

Embracing IR 4.0: Market Readiness and Perceptions of Smart Manufacturing in Malaysia's Oil Palm Industry

Fadzilah Salim^{1*}, Adam Samsudin¹, Sayed Kushairi Sayed Nordin², Aminah Ahmad³, Nur Aiman Hanis Hasim⁴, Emi Normalina Omar⁵

¹Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

²Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

³Faculty of Electronics and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

⁴Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

⁵Faculty of Management and Business, Universiti Teknologi Mara, Shah Alam, Malaysia

Email: *fadzilah@utem.edu.my

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Abstract

The oil palm industry has long been a cornerstone of Malaysia's economy, generating significant revenue and driving economic growth. With the advent of the Fourth Industrial Revolution (IR 4.0), the integration of smart manufacturing systems is poised to enhance efficiency and cost-effectiveness, potentially boosting industry revenues in alignment with the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production). This study investigates market perceptions and readiness among key players in the oil palm sector to adopt smart sensors in decanter machines, aiming to improve manufacturing performance. Data was collected through an online survey, which, despite limitations, yielded valid responses. Statistical analysis of the results reveals a general optimism towards the benefits of smart manufacturing, including increased efficiency, sustainability, and profitability. However, the findings also indicate a prevalent lack of readiness to invest in these technologies, primarily due to insufficient awareness, information, and knowledge about their effectiveness. By aligning with SDG 8 (Decent Work and Economic Growth), this research provides valuable insights for policy-makers, industry leaders, and technology developers seeking to foster innovation and drive the future growth of Malaysia's oil palm industry.

Keywords

Industry 4.0, Market Perceptions, Oil Palm Industry, Smart Manufacturing,

Technology Adoption

1. Introduction

The worldwide demand for palm oil persists at a consistently high-level owing to its diverse functional benefits and nutritional importance. Originally native to West Africa, palm oil production has since developed, with Indonesia and Malaysia being the primary producers. These two countries collectively account for around 85% to 90% of the global palm oil supply. In 2020, Malaysia exported palm oil worth around USD 10,884 million, supported by 457 operational palm oil mills. This robust infrastructure establishes Malaysia as a potential leader in the global palm oil industry.

The Fourth Industrial Revolution (IR 4.0) is transforming global industry, significantly enhancing product development through technological innovation. Within the context of IR 4.0, manufacturing technologies have evolved to meet the increasing demands of the palm oil market. Technologies such as the Internet of Things (IoT), Big Data, Blockchain, and cyber-physical systems are becoming increasingly vital to modern manufacturing processes [1]. These advances can significantly improve agricultural efficiency across all stages, from crop management to processing and distribution.

The incorporation of intelligent systems, such as IoT, into industrial processes could revolutionize the agriculture and plantation sectors [2]. The Internet of Things enables real-time monitoring and data collection, optimizing resource use, improving predictive maintenance, and raising overall operational efficiency. Big Data analytics offer insights into production trends and consumer preferences, while Blockchain ensures transparency and traceability across the supply chain. Cyber-physical systems facilitate the seamless amalgamation of physical processes with digital technologies, yielding more intelligent and responsive industrial settings.

Furthermore, the use of these technologies mitigates environmental impacts by improving resource efficiency and reducing waste. This aligns with Sustainable Development Goal (SDG) 12, which promotes responsible consumption and production by encouraging efficient resource use and minimizing waste. The integration of smart manufacturing also supports SDG 9 by fostering innovation and infrastructure development within the oil palm industry. Additionally, by enhancing operational efficiency and creating opportunities for skilled employment, these advancements contribute to SDG 8, which advocates for decent work and economic growth.

This research aims to examine the perspectives and readiness of stakeholders in the oil palm industry regarding the implementation of smart sensors in decanter machines, which are crucial for palm oil production. The study seeks to ascertain the possible benefits and challenges of employing these technologies, conse-

quently enhancing the industry's growth and sustainability.

2. Literature Review

2.1. Oil Palm Industry in Malaysia

Palm oil (*Elaeis guineensis*) was first introduced in Malaysia as an ornamental plant in 1870. Since 1960, the planted area has increased at a rapid pace. In 1985, 1.5 million hectares were planted with palm trees, and this increased to 4.3 million hectares by 2007. Palm oil has become the most important commodity crop in Malaysia. As of 2011, the total planted area was 4.917 million hectares.

