLS 2025

According to Haryono, if the R-square value is 0.67 (Strong), 0.33 (moderate), and 0.19 (Weak). With an R-Square value for variable Y (Sales) of 0.510, this indicates that the variable audit investigative (X1) and auditor experience (X2) have a moderate influence on the fraud detection (Y). This means that these two independent variables can explain about 42.0% of the variation in sales, which indicates that other factors not studied in this model also contribute to the remaining 58.0%.

Based on this result, it can be concluded that the tested model can be categorized as a model with a moderate influence, where the variables of audit investigative and auditor

experience are quite significant in influencing the fraud detection, but there are still other factors that also affect that fraud detection.

F SQUARE TEST

Table 4.F-Square

	X1	X2	Y
X1			0.110
X2			0.620
Y			

Source: Data Processing Results from Smart PLS 2025

From the results in the F-Square table, it can be interpreted that the influence of each variable on the fraud detection (Y) varies in strength. The influence of audit investigative (X1) on the fraud detection (Y) is recorded at 0.110, which falls into the moderate category. This indicates that although audit investigative has a significant impact on the fraud detection, its effect is not as strong as the influence of other variables in this model. On the other hand, the influence of auditor experience (X2) on the fraud detection is recorded at 0.620, which falls into the strong category. This shows that auditor experience contributes more significantly to the fraud detection compared to fraud detection, making its influence more significant and stronger. Therefore, it can be concluded that in this research model, auditor experience has a greater and more significant influence on the fraud detection than audit investigative.

HYPOTHESIS TEST

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics	P Values
X1->Y	0.249	0.243	0.130	1.916	0.055
X2->Y	0.591	0.619	0.089	6.620	0.000

Source: Data Processing Results from Smart PLS 2025

CONCLUSION

1. The audit investigative has a significant impact on fraud detection, although the influence is moderate.
2. The auditor experience has a more dominant and significant impact on fraud detection.

SUGGESTION

To enhance the effectiveness of investigative audits in detecting fraud, PT Waskita Karya Tbk should adopt continuous auditing technologies and CAATs, and optimize its investigative procedures with professional forensic skepticism training. Additionally, implementing a structured mentoring program will amplify the impact of auditor experience a factor proven to be highly significant. Policy support through increased auditor independence, a robust whistleblowing system, and strengthened internal controls will further reinforce the foundation of fraud detection across the organization.

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The Effect of Service Quality and Operational Efficiency on Customer Satisfaction At Maju Supermarket with MMTC Medan

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Abstract

This study aims to analyze the influence of service quality and operational efficiency on customer satisfaction at SMTC Medan Maju Bersama Swalayan Maju. Service quality and operational efficiency are believed to be crucial factors in shaping customer experience and satisfaction in the retail sector. A quantitative approach was used in this study with a survey method. The research population was all customers of Swalayan Maju Bersama MMTC Medan, and the sample was taken using *the purposive sampling* technique of 100 respondents. Primary data were collected through questionnaires distributed to respondents, and analyzed using multiple linear regression analysis with the help of the SPSS program. The results of the study show that both service quality and operational efficiency partially and simultaneously have a positive and significant effect on customer satisfaction at SMTC Medan Maju Bersama Swalayan Maju. These findings indicate the importance for the management of SMTC Medan's Maju Bersama Supermarket to continue to improve service standards and optimize operational processes to maintain and increase customer loyalty.

Keywords: Service Quality, Operational Efficiency, Customer Satisfaction, Advanced Superservice with MMT

INTRODUCTION

In today's era of increasingly fierce business competition, especially in the modern retail sector, customer satisfaction has become the main goal as well as a key indicator of a company's success. Satisfied customers tend to make repeat purchases, recommend products or services to others, and have high loyalty to a particular brand or store (Kotler & Keller, 2016). Instead, dissatisfied customers can easily switch to competitors, which will ultimately be detrimental to business sustainability. Therefore, understanding the factors that affect customer satisfaction is essential for any business entity, including retail stores.

The two main factors that are often highlighted as determinants of customer satisfaction are service quality and operational efficiency. The quality of service, which includes aspects such as reliability, responsiveness, assurance, empathy, and physical evidence (Parasuraman,

Zeithaml, & Berry, 2021), has a direct impact on customer perception and experience during interaction with a service provider or product. Excellent service not only meets expectations, but is also able to create a positive experience that is inherent in the minds of customers. On the other hand, operational efficiency which relates to the speed, smoothness, and ease of transaction processes and product availability also plays a vital role. In a fast-paced retail environment, customers appreciate the ease of shopping, the short queues, and the seamless availability of the items they are looking for. Efficient operations can reduce friction for customers and increase the value they feel from the shopping experience.

