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Autonomous Vehicles in Warehouse Inventory Management: Insights from Malaysia's National Telecommunication and Digital Infrastructure Provider

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Abstract:

Purpose: This study examines the role of autonomous vehicles (AVs) in warehouse inventory management, with a specific focus on Malaysia's national telecommunication and digital infrastructure provider. It identifies key challenges, operational efficiencies, and strategic implementation considerations to enhance supply chain resilience.

Design/methodology/approach: A mixed-method research approach was employed, integrating qualitative interviews with logistics experts and a quantitative survey of warehouse personnel. Thematic analysis was applied to qualitative data, while Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to analyze quantitative findings.

Findings: The study highlights that workforce adaptation is the strongest predictor of successful AV adoption, with employee upskilling emerging as a critical factor. Despite AVs' potential to optimize inventory accuracy and streamline operations, challenges such as budget constraints, cybersecurity risks, and system integration complexities persist. Notably, the research reveals a paradoxical misalignment between management support and AV adoption success, underscoring the need for strategic leadership engagement.

Research limitations/implications: The study primarily focuses on a national telecommunication provider, limiting the broader applicability to diverse logistics sectors. Future research should explore AV integration across varied industries and regions to enhance generalizability.

Practical implications: The findings provide logistics managers with an empirically driven framework for AV integration, emphasizing the importance of phased implementation, workforce readiness programs, and system compatibility measures. Additionally, the study informs policymakers on the regulatory considerations necessary for AV adoption in Malaysia's telecommunications sector.

Social implications: Automation in warehouse management raises workforce displacement concerns, necessitating proactive upskilling initiatives. The study also contributes to sustainable logistics practices by demonstrating AVs' potential to reduce energy consumption and improve space utilization in warehouse environments.

Originality/value: This research fills a critical gap in AV adoption literature by offering an empirically validated framework specific to warehouse inventory management in the telecommunications sector. It extends the Technology Acceptance Model (TAM) and Resource-Based View (RBV) theories to assess AV adoption drivers and barriers.

Keywords: autonomous vehicles, warehouse inventory management, supply chain automation, workforce adaptation, technology acceptance, telecommunications logistics, industry 4.0

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1. Introduction

Logistics and supply chain management play a crucial role in today's globalized economy, ensuring the seamless movement of goods from production to consumption. As industries strive to optimize efficiency, minimize costs, and enhance responsiveness, technological innovations such as automation and artificial intelligence (AI) have gained prominence (Zhang, 2024). Among these advancements, autonomous vehicles (AVs) have emerged as a transformative force in warehouse inventory management, offering potential solutions to persistent inefficiencies in order fulfillment, stock tracking, and warehouse operations (de-Koster, 2022).

Recent trends indicate a growing reliance on automation in supply chain management, driven by increasing consumer demand, labor shortages, and the need for real-time inventory accuracy. The global warehouse automation market is expected to grow substantially in the coming years, reaching a value of approximately USD 100 billion by 2025, with a compound annual growth rate (CAGR) of around 14-15% (Co, Sham, Ahmad & Acesor, 2023). Companies such as Amazon, DHL, and Walmart have already incorporated AV technologies to improve efficiency and reduce dependency on manual labor (Odumbo & Onuma, 2025). However, despite this progress, the integration of AVs remains uneven across industries, with several organizations struggling to overcome barriers related to cost, infrastructure, and workforce adaptation.

Despite the apparent benefits of AVs, there remains a significant research gap regarding their large-scale implementation in warehouse inventory management. Existing studies have primarily focused on their application in transportation and last-mile delivery, overlooking the operational challenges and strategic considerations associated with their deployment within warehouses (Wang, Yuan, Lu, Xiao, Hong & Zhang, 2024). Furthermore, the long-term financial viability and regulatory frameworks governing AV adoption remain underexplored, posing uncertainties for industry stakeholders (Richter, Hagenmaier, Bandte, Parida & Wincent, 2022). This study seeks to bridge this gap by providing an empirically driven framework for AV implementation in warehouse settings.