Palm oil production in Malaysia has risen significantly over the years, from 4.1 million tons in 1985 to 6.1 million tons in 1990 and reaching 16.9 million tons in 2010. It peaked at 18.9 million tons in 2011 and reached 19.4 million tons in 2012. Estimated production for 2023 is 19 million tons, compared to 18.45 million tons last year, influenced by the El Niño weather pattern in 2024 [3].

The Malaysian palm oil industry easily meets local demand for oils and fats, with the excess available for export. Palm kernel oil production was 1.3 million tons in 1999 and rose to 4.7 million tons in 2011. Prior to 1970, most of the palm kernel oil produced was exported. Since 1979, palm kernels have been crushed locally to produce crude palm kernel oil and palm kernel cake. Malaysia is now the second-largest producer of palm oil in the world, having been overtaken by Indonesia in 2006. Since 1985, palm oil has become the second most consumed oil globally, after soybean oil. Malaysia's share of global production was 51% in 1999, but it decreased to 38% in 2011. Recent trends indicate that Malaysia remains one of the largest exporters of palm oil in the world, as shown in **Figure 1**.

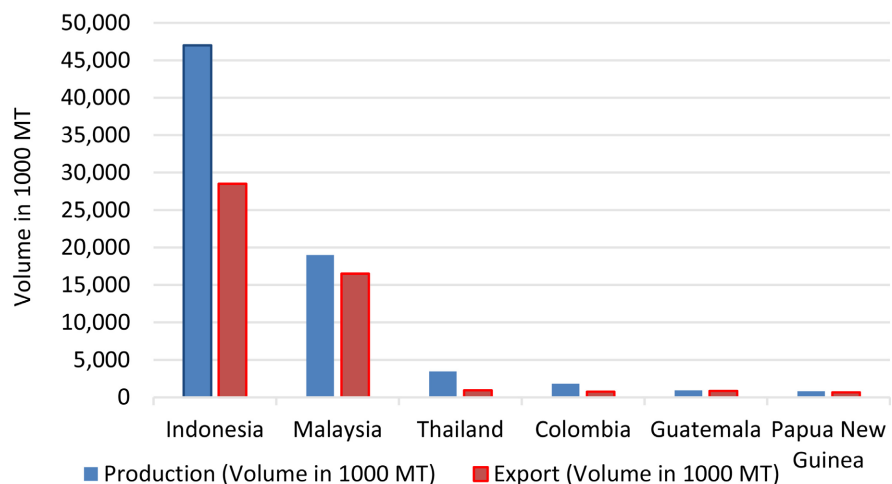


Figure 1. Major palm oil producers and exports in the world (Source: Statista 2023 and USDA).

Recognizing the significant role of Malaysia as a leading producer and exporter in the palm oil sector, there is an opportunity to further enhance the efficiency of palm oil production. With Industry 4.0 and Internet of Things technologies, im-

plementing a smart manufacturing system to improve production efficiency is essential.

2.2. Smart Manufacturing System

In the era of Industrial Revolution 4.0 (IR 4.0), advancements in technology have compelled industries to move toward automation, digitalization, and smart manufacturing. Smart manufacturing systems can increase efficiency, productivity, and product customization in manufacturing industries [4]-[8]. This development suggests that manufacturers must be adaptable in their business operations. However, industries must be prepared to face challenges in order to implement these new developments [9]-[11].

Production technology has emerged to meet the high demand in the palm oil market. Research and development (R&D) efforts have been undertaken to explore the future direction of the oil palm industry. Key areas of focus include increasing productivity, biomass and bioenergy, palm oil in food and nutrition, and palm-based oleochemicals. Improvements have also been suggested, including the use of big data, IoT, and cloud computing mechanisms to enhance harvesting and production [12]. Thus, smart manufacturing systems in the oil palm industry are vital for production performance.

Smart manufacturing systems integrate various technologies to create a more connected and intelligent production process. Sensors and devices are employed to collect data from various stages of production, which is then analyzed in real-time using AI and machine learning algorithms. This enables predictive maintenance, optimized production scheduling, and improved quality control.



