

Design and Evaluation of a PDA-RFID-Based Digital Inventory System for Warehouse Operations

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Abstract

Digitizing warehouse inventory processes is a crucial requirement for improving operational accuracy and efficiency in the manufacturing and distribution industries. PT XYZ still faces the problem of manual inventory recording through spreadsheets and subsequent input into the SAP system, which can potentially lead to shipping errors, stock data discrepancies, and processing time inefficiencies. The purpose of this study is to design and evaluate a Personal Digital Assistant (PDA)-based digital inventory system integrated with RFID technology to improve warehouse operational performance. The research method used is a case study with a before-after approach, beginning with field observations and mapping of inbound and outbound workflows before system implementation. Next, the digital inventory system is designed to automate the recording process for inbound, picking, and packing activities. Operational performance evaluation is carried out by comparing processing time and the frequency of shipping errors before and after implementation. In addition, the usability and ergonomic aspects of the system are assessed using the System Usability Scale (SUS) involving 15 warehouse personnel. The results show that the implementation of PDA-RFID can significantly reduce inbound and outbound processing times and eliminate shipping errors in the period after implementation. The average SUS score of 73.5 indicates that the system has a good level of usability and is acceptable to users. This research provides a practical contribution to the implementation of warehouse inventory digitization and demonstrates that technology integration and human-centered design-based evaluation enable to improve the operational efficiency and reliability of industrial inventory systems.

Keywords

Inventory Management, Warehouse, Personal Digital Assistant, Operational Efficiency, Inventory Accuracy

1. Introduction

Warehouse inventory management is an important aspect of modern supply chains, as it directly affects operational efficiency, logistics costs, and customer service quality. The growth of distribution activities and the increasing complexity of supply chains require companies to provide real-time inventory systems, maintain high data accuracy, and ensure fast and reliable delivery processes (Ali et al. 2024; Tan and Sidhu 2022). However, many companies still rely on manual or semi-digital inventory systems that use spreadsheet-based records and require repeated data entry into enterprise systems. This condition may lead to delays in data updates, stock discrepancies, and a higher risk of human error (Budiyanto and Muslim 2024; Fernández-Caramés et al. 2019; Zhang et al. 2025). These issues not only slow down warehouse operations but also increase the risk of shipping errors and limit real-time inventory monitoring. Several previous studies have shown that the digitalization of warehouse management through automatic identification technologies can improve process efficiency and reduce operational errors in industrial settings (Bae et al. 2016; Beul et al. 2018; Crooks and Haddud 2025; Fernández-Caramés et al. 2019; Zhong et al. 2017). The implementation of RFID in warehouse management systems has been reported to improve inventory accuracy, accelerate item processing, and enhance real-time synchronization of inventory data. One technology that can be further developed in warehouse digitalization is the integration of Personal Digital Assistants (PDAs) and Radio Frequency Identification

(RFID) (Bae et al. 2016; Beul et al. 2018; Büyüközkan et al. 2012; Fernández-Caramés et al. 2019; Tserng et al. 2005; Zhong et al. 2017). RFID enables automatic item identification and tracking, while PDAs support operator mobility in scanning, validation, and direct inventory data updates within the warehouse area. The integration of these two technologies enables inbound, picking, and packing processes to be carried out more quickly, accurately, and in a more integrated manner. Previous studies also indicate that the use of RFID in logistics operations can reduce cycle time, improve inventory location accuracy, and reduce dependence on manual recording (Budiyanto and Muslim 2024; Zhang et al. 2025). In addition, RFID-based inventory systems contribute to improved operational performance and data-driven decision-making in modern warehouse environments (Unhelkar et al. 2022; Zhang et al. 2025).