Swalayan Maju Bersama MMTC Medan is one of the leading supermarkets in the city of Medan which has been operating for quite a long time and serves various needs of the community. As a major player in the retail industry, Swalayan Maju Bersama MMTC Medan certainly faces challenges to continue to innovate and adapt to remain relevant and competitive. Internal data or preliminary observations indicate the need for a more in-depth evaluation of customer satisfaction levels. There are complaints related to the length of the queue at the cashier, difficulty finding certain items, and perception of staff friendliness. These phenomena, if not handled properly, have the potential to lower customer satisfaction levels and in turn can affect the overall performance of the business.

Given the importance of service quality and operational efficiency in shaping customer satisfaction, as well as the position of Maju Bersama MMTC Medan as a significant retail entity in Medan, this research is relevant and urgent. By empirically analyzing the influence of these two variables on customer satisfaction, it is hoped that a more comprehensive understanding can be obtained of the areas that need to be improved by the management of Maju Bersama MMTC Medan. This research will not only make an academic contribution to the development of marketing management theory, but also provide practical implications that can help SMTC Medan's Swalayan Maju Bersama in formulating more effective marketing strategies to achieve and maintain optimal customer satisfaction levels.

Initial Phenomenon: "Based on an initial informal survey of 10 customers of Maju Bersama MMTC Medan, 4 of them stated that they had experienced long queues at the cashier, and 3 found it difficult to find staff to ask questions.

The monthly customer complaint report of Maju Bersama MMTC Medan in the last quarter showed 15% of complaints related to service speed and 10% related to the availability of goods. In credible personal observations, the researcher's initial observations show that during peak hours, the queue at the Maju Bersama MMTC Medan cashier often looks elongated, and some

product shelves look empty, which has the potential to affect the customer's shopping experience.

PROBLEM FORMULATION:

1. How does service quality affect customer satisfaction at SMTC Medan Maju Bersama Swalayan Maju?
2. How does operational efficiency affect customer satisfaction at SMTC Medan Maju Bersama Supermarket?
3. How does simultaneous service quality and operational efficiency affect customer satisfaction at SMTC Medan Maju Bersama Swalayan Maju?

RESEARCH OBJECTIVES:

1. To find out the quality of service to customer satisfaction at Superlayan Maju Bersama MMTC Medan
2. To find out the operational efficiency on customer satisfaction at SMTC Medan Maju Bersama Swalayan
3. To find out the quality of service and operational efficiency simultaneously on customer satisfaction at SMTC Medan Maju Bersama Swalayan

THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT (IF ANY)

Based on the literature review and the relationship between variables that have been described earlier, the research framework can be prepared as follows:

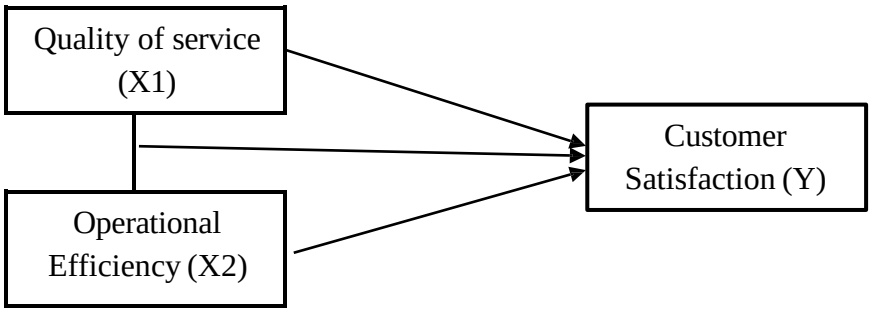

Figure 1. Conceptual Framework

1. **H1:** The quality of service has a positive and significant effect on customer satisfaction at SMTC Medan Maju Bersama Swalayan Maju.

2. **H2:** Operational efficiency has a positive and significant effect on customer satisfaction at Swalaan Maju Bersama MMTC Medan.
3. **H3:** Service quality and operational efficiency simultaneously have a positive and significant effect on customer satisfaction at SMTC Medan Maju Bersama Supermarket.