The primary objective of this research is to examine the integration of AVs in warehouse inventory management, evaluating their impact on operational efficiency, cost-effectiveness, and workforce adaptation. Specifically, this study addresses the following research questions: (1) What are the key technological and operational challenges associated with AV adoption in warehouses? (2) What strategies can organizations implement to optimize AV integration? (3) How does AV deployment influence overall supply chain efficiency and return on investment (ROI)? By addressing these questions, this research contributes to both academic literature and practical industry insights.

From a theoretical perspective, this study expands existing knowledge by integrating the Technology Acceptance Model (TAM) and the Resource-Based View (RBV) to assess the factors influencing AV adoption (Chen, 2023). It also contributes to supply chain literature by offering a structured framework for evaluating automation scalability in warehouse operations. From a practical standpoint, the findings provide logistics managers, policymakers, and industry leaders with actionable strategies to overcome AV implementation challenges and maximize their operational benefits.

Beyond its technical implications, the study holds broader relevance for the industry and society. As automation continues to reshape the global workforce, understanding the implications of AV adoption is critical for managing labor transitions, ensuring regulatory compliance, and maintaining ethical automation practices. Additionally, the study informs sustainability efforts, as AVs have the potential to reduce carbon footprints by optimizing warehouse space utilization and energy consumption.

There is a notable lack of empirical research on the adoption of autonomous vehicles (AVs) in telecommunications warehouse operations, despite growing interest in automation across logistics. Unlike sectors such as e-commerce, telecommunications firms face unique challenges–such as equipment-specific handling, regulatory constraints, and unclear ROI–that remain underexplored. This study addresses these gaps by examining AV implementation within Telekom Malaysia, offering insights into feasibility, cost-effectiveness, workforce readiness, and policy implications specific to the telecommunications sector.

This research makes significant contributions to the field of warehouse automation and logistics innovation, particularly within the telecommunications sector. By integrating empirical data and theoretical models, the study delivers actionable insights for both academia and industry stakeholders:

1. **Techno-Strategic Integration Framework:** Introduces a novel framework for integrating Autonomous Vehicles (AVs) with Warehouse Management Systems (WMS), emphasizing the enabling role of advanced digital infrastructure such as private 5G and IoT networks for real-time control and operational synergy.
2. **Empirical Insights from a Digitally Mature Environment:** Offers rare, sector-specific evidence from Malaysia's national telecommunications provider, providing a "lighthouse" case of AV deployment in a high-tech, non-traditional logistics setting–an underexplored context in current literature.
3. **Rigorous Mixed-Methods Validation:** Combines qualitative insights with quantitative validation using PLS-SEM to identify critical success factors like system integration and digital readiness, delivering empirical depth often lacking in implementation studies.

The remainder of this paper is structured as follows: Section 2 reviews existing literature on AVs in supply chain management, identifying key research gaps. Section 3 outlines the research methodology, including data collection and analysis techniques. Section 4 presents the results and discussion, synthesizing empirical findings with theoretical insights. Section 5 concludes the study with practical implications, limitations, and recommendations for future research.

2. Literature Review

2.1. Key Terminologies

Autonomous Mobile Robot (AMR): A smart, self-navigating robot that adapts to dynamic warehouse environments using sensors and AI–unlike AGVs, AMRs avoid fixed paths and optimize routes in real time.

Warehouse Management System (WMS): The central software that controls warehouse operations, extending beyond inventory tracking to manage real-time tasks and coordinate AMR movements.

Digital Twin: A live, virtual replica of the warehouse, updated by IoT data, used for real-time monitoring, predictive simulations, and process optimization.

Partial Least Squares Structural Equation Modeling (PLS-SEM): A robust statistical tool for modeling complex relationships between variables, ideal for small samples and predictive, variance-focused research.

Digital Infrastructure: The tech backbone–private 5G, IoT sensors, and computing systems–that enables seamless, real-time communication between warehouse systems and autonomous technologies.