In addition to operational aspects, the successful implementation of digital technology in industrial environments is also influenced by users' acceptance of the system (Langendorf and Khalid 2025). Systems with low usability may increase users' workload, raise the likelihood of operational errors, and hinder the effectiveness of technology implementation (Cheng et al. 2025; Schrank et al. 2024; Zigart et al. 2023). Therefore, usability evaluation is an important part of developing human-centered digital inventory systems (Langendorf and Khalid 2025). One commonly used method is the System Usability Scale (SUS), which can quickly and reliably measure users' perceptions of ease of use, comfort, and system acceptance (Macris et al. 2025; Persson et al. 2025). Usability evaluation enables companies to assess the success of technology not only from technical and operational perspectives, but also from the user experience perspective in daily work activities.

PT XYZ, a fast-moving consumer goods (FMCG) company, faces inventory operational problems due to its continued use of manual and semi-digital systems. The recording of incoming and outgoing goods still relies on spreadsheets before the data are re-entered into the System Application and Product in Data Processing (SAP) system. This process leads to redundant data entry, delays in stock data updates, and a high risk of input errors by operators. These conditions contribute to shipping errors, including wrong shipments and short shipments, particularly when warehouse activity volume increases, as shown in Figure 1. In addition, the manual inventory verification process makes inbound and outbound processing times relatively long and less efficient. Previous studies have stated that inventory systems based on manual recording tend to have lower accuracy, are more prone to human error, and may hinder warehouse operational efficiency (Akkerman et al. 2025; Shahrabi 2023).

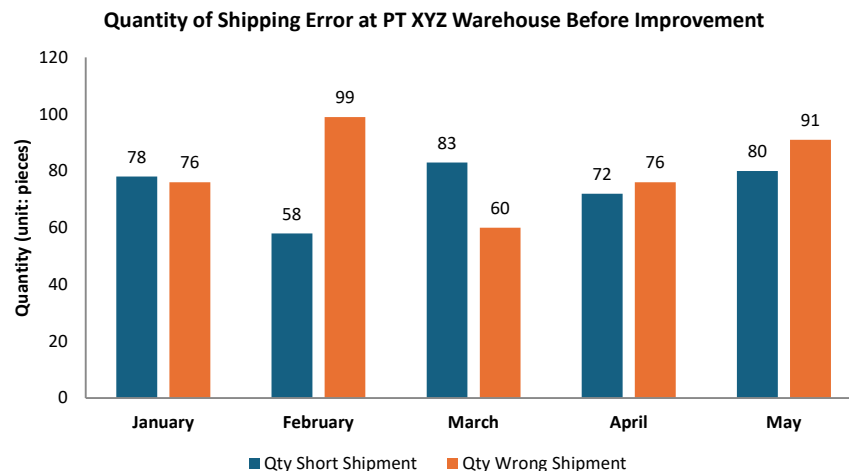


Figure 1. Quantity of shipping errors at PT XYZ Warehouse from January to May 2024 before improvement (in pcs)

The implementation of RFID and automated inventory systems has been reported to improve inventory monitoring, accelerate item identification, and reduce operational errors (Shahrabi 2023; Unhelkar et al. 2022; Zhang et al. 2025). Although many studies have examined the implementation of RFID in warehouse management, most have focused on technical or conceptual benefits without simultaneously integrating operational performance evaluation and user usability assessment. In addition, empirical studies on PDA-RFID implementation in the Indonesian manufacturing industry remain relatively limited. Therefore, this study aims to design and evaluate a PDA-RFID-based digital inventory system for the warehouse of PT XYZ using a before-after case study approach. The evaluation compares operational performance before and after system implementation, including processing time and shipping errors, while

also assessing system usability using the SUS. This study is expected to provide practical and academic contributions to the development of efficient, accurate, and user-centered digital inventory systems.