Figure 2. Smart manufacturing systems for oil palm industry.

One of the stages in producing palm oil at an oil mill involves using a decanter centrifuge machine to separate the liquid from the solid. Traditionally, this process required allowing the mixture to settle in a tank and then manually separating the two components. However, this method was time-consuming, inefficient, and often resulted in lower-quality palm oil.

Using a decanter machine can significantly speed up the processing time and produce a higher-quality product. The decanter centrifuge effectively separates the liquid and solid components, removes more impurities, and results in clearer, cleaner oil. It is suggested that integrating a smart sensor into the machine, as shown in **Figure 2**, can further reduce labor costs, improve safety, enhance environmental impact, and ultimately improve oil production.

The implementation of a smart manufacturing system can bring significant benefits to a company, including reduced operational costs, increased productivity, and improved quality control. Additionally, smart manufacturing systems can help companies meet sustainability goals by reducing waste, optimizing resource usage, and improving energy efficiency.

2.3. Market Research

Market research in smart manufacturing systems involves gathering and analyzing information about the market for advanced manufacturing technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), robotics, and automation. It may also involve collecting data on the size of the market, including the number of companies currently using or planning to use smart manufacturing technologies.

Market research in smart manufacturing systems can also involve gathering data on customer preferences and needs. This includes understanding the specific challenges manufacturers face and how smart manufacturing technologies can help address these challenges. Market research can also help businesses understand customer perceptions of smart manufacturing technologies, including their perceived benefits and concerns.

Market research in smart manufacturing systems can provide valuable insights into market trends and opportunities for growth. This information can be used to develop new products and services that meet customer needs and stay ahead of the competition. By understanding customer needs and preferences, businesses can develop effective marketing strategies that drive sales and growth.

Past research has identified the advantages and disadvantages of conducting market research for any new product in a company or organization [13]–[15]. Some advantages of conducting market research are as follows:

- 1) Better understanding of the market: Conducting market research helps businesses gain insights into their target audience, competitors, and industry trends. This can lead to a better understanding of customer needs and preferences, as well as potential gaps in the market that the business can fill.
- 2) Identifying opportunities: Market research can help businesses identify po-

tential opportunities for growth and expansion. This could include new markets to enter, new products or services to offer, or changes to existing products or services based on customer feedback.

3) Reducing risks: Market research can help businesses make more informed decisions, reducing the risks associated with launching new products or entering new markets. This can also help businesses avoid costly mistakes that could harm their reputation or bottom line.

4) Enhancing marketing efforts: Market research can provide businesses with insights into the most effective marketing channels and messaging for reaching their target audience. This can help them create more targeted and effective marketing campaigns.

Some disadvantages are highlighted as follows:

1) Cost: Conducting market research can be expensive, particularly if the business outsources the research to a third party. This can be a significant barrier for small businesses or start-ups with limited budgets.

2) Time-consuming: Market research can be a time-consuming process, particularly if the research involves collecting data from a large sample size or conducting in-depth interviews or focus groups.

3) Data quality: The accuracy and reliability of market research data can be impacted by a range of factors, such as sample size, survey questions, and data collection methods. Poor quality data can lead to inaccurate or misleading insights, which can harm business decisions.

4) Limited scope: Market research is often limited to a specific point in time and may not reflect changing market conditions or customer preferences. This means that businesses may need to conduct ongoing research to stay up-to-date on market trends and customer needs.

Overall, market research in smart manufacturing systems is a crucial component of business strategy. By understanding the market for advanced manufacturing technologies, businesses can make informed decisions that help them stay ahead of the competition and drive growth.

3. Materials and Methods

This study attempts to evaluate market perception, preparedness, and acceptance of the implementation of an IoT-based sensor into a decanter centrifuge machine to improve oil palm production. The research carried out using a survey, recognising the possible difficulties [16] [17].

To guarantee a strong response rate, it was initially proposed that the questionnaire be administered in person. This methodology was adopted to target certain respondents having important positions within the company, such as Managers or Assistant Managers of the palm oil refineries. These individuals are generally engaged in financial decision-making and strategic planning, rendering them the most appropriate candidates to offer knowledgeable answers to enquiries concerning investment and decision-making processes.