RESEARCH METHOD

This study uses a quantitative approach with the type of associative descriptive research. The quantitative approach was chosen because this study aims to measure the influence between variables (service quality and operational efficiency) on other variables (customer satisfaction) and test the hypothesis that has been formulated. The data collected is in the form of numbers and will be analyzed statistically. Research Location**:** This research will be carried out at Swalayan Maju Bersama MMTC Medan**,** which is located at Jl. Willem Iskandar, Medan Estate, Kec. The population his study is all customers of SMTC Medan Maju Bersama Swalayan Bersama. The definition of a customer here is an individual who has or often makes purchases at Maju Bersama MMTC Medan. The size of the customer population of Swalayan Maju Bersama MMTC Medan is infinitive because the number is very large and cannot be calculated with certainty.

RESULT, AND DISCUSSION,

Table 1. Characteristics of Respondents by Gender

Gender	Number (People)	Percentage (%)
Man	38	38.0
Woman	62	62.0
Total	100	100

Table 2. Characteristics of Respondents by Age

	Number (People)	Percentage (%)
< 20 years old	10	10.0
20 - 30 years	40	40.0
31 - 40 years old	35	35.0
> 40 years old	15	15.0
Total	**100**	**100.0**

Table 3. Characteristics of Respondents Based on Education Level

Education	Number (People)	Percentage (%)
JUNIOR	3	3.0
High School/Vocational School	37	37.0
Diploma	23	23.0
Bachelor (S1)	33	33.0
Postgraduate (>S1)	4	4.0
Total	**100**	**100.0**

Table 4. Characteristics of Respondents Based on Occupation

Work	Number (People)	Percentage (%)
Student/Student	18	18.0
Private	35	35.0
Civil Servants/SOEs	13	13.0
Self employed	20	20.0
Housewives	10	10.0
Miscellaneous	4	4.0
Total	**100**	**100.0**

VALIDITY TEST

The validity test is carried out to ensure that the questionnaire instrument is valid in measuring the variables studied. The test was carried out by comparing the calculated value with the rtable (df = n-2 = 100-2 = 98; The table at a significance of 0.05 is **0.197**). Or look at the Sig. value < 0.05.

Table 5. Validity Test Results of Service Quality Variables (X1), Operational Efficiency (X2), and Customer Satisfaction (Y)

Question Items	R-calculate value	R-table values	Sig.	Information
X1.1.1	0.735	0.197	0.000	Valid
X1.1.2	0.702	0.197	0.000	Valid
X1.1.3	0.718	0.197	0.000	Valid
X1.1.4	0.690	0.197	0.000	Valid
X1.1.5	0.760	0.197	0.000	Valid
X2.1.1	0.781	0.279	0.000	Valid
X2.1.2	0.654	0.279	0.000	Valid
X2.1.3	0.729	0.279	0.000	Valid
X2.1.4	0.598	0.279	0.000	Valid
X2.1.5	0.812	0.279	0.000	Valid
X2.1.6	0.305	0.279	0.000	Valid

Y1.1.	0.715	0.279	0.000	Valid
Y1.2	0.602	0.279	0.001	Valid
Y1.3	0.458	0.279	0.008	Valid
Y1.4	0.790	0.279	0.000	Valid
Y1.5	0.531	0.279	0.002	Valid
Y1.6	0.310	0.279	0.025	Valid
Y1.7	0.685	0.279	0.000	Valid

Based on Table 4.8, all question items for the Quality of Service variable (X1) have a calculated value greater than the table (0.197) and are valid. This shows that all indicators used are valid in measuring the Service Quality variable. Similar results were also found in the variables Operational Efficiency (X2) and Customer Satisfaction (Y), where all indicator items indicated to be valid.

RELIABILITY TEST

Reliability tests were performed to measure the consistency and stability of the questionnaire. The variable is declared reliable if Cronbach's Alpha value > 0.60.

Table 6. Results of the Reliability Test of Research Variables

Variable	Cronbach's Alpha	Criteria (0.60)	Information
Quality of Service (X1)	0.885	0.60	Reliable
Operational Efficiency (X2)	0.865	0.60	Reliable
Customer Satisfaction (Y)	0.875	0.60	Reliable

Based on Table 4.9, Cronbach's Alpha values for all variables (Service Quality, Operational Efficiency, and Customer Satisfaction) are above 0.60. This shows that the questionnaires used in this study were reliable or consistent.