2. Literature Review

2.1 Digitalization of Warehouse Inventory Systems

The digitalization of warehouse inventory systems is an important aspect of modern supply chain transformation, as warehouses no longer function only as storage facilities but also as control centers for the flow of goods, information, and operational decisions (Tubis and Rohman 2023). Digital inventory systems can help companies obtain stock data more quickly, accurately, and traceably, thereby improving inventory visibility and operational responsiveness (Zaman et al. 2023). In relation to digital supply chains, technologies such as RFID, the Internet of Things (IoT), warehouse management systems (WMS), and data-driven systems have been widely used to improve inventory management efficiency, reduce data inaccuracies, and enhance coordination among logistics activities. Tan and Sidhu (2022) showed that the integration of RFID and IoT in supply chain management contributes to improved system efficiency, productivity, and reduced operational costs. In addition, Zhang et al. (2025) emphasized that RFID-based digital transformation can improve data accuracy, traceability, and operational transparency through automatic identification mechanisms.

In relation to modern warehouses, inventory digitalization plays an important role in addressing the limitations of manual and semi-digital systems that still rely on spreadsheet records, physical documents, and repeated data entry into enterprise systems. Sgarbossa et al. (2022) explained that digitalization in production and warehousing, including through automation and data analytics, can support smarter production planning, material control, and material handling systems. Similarly, Tubis and Rohman (2023) emphasized that the Warehouse 4.0 concept adopts Industry 4.0 technologies, such as IoT, RFID, augmented reality, visual technology, and autonomous vehicles, to improve information exchange, particularly real-time inventory levels, and support smart warehouse design. In addition, Leung et al. (2022) showed that digital twins and IoT can be used to synchronize inbound processes through the integration of order fulfillment, replenishment, and information synchronization. These findings indicate that warehouse inventory digitalization can improve data accuracy, information flow speed, and operational efficiency in modern warehouse systems.

2.2 Application of PDA and RFID Technology in Warehouse Operations

One form of digitalization in warehouse operations is the use of mobile devices, such as Personal Digital Assistants (PDAs) or handheld mobile devices, which enable operators to record, scan, validate, and update data directly at the work area (Büyüközkan et al. 2012; Tserng et al. 2005). These devices serve as a mobile interface between physical warehouse activities and the company's information system, thereby reducing dependence on manual recording and accelerating the flow of operational information. In warehouse management, PDAs or mobile scanning devices can be used for inbound activities, stocktaking, picking, packing, and shipment verification. Carrulo (2024) discussed the development of a warehouse management system integrated with PDA, barcode scanning, and mobile scanning devices to support warehouse operation optimization. The use of PDAs in warehousing enables real-time data input and inventory updates, which can reduce manual input errors and improve the speed of stock management.

Meanwhile, RFID is an automatic identification technology that enables item tracking and information reading in a more flexible manner than conventional barcode methods. In warehouse operations, RFID can be used to accelerate item identification, improve inventory location accuracy, and support real-time stock monitoring. Unhelkar et al. (2022) stated that RFID can improve supply chain performance through more precise data collection, better information management, and support for decision support systems in the context of Industry 4.0. Casella et al. (2022) further noted that RFID has developed into an important technology in logistics because of its ability to improve visibility and the efficiency of goods flow. In addition, Shahrabi (2023) compared RFID with an inventory counting approach and showed that RFID can help reduce inventory inaccuracy caused by transaction errors. The integration of PDA and RFID has the potential to strengthen recording accuracy, accelerate operational processes, and reduce dependence on manual verification.

2.3 Operational Performance and Usability Evaluation of Digital Systems

Operational performance and usability evaluations are needed to assess the success of digital inventory system implementation comprehensively (Akbar and Fajar 2024; Zaman et al. 2023). From an operational perspective, metrics such as inbound and outbound processing time, inventory accuracy, shipping error rate, item identification speed, and

workflow efficiency can be used to compare conditions before and after system implementation. Previous studies have shown that RFID and automated inventory systems can improve real-time tracking, data accuracy, and operational efficiency, while their successful adoption is also influenced by system integration, cost-effectiveness, and the socio-technical readiness of the organization (Budiyanto and Muslim 2024; Zhang et al. 2025). In addition, usability needs to be evaluated because systems with low usability can increase user workload, raise the risk of operational errors, and hinder implementation effectiveness. One widely used method is the SUS, as it is simple, fast, and reliable in measuring users' perceptions of ease of use, comfort, and system acceptance (Sharfina and Santoso, 2017). Therefore, combining operational and usability evaluations provides a more complete understanding of the success of digital inventory systems, both in terms of process efficiency and user experience.