A pilot questionnaire was conducted before the main poll to enhance the questions and guarantee clarity and pertinence. Feedback from the pilot study was instrumental in refining the final survey questions by identifying ambiguous wording, improving relevance, and ensuring alignment with the study's objectives. The target respondents were selected according to their industry functions, guaranteeing that the collected data would be pertinent and informative.

Palm oil mills are extensively located throughout East and West Malaysia, encompassing areas such as Sabah and Sarawak. Carrying out physical surveys in these areas would be both labour-intensive and expensive. Due to the constrained timeline for the research, an online survey was considered the most viable method. This method facilitated a wider outreach and proved to be more economical, albeit its intrinsic obstacles and constraints [18] [19].

The online survey was sent out through email to over 500 prospective respondents over a duration of seven months. Given the comprehensive outreach, merely 33 responds were obtained, of which 31 were deemed valid for study. The low response rate shows the problems associated with online surveys, particularly with participant motivation and participation [20] [21]. Issues like survey duration, perceived significance, and the demanding schedules of prospective respondents likely influenced the low participation percentage [22].

Multiple validation approaches were utilised to guarantee the reliability and authenticity of the gathered data. The pilot questionnaire facilitated the identification and rectification of ambiguities or biases in the survey questions. Responses were evaluated for consistency and completeness during data collection. Responses that were incomplete or inconsistent were omitted from the final analysis to preserve data integrity.

Furthermore, statistical techniques were employed to confirm the results. Descriptive statistics provide a summary of the data distribution, but inferential statistics facilitated the identification of noteworthy trends and relationships. Cross-validation methods were employed to confirm the reliability of the results. These measures guaranteed the accuracy and reliability of the data utilised in the analysis, establishing a robust basis for the study's conclusions.

The gathered data was examined through statistical techniques to find trends and insights concerning the preparedness and acceptability of IoT-based sensors within the oil palm sector. The investigation concentrated on comprehending the perceived advantages, possible obstacles, and general readiness to embrace new technology among industry players.

4. Results and Discussion

This study examined market perception, awareness, and preparedness for the adoption of a smart manufacturing system, particularly involving the integration of an IoT-based sensor into a decanter centrifuge machine within Malaysia's palm oil sector. The findings from the survey offer significant insights into the perspectives and attitudes of industry professionals, emphasising their receptiveness to

new technology and the obstacles that remain to be resolved.

Figure 3 shows that the majority participants in this study were managers and assistant managers, with assistant managers constituting 40% and managers 33% of the total. This was deliberate, as these individuals are more likely to participate in decision-making processes about technology adoption and expenditure. Twenty-seven percent of respondents held other technical roles, namely engineers and assistant engineers, who similarly possess access to operational data pertinent to the survey. This diverse group of respondents guarantees that the questionnaire encompasses opinions from individuals with both strategic and technical viewpoints, thus offering comprehensive knowledge of the industry's assessment of IoT technology integration.

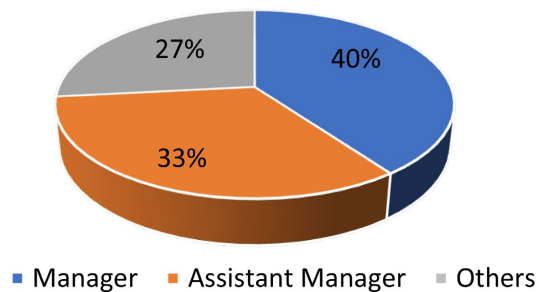


Figure 3. Position of the respondents in the palm oil industries.

Figure 4 demonstrates that the largest percentage of survey participants originates from East Malaysia (37%), followed by the Southern region (33%), Eastern region (17%), Northern region (10%), and Central region (3%). This geographic distribution illustrates the extensive presence of palm oil mills throughout Malaysia, facilitating a thorough comprehension of regional viewpoints.