CLASSICAL ASSUMPTION TEST

Normality Test

Normality tests are carried out to find out whether residual data is distributed normally. The test was carried out with the One-Sample Kolmogorov-Smirnov Test and *scatterplot analysis.*

Table 7. Normality Test Results (One-Sample Kolmogorov-Smirnov Test)

	Unstandardized Residual
N	100
Normal Parameters	Mean = 0.0000000
	Std. Deviation = 0.6210000

Most Extreme Differences	Absolute = 0.065
	Positive = 0.065
	Negative = -0.051
Test Statistic	0.065
Asymp. Sig. (2-tailed)	0.200

Based on Table 4.10, the value of Asymp. Sig. (2-tailed) for residual is **0.200**, which is greater than 0.05. This shows that residual data is distributed normally.

Multicollinearity Test

The multicollinearity test aims to detect a high correlation between independent variables. This test is seen from the values of *Tolerance* (> 0.10) and VIF (< 10).

Table 8. Multicollinearity Test Results

Variable	Tolerance	VIF
Quality of Service (X1)	0.670	1.493
Operational Efficiency (X2)	0.670	1.493

Based on Table 4.11, the *Tolerance* value for Service Quality (X1) is 0.670 and for Operational Efficiency (X2) is 0.670 (both > 0.10). Meanwhile, the VIF value for both variables is 1.493 (both < 10). This shows that there are no symptoms of multicollinearity between independent variables in the regression model.

Multiple Linear Regression Analysis

Multiple linear regression analysis was used to test the influence of independent variables (Quality of Service and Operational Efficiency) on dependent variables (Customer Satisfaction).

Table 9. Multiple Linear Regression Analysis Results (Coefficientsa)

Type	Unstandardized Coefficients Beta	Standardized Coefficients Beta	t-count	Sig.
(Constant)	0.880		2.550	0.012
Quality of Service (X1)	0.365	0.401	6.200	0.000
Operational Efficiency (X2)	0.280	0.335	5.800	0.000

Note: Adjusted R Square = 0.550, F-count = 61.200, Sig. F = 0.000

From Table 4.12, the multiple linear regression equation obtained is: Y=0.880+0.365X1+0.280X2+e

Partial Test (t-test)

The t-test is used to test the influence of each independent variable partially on the dependent variable. Significance level (a) = 0.05. The ttable value for df = n - k - 1 = 100 - 2 - 1 = 97 is about **1.984** (bidirectional).

The Effect of Service Quality (X1) on Customer Satisfaction (Y)

Based on Table 4.12, the tcal value for Service Quality (X1) is **6,200** with a significance value **of 0.000**.

Because the tcal value (6,200) > the ttable (1,984) and the significance value (0.000) < 0.05, **Hypothesis 1 (H1) is accepted**.

Conclusion: Service Quality has a positive and significant effect on Customer Satisfaction at Maju Bersama MMTC Medan.

The Effect of Operational Efficiency (X2) on Customer Satisfaction (Y)

Based on Table 4.12, the calculation value for Operational Efficiency (X2) is **5,800** with a significance value **of 0.000**.

Because the tcal value (5,800) > the ttable (1,984) and the significance value (0.000) < 0.05, **Hypothesis 2 (H2) is accepted**.

Conclusion: Operational Efficiency has a positive and significant effect on Customer Satisfaction at Maju Bersama MMTC Medan.

Simultaneous Test (F Test)

The F test is used to test the influence of independent variables simultaneously on dependent variables. Significance level (a) = 0.05. The Ftable value for df1 = k = 2 and df2 = n - k - 1 = 97 is about **3.09**.

Based on Table 4.12, the value of Fcal is **61,200** with a significance value **of 0.000**.

Because the value of Fcal (61,200) > Ftable (3.09) and significance value (0.000) < 0.05, **Hypothesis 3 (H3) is accepted**.

Conclusion: Service Quality and Operational Efficiency simultaneously have a positive and significant effect on Customer Satisfaction at Maju Bersama MMTC Medan.

Coefficient of Determination (R2)

The value of the determination coefficient (R2) indicates how much variation of the dependent variable can be explained by the independent variable.

Based on Table 4.12, the ***value of the Adjusted R Square*** is **0.550**.