3. Methods

This study used a before-after case study approach to evaluate the impact of warehouse inventory digitalization using a PDA integrated with RFID technology. The study was conducted in the finished goods warehouse of PT XYZ, where the inventory process had previously been carried out manually through spreadsheet-based recording and subsequent data entry into the SAP system. The research methodology began with direct field observations to map the existing inbound and outbound workflows, followed by the identification of operational inefficiencies and shipping errors. Based on these findings, an improved digital inventory system was designed by integrating PDA devices and RFID labels to automate data recording in inbound, picking, and packing activities. The analysis then compared the operational sequences before and after system implementation, allowing a systematic evaluation of time efficiency and error reduction.

To assess system usability and ergonomic suitability, the SUS questionnaire was administered after system implementation. Research data were collected through a survey of 15 warehouse personnel, consisting of checkers, pickers, warehouse administrators, and supervisors who directly interacted with the PDA system. The SUS score was then calculated using the standard scoring procedure, resulting in a usability score ranging from 0 to 100. The reliability of the respondents' answers was tested using Cronbach's Alpha to ensure the internal consistency of the instrument. In addition, operational performance metrics, including processing time and shipping error frequency, were analyzed descriptively and compared between the pre- and post-implementation conditions.

4. Results and Discussion

4.1 Current-State Analysis of PT XYZ's Warehouse Operations

During the period from January to May 2024, PT XYZ carried out product shipments with varying monthly volumes. The recorded shipment quantities were 19,496 pieces in January, 19,793 pieces in February, 27,174 pieces in March, 53,019 pieces in April, and 26,767 pieces in May. These variations indicate fluctuations in warehouse operational activity, highlighting the need for an accurate and responsive inventory recording system to ensure consistency between actual stock, system data, and shipment requirements.

In the current condition, PT XYZ's warehouse operations still use a manual and semi-digital stock recording system. The warehouse team first records data using Google Sheets and then re-enters the data into the SAP system. This double-recording process may lead to delays in data updates, stock discrepancies, and input errors caused by human error. Its impact can be seen in the emergence of two main types of shipping errors, namely short shipments and wrong shipments, as previously shown in Figure 1.

Based on the observation results, there were 78 short shipment cases and 76 wrong shipment cases in January. This finding indicates that the existing warehouse inventory system is not yet optimal, as weaknesses remain in the processes of recording, validation, and stock data updates. Shipping errors may not only reduce customer satisfaction but also increase operational and logistics costs due to correction activities, reshipment, or complaint handling. Therefore, system improvement is required through the digitalization of the inventory process using a PDA integrated with RFID to improve data accuracy, accelerate item validation, and support warehouse operational efficiency.

4.2 Current-State and Proposed Inbound–Outbound Process Flows

Before the improvement, the inbound process required a total processing time of 19 minutes and 50 seconds. The process included receiving the delivery note, printing the unloading instruction document, checking the quantity of goods, and manually entering stock data into the SAP system. This manual process not only required more time but also increased the risk of human error, which could lead to stock data discrepancies. After the implementation of the

PDA integrated with RFID, the inbound processing time was reduced to 11 minutes and 5 seconds, representing a 44.12% reduction in processing time. The use of RFID enables warehouse personnel to scan items automatically, making stock recording faster and more accurate. In addition, the automated system facilitates the preparation of reports for stock shortages or excess quantities, thereby reducing administrative workload and improving data transparency.