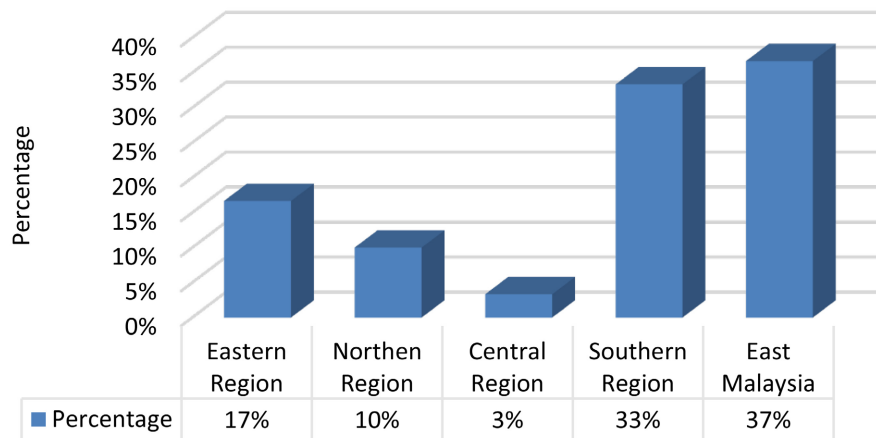


Figure 4. Location of the palm oil mills.

A traditional decanter machine is an essential apparatus in palm oil mill production, demanding continuous monitoring. According to the survey, 47% of respondents record the vibration readings of the decanter machine one to three

times daily, as shown in **Figure 5**. Simultaneously, 43% reported that their employees lack a procedure for doing daily vibration assessments, while 10% noted that assessments are performed more than four times per day. These data show the inconsistency in monitoring techniques among various mills.

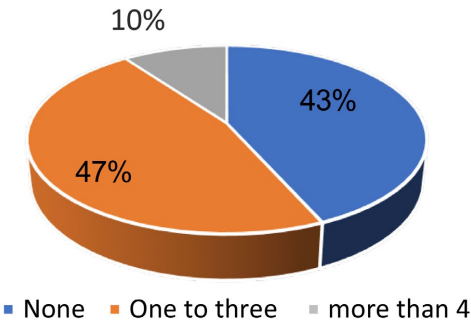


Figure 5. Frequency of daily vibration readings.

Figure 6 shows the average frequency of decanter machine breakdowns within six months. Many respondents (47%) reported that their machines are generally in good condition, experiencing breakdowns one or two times in six months. However, 16% of respondents encountered three or more breakdowns within the same period. This indicates a need for improved maintenance and monitoring practices to enhance equipment reliability.

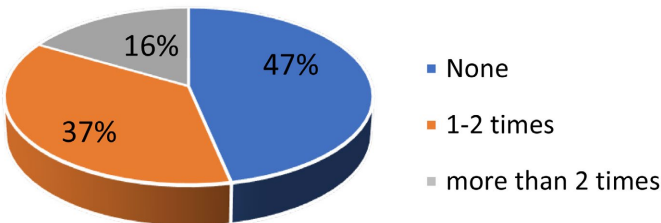


Figure 6. Frequency of decanter machine breakdowns in six months.

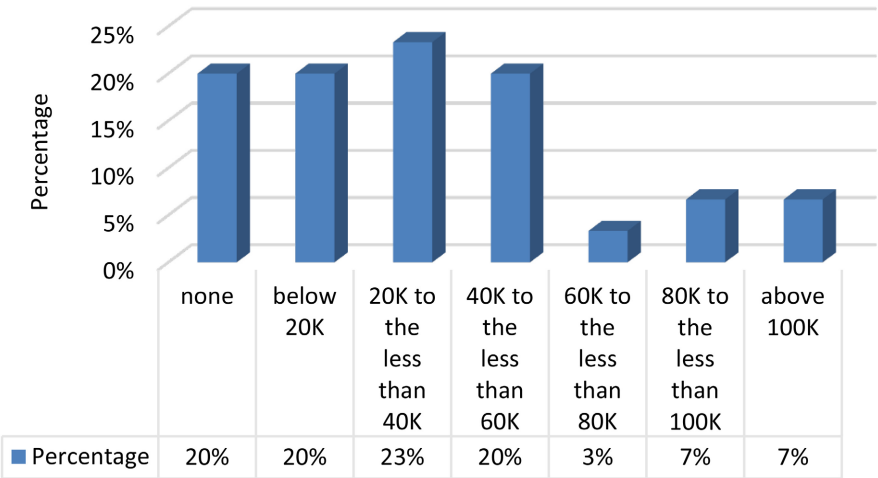


Figure 7. Factory expenditure on maintenance services in six months.