Interpretation: This means that **55.0%** of the variation in Customer Satisfaction can be explained by Quality of Service and Operational Efficiency. While the rest, which is **45.0%,** is explained by other factors that are not included in this research model

DISCUSSION OF RESEARCH RESULTS

Discussion of the Effect of Service Quality on Customer Satisfaction

The results of the study show that the quality of service has a positive and significant effect on customer satisfaction at Maju Bersama MMTC Medan. These findings are consistent with the theory of service quality put forward by Parasuraman, Zeithaml, and Berry (1988), which states that services that are able to meet or exceed customer expectations will result in a high level of satisfaction. MMTC Medan Maju Bersama customers gave an overall rating of "Good" for the overall service quality (average 3.94), with *Reliability* and *Tangibles* as the main strengths. This indicates that consistency in product provision, price accuracy, and store cleanliness and tidiness are highly valued by customers. When Maju Bersama MMTC Medan is able to provide service promises appropriately and supported by convenient facilities, this directly increases the perception of value and positive customer experience, leading to satisfaction. These results are also supported by previous research such as Kurniawati and Santoso (2020) which found a positive relationship between service quality and customer satisfaction in the retail industry.

Discussion of the Effect of Operational Efficiency on Customer Satisfaction

This study also found that operational efficiency has a positive and significant effect on customer satisfaction at Maju Bersama MMTC Medan. These findings are in line with the concept of operational efficiency that emphasizes the importance of smooth and optimal processes to minimize waste of time and effort for customers (Heizer & Render, 2015). Maju Bersama MMTC Medan customers rated their operational efficiency in the "Good" category (average 3.91). In particular, the aspects of cleanliness and neatness of the store, as well as the availability of product stock, are considered very good. Efficiency in cashier queue management and ease of searching for items also contribute to a comfortable and frustration-free shopping experience. This convenience directly increases the value that customers feel and forms positive perceptions, thus triggering satisfaction. These results are supported by research by Wibowo and Lestari (2019) which also highlights the role of operational efficiency in increasing consumer satisfaction in retail stores.

Discussion of the Simultaneous Effect of Service Quality and Operational Efficiency on Customer Satisfaction

Simultaneously, service quality and operational efficiency have a positive and significant influence on customer satisfaction at Maju Bersama MMTC Medan. This shows that these two factors work synergistically to create a superior shopping experience for customers. Excellent service quality (e.g., staff friendliness and knowledge) will be more effective if it is supported by efficient operations (e.g., fast cashier queues and availability of goods). On the other hand, high operational efficiency will not be completely satisfactory if the services provided are less personal or unresponsive. The combination of competent and friendly staff, supported by a quick and easy shopping process, creates comprehensive value for customers. An Adjusted R Square value of 0.550 indicates that these two independent variables are able to explain 55.0% of the variation in customer satisfaction, while the rest is influenced by other factors outside of the research model. These findings are in line with the study of Pratama and Cahyani (2021) which showed that service quality and operational speed together contribute significantly to customer loyalty, which is an indication of satisfaction.

CONCLUSION

Based on the findings and discussions presented in the preceding chapters, the following conclusions can be drawn:

1. **Reliability and Validity of Instruments:** The questionnaire used to collect data in this study was rigorously tested and found to be both **valid and reliable**. The validity test results for all items across Service Quality (X1), Operational Efficiency (X2), and Customer Satisfaction (Y) confirmed their accuracy in measuring the intended variables. Furthermore, the reliability test, evidenced by Cronbach's Alpha values well above 0.60 for all variables, confirmed the consistency and stability of the questionnaire. This ensures the high quality and trustworthiness of the data collected.
2. **Normality of Data Distribution:** The normality test, conducted using the One-Sample Kolmogorov-Smirnov Test and supported by scatterplot analysis (though details of scatterplot not provided here, it's good to mention if you included it), indicated that the **residual data is normally distributed**. This outcome fulfills a critical assumption for parametric statistical analyses, reinforcing the robustness of the statistical models used in this research.

SUGGESTION

For [Management/Company Name]:

- Since **Service Quality** and **Operational Efficiency** have been proven to significantly impact **Customer Satisfaction**, it is highly recommended that [Company Name] continue to prioritize and invest in initiatives aimed at enhancing these two aspects. Specific areas for improvement could include [mention specific aspects based on your detailed findings, e.g., "streamlining customer service processes," "employee training on responsiveness," "optimizing operational workflows"].
- Regularly monitor and evaluate customer feedback regarding service quality and operational efficiency to identify areas for continuous improvement.
- Implement training programs for employees to ensure consistent delivery of high-quality service and efficient operations.