For the outbound process, the total processing time before the improvement was 19 minutes and 5 seconds. This process involved several manual steps, including order receipt, item picking, item packing, and manual stock deduction through the SAP system. Similar to the inbound process, dependence on manual recording increased the risk of errors and extended operational time. After the implementation of the PDA integrated with RFID, the outbound processing time was reduced to 14 minutes and 10 seconds, representing a 25.76% reduction in processing time. With RFID, the picking and packing processes became faster and more accurate, while stock deduction was performed automatically through the system, eliminating the need for time-consuming manual input.

The implementation of PDA technology integrated with RFID provided several positive impacts on PT XYZ's warehouse operations. The PDA-RFID implementation improved operational efficiency, as indicated by the reduction in inbound processing time by 44.12% and outbound processing time by 25.76%. This reduction in processing time enables the warehouse team to complete more tasks within a shorter period, thereby improving overall productivity. In addition, the automation of stock recording through RFID scanning significantly reduces the risk of human error in data entry. As a result, stock data become more accurate and up to date, reducing errors in checking the quantity of goods received and issued.

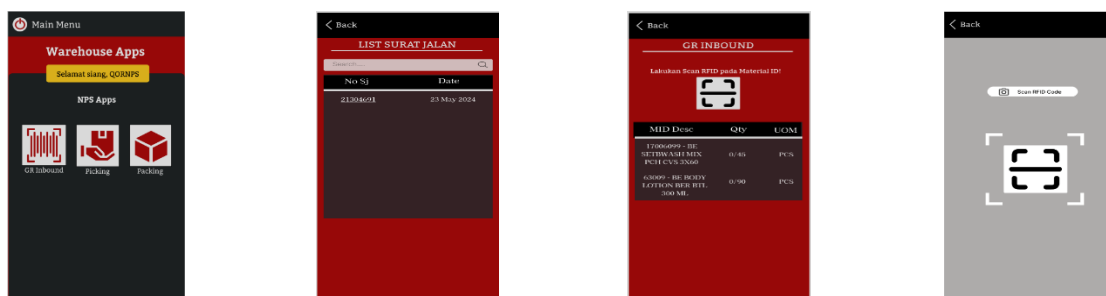
In addition, the integration of RFID with the PDA system ensures that stock data remain up to date and can be accessed by management in real time, thereby improving data transparency and accuracy. The automatic generation of reports for stock shortages or excess quantities also improves administrative efficiency. As a result, the warehouse team can focus on other operational tasks, which ultimately enhances work efficiency and effectiveness. This technology implementation also contributes to customer satisfaction, as orders can be processed and shipped more quickly and accurately, ensuring that customers receive the correct items on time.

4.3 Design of a PDA-RFID-Based Warehouse Inventory System at PT XYZ

The PDA-RFID interface proposed for inventory management in PT XYZ's warehouse is illustrated in Figure 2. The interface consists of three main menus that support the warehouse team in carrying out operational activities. The first menu is GR Inbound (Good Receipts Inbound), as shown in Figure 2(a–f). This menu is used during the inbound process, when the production plant sends stock to the warehouse. Through the GR Inbound menu, the warehouse team can input received stock directly into the system. This feature helps ensure that incoming stock data are recorded accurately and in real time, reducing the risk of errors commonly associated with manual recording.

The next menu is the Picking menu, as shown in Figure 2(g). This menu is used for retrieving items from warehouse stock. In this process, the warehouse team scans the RFID labels attached to the products. The scanning process enables the system to automatically deduct warehouse stock according to the quantity of items picked. Through this automation, errors in stock deduction can be minimized, and inventory data can remain up to date.

The final menu is the Packing menu, as shown in Figure 2(h). This menu is used for packing items that will be shipped to customers or transferred to other warehouses. It ensures that each packed item is properly recorded and matches the order received. This process helps ensure that the correct items are shipped in the correct quantities.