Regular maintenance is essential to ensure the optimal performance of decanter machines. As shown in **Figure 7** below, about 43% of companies spend between RM20,000 to RM60,000 on machine maintenance over six months. However, 20% of companies reported not conducting any maintenance on their machines. This disparity in maintenance practices could impact the overall efficiency and longevity of the equipment.

A decanter machine is important for extracting raw palm oil by separating particles from liquids by rotational acceleration. The survey indicates that 47% of respondents monitor the daily quantity of faulty palm seed waste, whereas 53% do not. Efficient waste management procedures are crucial for enhancing production efficiency and minimising losses.

A traditional decanter machine often serves as the primary apparatus in palm oil mill production. However, there is a deficiency in efficiency and productivity. A smart sensor utilising IoT and wireless connectivity will be included into a decanter centrifuge machine. This innovation can diminish energy consumption, enhance manufacturing system efficiency, and simultaneously boost palm oil production.

Figure 8 shows that majority believed that IoT technologies could increase efficiency, elevate manufacturing performance, and provide cost advantages. Nonetheless, there was significant uncertainty concerning employment loss, as 50% of respondents were not persuaded that IoT would necessitate a decreased workforce. This indicates that although there is optimism over the advantages of smart systems, there are also concerns about their effects on employment, which may affect adoption choices.

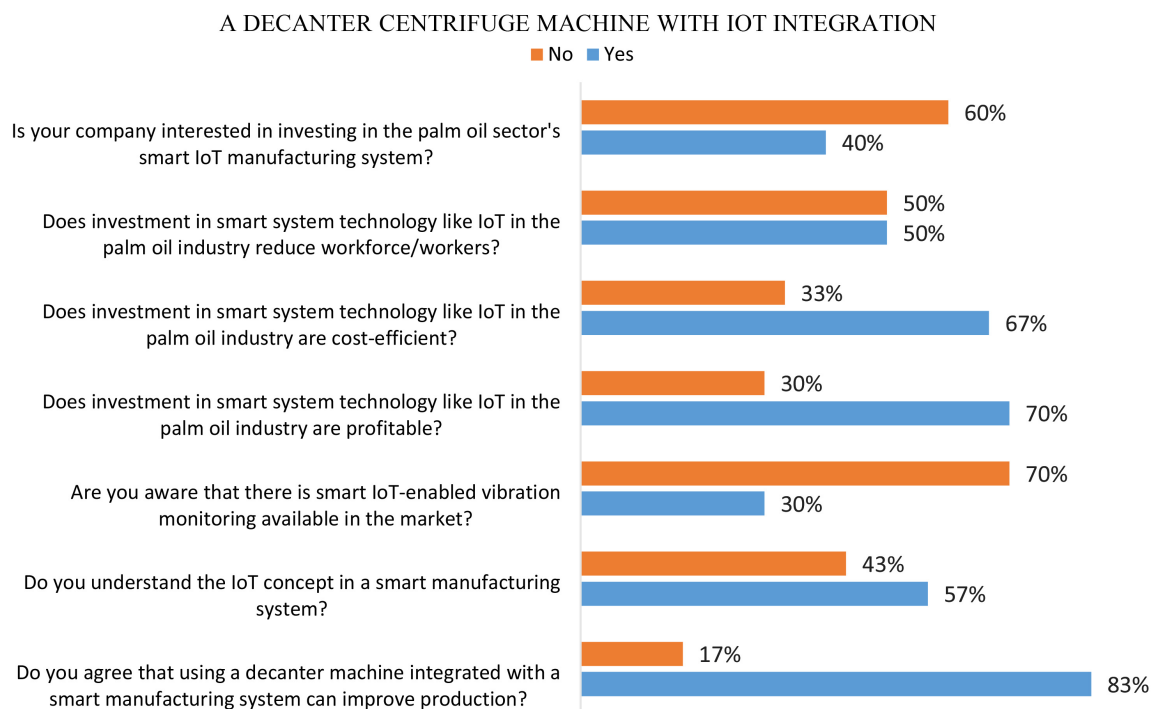


Figure 8. Internet of things—awareness, perception and readiness.