2.2. Overview of Warehouse Inventory Management

Warehouse inventory management is a fundamental aspect of logistics and supply chain operations, ensuring that goods are stored, tracked, and distributed efficiently. The primary objective of warehouse inventory management is to maintain optimal stock levels, reduce operational costs, and enhance service delivery (Oluwaseyi, Onifade & Odeyinka, 2017). Traditionally, warehouse inventory management relied on manual processes, which were often plagued by inefficiencies, human errors, and scalability issues. These challenges have led to inaccurate stock counts, misplaced goods, and delays in order fulfillment, ultimately affecting supply chain performance (Li, 2024).

The evolution of technology has significantly transformed warehouse inventory management, shifting from paper-based records to digitized and automated systems. Radio-frequency identification (RFID), barcoding, and warehouse management systems (WMS) have improved inventory tracking and accuracy (Nisa & Rahmawati, 2023). More recently, artificial intelligence (AI), machine learning, and automation technologies, such as autonomous vehicles (AVs), have further modernized warehouse operations (Zhang & Hu, 2024). These advancements help organizations optimize inventory flow, reduce labor dependency, and enhance scalability, positioning AVs as a key solution for the future of warehouse management. However, despite these improvements, challenges remain in integrating new technologies with existing infrastructure, underscoring the need for further research into the strategic implementation of AVs in warehouse environments (Suwaidi, Aydin, Rashid, Hairunnas & Louk, 2022).

2.3. AVs in Warehouse Inventory Management

AVs are self-navigating systems that utilize AI, machine learning, and sensor technologies to operate with minimal or no human intervention. These vehicles are categorized into two primary types: Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs). AGVs operate in structured environments, such as warehouses and distribution centers, by following predefined paths using magnetic strips or sensors (Oyekanlu, Smith, Thomas, Mulroy, Hitesh, Ramsey et al., 2020). In contrast, AMRs are equipped with advanced navigation systems, including LiDAR and computer vision, enabling them to adapt to dynamic environments and real-time changes in warehouse layouts (Liaqat, Hutabarat, Tiwari, Tinkler, Harra, Morgan et al., 2019).

The application of AVs in logistics extends across various domains, including material handling, freight transportation, last-mile delivery, and port operations. Companies such as Amazon and FedEx have significantly invested in self-driving trucks and delivery drones to optimize supply chain efficiency (Odumbo & Onuma, 2025). AVs streamline logistics processes by automating repetitive tasks such as picking, sorting, and transporting goods, thereby reducing delays and minimizing human errors. This automation allows human workers to focus on more complex decision-making tasks, enhancing overall operational productivity.

The use of AVs in warehouse inventory management is transforming traditional logistics by automating tasks such as inventory tracking, storage, and retrieval. AVs are equipped with advanced navigation and sensor technologies that enable them to transport goods efficiently within warehouses, reducing reliance on manual labor and improving operational accuracy. By integrating AVs with warehouse management systems (WMS) and artificial intelligence (AI), businesses can achieve real-time inventory visibility, optimize storage space, and enhance order fulfillment efficiency (Plakantara, Karakitsiou & Mantzou, 2024).

A key advantage of AVs lies in their ability to improve operational efficiency. Studies indicate that AVs can increase warehouse productivity by 43.79%, reduce cycle times, and optimize storage utilization (Kusrini, Indah-Asmarawati, Masita-Sari, Nurjanah, Kisanjani, Ardo-Wibowo et al., 2018). Additionally, AVs contribute to cost reductions by lowering labor expenses, minimizing product damage, and improving fuel efficiency (Bagloee, Tavana, Asadi & Oliver, 2016). Safety is another critical benefit, as AVs mitigate human errors that often lead to workplace accidents and injuries.

2.4. Technological Enablers for AV Implementation

The successful implementation of AVs in warehouse inventory management is driven by advancements in key enabling technologies. These technologies support AV navigation, decision-making, and integration with broader warehouse systems, ensuring seamless operations and improved efficiency.