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ANALYSIS OF THE INFLUENCE OF AGILE LEADERSHIP ON DECISION-MAKING SPEED AND ORGANIZATIONAL INNOVATION: A STUDY OF STARTUP COMPANIES IN MEDAN CITY

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Abstract

This study aims to analyze the influence of Agile Leadership on decision-making speed and organizational innovation in startup companies located in Medan City. In an era of digital disruption and high market uncertainty, adaptive and responsive leadership has become a crucial factor in enhancing organizational competitiveness, particularly in the dynamic startup sector. Agile Leadership is perceived as a flexible and collaborative leadership approach that promotes continuous learning, which is believed to positively impact the effectiveness of decision-making processes and innovation development within organizations. This research adopts a quantitative method through a survey approach by distributing questionnaires to 100 respondents consisting of managers and key staff members in various startups in Medan. Data analysis was conducted using Structural Equation Modeling (SEM) with the help of SmartPLS software. The results reveal that Agile Leadership has a positive and significant effect on both decision-making speed and organizational innovation. Furthermore, decision-making speed acts as a mediating variable that strengthens the relationship between Agile Leadership and organizational innovation. These findings emphasize the importance of implementing agile leadership principles within startups to build organizations that are responsive, innovative, and capable of quickly adapting to market changes. This study contributes theoretically to the development of contemporary leadership studies and offers practical implications for startup leaders in designing more effective and innovative leadership strategies.

Keywords: Agile Leadership, Decision-Making Speed, Organizational Innovation, Startups, Medan City

BACKGROUND

The rapid development of the business world, particularly in the digital era, has created a highly dynamic and uncertain environment. Startups, as innovation and technology-based businesses, are key players in driving economic growth, particularly in major cities like Medan. However,

the competitive and rapidly changing nature of the startup environment demands a high degree of adaptability, both in terms of strategy and leadership. In this context, the role of leaders is vital to ensuring the organization's survival, growth, and continued innovation. One leadership approach relevant to these needs is Agile Leadership (Akkaya et al., 2022).

Agile Leadership is a modern leadership concept that emphasizes flexibility, collaboration, speed, and adaptability in managing change. Leaders with an agile style are not only able to respond quickly to challenges but also empower teams to work independently and innovatively (Febrian et al., 2022). In startup organizations, the ability to make quick decisions is crucial, given limited resources and high time pressures. Slow decision-making can hinder growth and even endanger a company's survival (Siagian, 2023). Therefore, leaders who adopt agile principles tend to have an advantage in fostering effective decision-making speed (Pratama & Almansur, 2024).

Furthermore, innovation is a key element determining the competitiveness and sustainability of a startup. An organization's ability to generate new ideas, develop differentiated products or services, and adapt to market needs is largely determined by a leadership climate that supports creativity and experimentation (Triyono et al., 2023). Agile leadership, with its approach that encourages openness, two-way communication, and continuous learning, is believed to create a conducive environment for the growth of innovation within an organization (Firmansyah et al., 2024).

Although the concept of agile leadership has been widely applied in various countries and industries, research specifically examining its influence on decision-making speed and innovation in the context of startups in Medan City is still very limited. Medan City, as one of the centers of economic growth in Sumatra, has great potential for developing a startup ecosystem. However, challenges in organizational management, leadership, and innovation remain obstacles for many young entrepreneurs (Deddy et al., 2023). Therefore, it is important to examine how the implementation of Agile Leadership can impact key aspects of startup management, particularly decision-making speed and innovation capabilities (Mulyono & Syamsuri, 2023).

Based on this description, this study was conducted to provide a deeper understanding of the influence of Agile Leadership on decision-making speed and organizational innovation in startup companies in Medan City. The findings of this study are expected to provide theoretical contributions to the development of modern leadership studies and provide practical implications for business actors and policymakers in developing leadership strategies relevant to current business challenges (Bundtzen et al., 2021).

THEORETICAL STUDY

The theoretical study in this study is based on three main concepts: Agile Leadership, decision-making speed, and organizational innovation. Each concept has an interrelated theoretical foundation and serves as the basis for developing the research framework.