Seventeen percent of respondents oppose the utilisation of the decanter machine, primarily due to insufficient information and inadequate worker skills. Nonetheless, 83% of the participants concur with the utilisation of a decanter machine incorporated into a smart production system. They argue that the technology has the potential to enhance industrial efficiency. Additionally, 57% of the respondents lack comprehension of the IoT idea inside a smart manufacturing system. Consequently, increased awareness is essential to educate others about smart manufacturing systems to enhance output productivity.

This knowledge gap may stem from several industry-specific factors, including limited exposure to digital technologies within traditional palm oil operations, a lack of targeted training programs, and minimal collaboration between tech developers and plantation stakeholders. The sector's reliance on manual labor and conventional machinery may also contribute to slower adoption and understanding of emerging technologies like IoT.

The chi-square test for independence is used to determine if there is a correlation between two categorical variables, as shown in **Table 1**. The null hypothesis states that there is no association between the variables, while the alternative hypothesis suggests that there is an association.

Table 1. Association between variables.

Variable 1	Variable 2	Pearson χ^2
Ability to improve production	understand the IoT concept in a smart manufacturing system	2.9217*
Ability to improve production	Awareness of smart IoT-enabled vibration monitoring in the market	2.4388
Ability to improve production	Investment in smart system technology are profitable	6.2182**
Ability to improve production	Investment in smart the system technology is cost-efficient	2.0996
Ability to improve production	Investment in smart system technology could reduce workers	2.3856
Understanding the IoT concept in a smart manufacturing system	Awareness of smart IoT-enabled vibration monitoring in the market	10.4439***
Understanding the IoT concept in a smart manufacturing system	Investment in smart system technology is profitable	7.2346***
Understanding the IoT concept in a smart manufacturing system	Investment in smart system technology is cost-efficient	7.2346***
Understanding the IoT concept in a smart manufacturing system	Investment in smart system technology could reduce workers	2.5869
Understanding the IoT concept in a smart manufacturing system	Interest in investing in the palm oil sector's smart IoT manufacturing system	0.0965
Awareness of smart IoT-enabled vibration monitoring in the market	Investment in smart system technology is profitable	2.5963

Continued

Awareness of smart IoT-enabled vibration monitoring in the market	Investment in smart system technology is cost-efficient	2.5963
Awareness of smart IoT-enabled vibration monitoring in the market	Investment in smart system technology could reduce workers	0.0789
Awareness of smart IoT-enabled vibration monitoring in the market	Interest in investing in the palm oil sector's smart IoT manufacturing system	0.0178
Investment in smart system technology is profitable	Investment in smart system technology is cost-efficient	15.3974***
Investment in smart system technology is profitable	Investment in smart system technology could reduce workers	10.2355***
Investment in smart system technology is profitable	Interest in investing in the palm oil sector's smart IoT manufacturing system	5.1285***
Investment in smart system technology is cost-efficient	Investment in smart system technology could reduce workers	15.7460***
Investment in smart system technology is cost-efficient	Interest in investing in the palm oil sector's smart IoT manufacturing system	2.1780
Investment in smart system technology could reduce workers	Interest in investing in the palm oil sector's smart IoT manufacturing system	1.7766

Note: ***, **, * denote statistically significant at 1%, 5% and 10% level, respective.

Table 1 displays the outcomes of the Pearson Chi-square test with one degree of freedom for twenty pairs of items. Nine pairs of elements exhibit significant relationships. There exists a significant correlation between respondents' comprehension of the IoT idea inside a smart manufacturing system and their awareness of smart IoT-enabled vibration monitoring in the marketplace. Moreover, substantial correlations exist between the belief that investment in smart system technology yields profit and the assumption that such investments are economically efficient.

Moreover, the belief that investment in smart system technology is valuable is closely linked to the notion that it can diminish the workforce and to the interest in investing in the smart IoT manufacturing system of the palm oil business. Likewise, the perception that investment in smart system technology is economically advantageous is closely linked to the assumption that it might diminish the workforce. The research suggests that respondents recognize and are prepared to invest in IoT technologies, provided they comprehend how these systems might improve productivity.