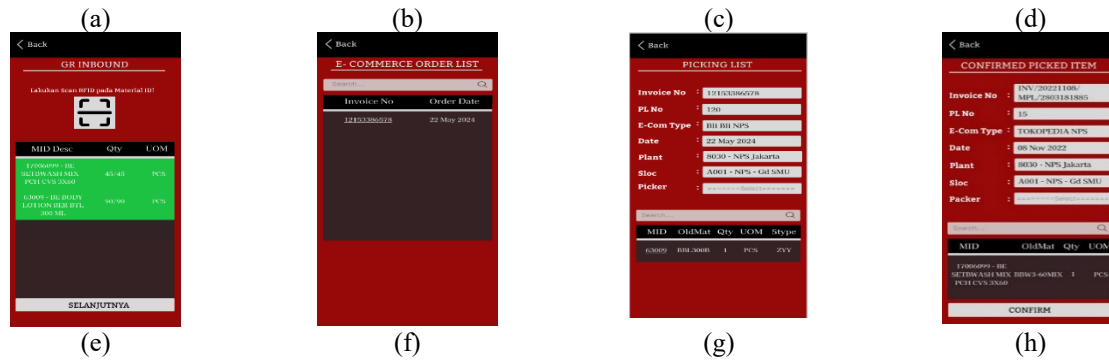


Figure 2. Illustration of the PDA-RFID-based warehouse inventory system design at PT XYZ, consisting of the Good Receipts Inbound menu (a–f), Picking menu (g), and Packing menu (h)

4.4 Before-After Comparison of Warehouse Operational Performance

After the implementation of the PDA-RFID system in PT XYZ's warehouse inventory process, an evaluation was conducted to identify changes in warehouse operational performance, particularly in processing time, inventory recording, data validation, and shipping accuracy. The observation results showed that no shipping errors occurred in June and July, either in the form of short shipments or wrong shipments. This condition indicates that inventory digitalization through the PDA-RFID system improved shipping accuracy, accelerated item verification, and minimized the risk of operational errors. In addition, the system reduced repeated manual recording through real-time inventory data updates and automatic validation in inbound, picking, and packing activities. Table 1 summarizes the comparison of warehouse operational performance before and after the implementation of the PDA-RFID-based inventory system at PT XYZ.

Table 1. Before-after comparison of warehouse operational performance

Process	Before Improvement	After Improvement	Time Reduction	Percentage Reduction	Main Improvement
Inbound process	19 min 50 sec	11 min 5 sec	8 min 45 sec	44.12%	RFID scanning and automatic stock recording reduced manual checking and SAP input activities
Outbound process	19 min 5 sec	14 min 10 sec	4 min 55 sec	25.76%	PDA-RFID integration improved picking, packing, and automatic stock deduction
Shipping error	Error occurred during January-May	No error in June-July	Reduced to zero in the observed post-implementation period	-	Digital validation reduced short shipment and wrong shipment cases
Inventory recording	Spreadsheet and manual SAP input	PDA-RFID-based real-time recording	-	-	Reduced redundant data entry and improved inventory visibility
Data validation	Manual verification	RFID-based automatic validation	-	-	Improved accuracy and reduced potential human error

4.5 Usability Assessment of the PDA-RFID System

Usability evaluation was conducted to assess the ease of use and user acceptance of the PDA-RFID system implemented in PT XYZ's warehouse inventory process. Data were collected using the SUS questionnaire, which was distributed to 15 warehouse personnel, including checkers, pickers, warehouse administrators, and the warehouse

head. Based on the calculation results, the PDA-RFID system obtained an average SUS score of 73.5. This score falls within the Good category, indicating that the system has a good level of usability and is acceptable to users in supporting warehouse operational activities. In addition, the Cronbach's Alpha value of 0.857 indicates that the SUS instrument has good internal consistency, meaning that the usability evaluation results can be considered reliable. These results show that the PDA-RFID system not only provides benefits in terms of operational efficiency but is also considered easy to use and suitable for the needs of users in PT XYZ's warehouse.