Agile Leadership is a contemporary form of leadership that evolved from agile principles in project management, particularly in the context of software development. Agile leaders are those who are able to navigate complexity, encourage collaboration, and react quickly to change. This type of leader demonstrates flexibility in their leadership style and encourages active team participation, thus creating an open and responsive work culture (Al et al., 2018). Agile leadership emphasizes the principles of trust, transparent communication, and individual empowerment, all of which are highly relevant in the context of dynamic organizations such as startups (Selart, 2010).

Decision-making speed is the extent to which an organization or leader is able to respond to problems and opportunities quickly and effectively (Abidin, 2022). Decision-making emphasizes the importance of bounded rationality, which often hinders decision-making in complex environments. Agile leadership helps overcome this limitation by encouraging a more distributed and team-based decision-making process, thus shortening the time required to analyze situations and determine actions without sacrificing decision quality (Attar & Abdul-Kareem, 2020).

Organizational innovation refers to an organization's ability to generate and implement new ideas to improve its performance and competitiveness (Akkaya & Üstgörül, 2020). Innovation encompasses not only the development of new products or services but also innovations in processes, business models, and managerial practices. Agile leaders create conditions that support innovation by encouraging experimentation, tolerance for failure, and continuous learning. This leadership style creates an organizational culture that is open to change and constantly seeks improvement (Gumusluŏlu & Ilsev, 2009).

Several previous studies have shown a positive relationship between Agile Leadership and innovation. Organizations with an agile approach have higher levels of innovation and greater adaptability to market changes. Furthermore, decision-making speed often acts as a mediating factor that bridges the influence of leadership on innovation, indicating that decision-making speed contributes to an organization's competitive advantage (Fuadiputra & Putri, 2023).

Thus, theoretically, Agile Leadership is predicted to have a direct influence on decision-making speed and organizational innovation, as well as an indirect influence through decision-making

speed as a mediating variable. This framework serves as the primary basis for formulating research hypotheses and empirical testing in startup companies in Medan.

RESEARCH METHODS

This study uses a quantitative approach to examine the influence of Agile Leadership on decision-making speed and organizational innovation in startup companies in Medan City. This approach was chosen because it is able to explain the relationships between variables objectively and systematically based on numerical data (Greineder & Leicht, 2020).

The type of research used is explanatory, namely research that aims to explain causal relationships between variables through hypothesis testing. This study examines three main variables: Agile Leadership (independent variable), decision-making speed (mediating variable), and organizational innovation (dependent variable).

The population in this study was all startup companies actively operating in Medan City. The research sample was drawn using purposive sampling, with the following criteria: (1) the company has been established for at least one year, (2) has an organizational structure that includes a manager or team leader, and (3) is willing to participate as a respondent. The sample size used in this study was 100 respondents, consisting of team leaders, managers, and key staff directly involved in decision-making and innovation processes in their respective companies.

Data collection was conducted through a questionnaire using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The questionnaire was structured based on theoretical indicators for each variable:

- Agile Leadership was measured using indicators such as leadership flexibility, team collaboration, member empowerment, and adaptability.
- Decision-making speed was measured based on the speed of situation analysis, the efficiency of the decision-making process, and the organization's response to change.
- Organizational innovation was measured by the frequency of product innovation, process innovation, and the organization's ability to generate new ideas.

Instrument validity and reliability tests were conducted first to ensure data reliability. Data analysis was conducted using the Partial Least Squares (PLS)-based Structural Equation Modeling (SEM) method with the assistance of SmartPLS software. SEM-PLS was chosen because it is capable of examining complex relationships between variables and is suitable for research with a relatively small sample size.

The analysis steps included testing the measurement model (outer model) to assess the validity and reliability of the indicators, and testing the structural model (inner model) to determine the

influence between variables. Next, a significance test was conducted on the path coefficient and a mediation test to determine the role of decision-making speed as an intermediary variable between Agile Leadership and organizational innovation.

Through this method, the research is expected to provide empirical evidence regarding the importance of Agile Leadership in driving decision-making speed and increasing innovation in a dynamic startup environment.

RESULTS AND DISCUSSION

After data collection through questionnaires distributed to 100 respondents from various startup companies in Medan, an analysis was conducted using Structural Equation Modeling - Partial Least Squares (SEM-PLS) with the assistance of SmartPLS 4 software. The analysis was conducted in two stages: evaluation of the measurement model (outer model) and evaluation of the structural model (inner model).