At the end of the survey, participants were questioned whether their organization is inclined to invest in a smart IoT manufacturing system for palm oil production. Notably, 61% of respondents express unwillingness in investing, whilst merely 39% demonstrate interest. The factors contributing to the reluctance in investing in a smart manufacturing system are shown in **Figure 9**.

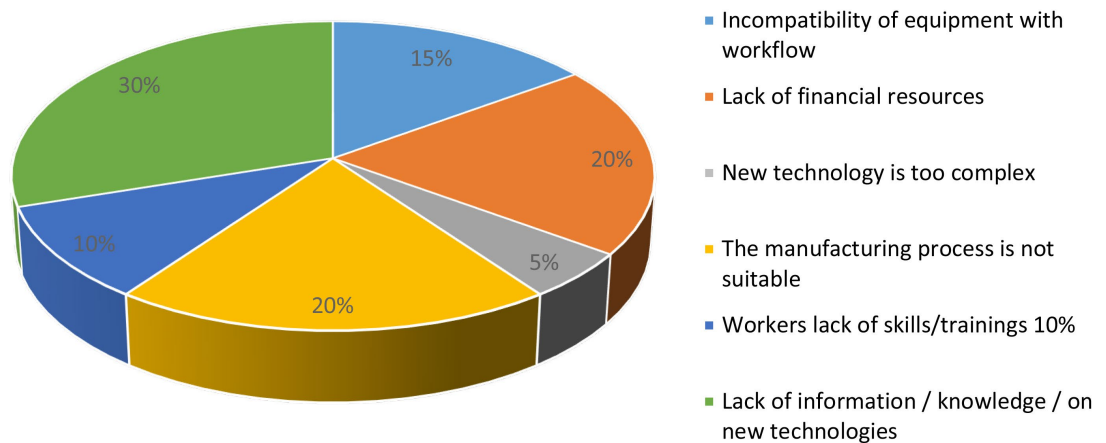


Figure 9. Reasons for lack of interest in investing in a smart manufacturing system.

It is important to note that the study's small sample size limit the generalizability of the findings to the broader Malaysian palm oil industry. While the data provides valuable insights into current perceptions and readiness, it may not fully capture the diversity of views across different regions, company sizes, or operational models. As such, the conclusions drawn should be interpreted with caution and viewed as indicative rather than definitive.

5. Conclusions

In conclusion, the implementation of a smart manufacturing system in Malaysia's palm oil sector offers substantial advantages, such as improved operational efficiency, increased production, and enhanced sustainability. By implementing smart manufacturing, organisations may more effectively satisfy the rising demand for sustainably manufactured goods and comply with rigorous environmental requirements, which are becoming increasingly significant to both consumers and investors.

Nonetheless, the shift to a smart manufacturing system presents some problems. Substantial initial investment expenses, the requirement for proficient personnel to manage and sustain the new systems, and possible interruptions to current operations throughout the transition phase are considerable obstacles. Organisations must meticulously evaluate these issues in relation to the enduring advantages of adopting such advanced technologies.

The transition to smart manufacturing in Malaysia's palm oil industry is a beneficial advancement towards establishing a more sustainable and competitive business. Adopting technological advancements such as IoT, big data, and cloud computing can enhance operational efficiency, mitigate environmental impact, and more effectively satisfy the requirements of consumers and stakeholders. Comprehensive market analysis and strategic planning may enhance production efficiency through the implementation of smart manufacturing systems, thereby establishing Malaysia as a global leader in palm oil production.

To address the identified gaps in awareness and readiness, several practical

steps are recommended. Policymakers should initiate targeted educational campaigns and incentives to promote digital literacy and technology adoption in the palm oil sector. Industry associations can facilitate training programs and workshops tailored to operational staff and decision-makers, focusing on the benefits and implementation of smart manufacturing systems. Technology developers are encouraged to collaborate closely with mill operators to design user-friendly, scalable solutions and provide ongoing technical support. These coordinated efforts can accelerate the sector's transition toward IR 4.0 and ensure inclusive, sustainable growth.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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