5. Conclusion

This paper aims to design and evaluate a PDA-RFID-based digital inventory system for PT XYZ's warehouse using a before–after case study approach by assessing changes in operational performance and the level of system usability for users. The results show that the implementation of the PDA-RFID system improved operational efficiency and shipping accuracy. The inbound processing time decreased by 44.12%, while the outbound processing time decreased by 25.76%, indicating an improvement in warehouse workflow after digitalization. In addition, the PDA-RFID system minimized shipping errors, as no short shipment or wrong shipment cases were found in June and July. From the user perspective, the SUS evaluation produced an average score of 73.5, indicating that the system has a good level of usability and is acceptable to warehouse personnel.

Although the findings indicate that the PDA-RFID system improved warehouse operational efficiency, shipping accuracy, and user acceptance, several limitations should be acknowledged. The evaluation was conducted in a single warehouse at PT XYZ, so the findings may not fully represent warehouse operations with different characteristics. In addition, the post-implementation observation period was relatively short, and the usability assessment involved a limited number of warehouse personnel. Future research may extend this study by involving several warehouse locations, conducting evaluations over a longer period, and including a larger group of respondents to improve the generalizability of the findings. In addition, future work could incorporate cost-benefit analysis, assess system scalability, and explore the integration of advanced analytics to better understand the broader impact of PDA-RFID implementation on warehouse operations and overall supply chain performance.

Authors' Contributions

Fitriadi: Conceptualization; investigation; writing—original draft; data collection; data curation; formal analysis; Software; visualization. Hwi-Chie Ho: writing—review and editing; validation; methodology; supervision funding acquisition; project administration.

Declaration of AI

During the preparation of this work, the authors used ChatGPT to enhance the clarity of the writing. After using the ChatGPT, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

Data Availability Statement

The data that supports the findings of this study are available in this article.

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Biographies

Fitriadi is a final-year undergraduate student at Bina Nusantara University Indonesia, majoring in Industrial Engineering with professional experience in the Fast-Moving Consumer Goods (FMCG) sector. He is currently undergoing an internship program at one of Indonesia's largest FMCG companies, where he contributes to various strategic projects within the logistics and distribution division. In his role as a Logistics Excellence Intern, he is involved in warehouse system analysis, inbound-outbound process optimization, and the digitalization of inventory processes using platforms such as AppSheet and Google Apps Script. He also actively participates in developing strategies for improving truck loading efficiency aimed at increasing Volume Space Optimization (VSO) and reducing cost ratios in distribution. Additionally, he has been actively involved in digitalization and improvement projects within the warehouse production sector. His engineering background, passion for automation, and hands-on industrial experience drive him to deliver innovative solutions in logistics, distribution, and sustainable industrial systems. Outside of his academic and professional responsibilities, he is actively involved in campus organizations. He previously served as Project Manager in the Bina Nusantara Industrial Engineering Student Association (HIMTRI), where he organized various training programs and workshops to enhance students' soft and hard skills. He also served as a staff member in the same organization, focusing on the development of student competencies in industrial engineering through seminars, technical workshops, and competitions. His dedication to continuous learning and development reflects his drive to contribute meaningfully to the future of industrial engineering and supply chain innovation.

Hwi-Chie Ho is a professional engineer and Associate Professor of Industrial Engineering at Bina Nusantara University (BINUS), Indonesia. Formerly Dean of the Faculty of Engineering and BASE (2009–2022), her expertise lies in ergonomics and industrial psychology. A committed IIESE member and faculty advisor, she led BINUS Student Chapter #716 to win the Gold Award (2012–2023) and received multiple regional awards as a faculty advisor. As an IEOM Fellow and frequent speaker, she actively contributes to global academic forums. Previously CEO of Audi & Volkswagen Indonesia, she was named one of *SWA Magazine's* Top 40 Executives in Indonesia in 2002.