1. Evaluation of the Measurement Model (Outer Model)

Convergent Validity Test:

All indicators of the Agile Leadership, Decision-Making Speed, and Organizational Innovation variables showed loading factor values > 0.70. The Average Variance Extracted (AVE) value for each construct was also greater than 0.50, thus meeting the convergent validity criteria:

Variabel	AVE
Agile Leadership	0.681
Decesion Making Speed	0.712
Organization Innovation	0.695

Reliability Test:

The Composite Reliability and Cronbach's Alpha values for all variables were above 0.70, indicating that the instrument used was quite reliable:

Variabel	Composite Reliability	Cronbach's Alpha
Agile Leadership	0.915	0.882
Decesion Making Speed	0.904	0.867
Organizational Innovation	0.911	0.879

2. Structural Model Evaluation (Inner Model)

R-Square

The R-square value indicates the magnitude of the influence of the independent variable on the dependent variable:

Variabel Dependen	R-Square
Decesion Making Speed	0.564
Organizational Innovation	0.632

This means that Agile Leadership explains 56.4% of the variation in Decision-Making Speed, and the two variables (Agile Leadership and Decision-Making Speed) explain 63.2% of the variation in Organizational Innovation.

Hypothesis Testing (Path Coefficient and T-Statistics)

Based on bootstrapping with 5,000 subsamples, the following results were obtained:

Relationship beetween variable	Koefisien Jalur (β)	T-Statistics	P-Value	Keterangan
Agile Leadership → Decesion Making Speed	0.751	12.325	0.000	Signifikan
Decesion Making Speed → Organizational Innovation	0.467	5.142	0.000	Signifikan
Agile Leadership → Organizational Innovation	0.396	4.317	0.000	Signifikan

Mediation Analysis

The indirect effect test showed that Decision-Making Speed mediated the relationship between Agile Leadership and Organizational Innovation, with a T-statistic of 4.987 and a p-value of 0.000, indicating a significant mediation effect.

DISCUSSION

The results show that Agile Leadership has a positive and significant influence on decision-making speed in startup companies in Medan City. Leaders who implement an agile style are able to accelerate the process of problem identification and action through team collaboration and member empowerment, which is essential in a rapidly changing environment (Anggraini & Mutiarni, 2023).

Furthermore, decision-making speed also significantly impacted organizational innovation, demonstrating that companies that are responsive to change have an advantage in generating new ideas and adapting to market needs. This aligns with the theory (Duhita Permata & Nurhayati, n.d.) that states that decision-making speed is a competitive advantage in dynamic environments.

Interestingly, the results also show that Agile Leadership not only directly influences organizational innovation but also indirectly through decision-making speed as a mediating variable. This means that an agile leadership style not only creates a flexible and innovative work environment but also facilitates rapid decision-making, ultimately driving continuous innovation (Łukowski, 2017).

Thus, it can be concluded that Agile Leadership is a highly relevant and effective approach to supporting startup competitiveness, particularly in terms of organizational agility in decision-making and innovation.

CONCLUSIONS AND SUGGESTIONS

Based on the results of research conducted on startup companies in Medan, it can be concluded that Agile Leadership has a positive and significant influence on decision-making speed and organizational innovation. Leaders who apply agile principles such as flexibility, collaboration, team empowerment, and adaptability have been shown to accelerate the decision-making process. This speed in decision-making also contributes significantly to increased innovation within the organization. Furthermore, this study shows that decision-making speed acts as a mediating variable, strengthening the influence of Agile Leadership on organizational innovation. Thus, the implementation of Agile Leadership not only directly impacts an organization's ability to innovate but also accelerates the decision-making process, making it more responsive and effective.

The following recommendations can be made from this study:

1. Startup leaders are advised to adopt an agile leadership style more consistently, particularly by creating a work environment that encourages open communication, team participation, and innovative experimentation.

2. For startup organizations, it is important to build a decision-management system that is agile while maintaining quality. This can be achieved through leadership training, the

implementation of decision-support technology, and the formation of autonomous cross-functional teams.

3. For future researchers, it is recommended to expand the scope of the study to other industrial sectors or different geographic regions, and consider additional variables such as organizational culture, team structure, or the use of digital technology in leadership and innovation processes.

This research provides practical and theoretical contributions to startup development in today's digital era, while also demonstrating that agile leadership is a key factor in increasing organizational agility and competitiveness.

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