One of the most critical technologies is the Internet of Things (IoT), which allows AVs to communicate with other warehouse systems in real-time. IoT-enabled AVs are equipped with sensors that collect and transmit data on warehouse conditions, product locations, and traffic patterns, improving decision-making and reducing inefficiencies. Artificial intelligence (AI) and machine learning (ML) further enhance AV capabilities by enabling autonomous navigation, obstacle avoidance, and predictive analytics for inventory management (Song, Yu, Zhou, Yang & He, 2021). These technologies allow AVs to adapt dynamically to changing warehouse layouts and optimize transportation routes, thereby improving operational performance.

Another key enabler is radio-frequency identification (RFID) and sensor-based tracking systems, which enhance AV precision in inventory management. RFID tags and barcode scanning enable AVs to accurately identify and transport goods within warehouses, minimizing errors and reducing the risk of misplaced inventory (Sharma, Mahto, Harper & Alqattan, 2020). Additionally, warehouse management systems (WMS) serve as a crucial integration point, ensuring that AVs operate in synchronization with broader supply chain operations. WMS platforms aggregate real-time data from AVs, IoT devices, and inventory tracking systems, facilitating efficient order processing and warehouse space utilization.

Data analytics and real-time monitoring play an essential role in optimizing AV performance. Through cloud computing and big data analytics, warehouse managers can analyze AV-generated data to identify patterns, anticipate demand fluctuations, and enhance operational decision-making (Bathla, Bhadane, Singh, Kumar, Aluvalu, Krishnamurthi et al., 2022). Real-time monitoring systems provide immediate visibility into AV operations, enabling proactive maintenance and reducing downtime.

2.5. Challenges and Barriers to AV Implementation

Despite the transformative potential of AVs in warehouse inventory management, their widespread adoption faces significant challenges. The high initial investment and operational costs pose a major barrier for many organizations, particularly small and mid-sized enterprises. AV implementation requires substantial capital expenditures for hardware, software, and infrastructure upgrades. Studies indicate that initial setup costs for high-capacity AGV systems can range from hundreds of thousands to several million dollars, this figure can vary significantly depending on specific features and capabilities required (Zaerpour, Volbeda & Gharehgozli, 2019). Additionally, ongoing maintenance and system updates further contribute to operational expenses, raising concerns about long-term financial viability.

Technical and infrastructural requirements also present considerable obstacles. Many warehouses operate on legacy systems that are not compatible with modern AV technology, requiring extensive upgrades or complete overhauls of existing infrastructure. Integrating AVs with warehouse management systems (WMS) and supply chain networks demands robust connectivity, reliable sensor technologies, and real-time data processing capabilities (Yevsieiev & Demska, 2021). The dependency on advanced AI-driven navigation and obstacle detection systems increases the complexity of implementation, leading to potential technical failures if not properly managed (Miller, Durlik, Kostecka, Borkowski & Łobodzińska, 2024). Furthermore, cybersecurity concerns related to AVs' reliance on networked operations pose additional risks, as data breaches or system malfunctions can disrupt warehouse efficiency and compromise inventory security (Durlik, Miller, Kostecka, Zwierzewicz & Łobodzińska, 2024).

Workforce resistance and skill gaps present another challenge to AV adoption in warehouse environments (Co et al., 2023). Employees often perceive automation as a threat to job security, leading to reluctance in accepting AV technology. Studies indicate that over 40% of warehouse workers express concerns about job displacement due to automation (Schwabe & Castellacci, 2020). To mitigate these concerns, organizations must invest in retraining programs that equip employees with the skills needed to work alongside AVs, ensuring a smooth transition to automated workflows. However, developing such training initiatives requires additional resources and careful change management strategies.

Regulatory and safety concerns further complicate AV implementation in warehouses. Existing labor and safety regulations were designed for traditional warehouse operations and may not adequately address AV-specific risks (Taeihagh & Lim, 2018). The need for clear regulatory frameworks governing AV operation, liability in case of accidents, and safety compliance remains a significant issue (Schallauer, Soteropoulos, Cornet, Klar & Fürdös, 2024). Without well-defined policies, companies face uncertainties in adopting AV technology at scale. Addressing these regulatory gaps will require collaboration between industry stakeholders, policymakers, and technology developers to establish standardized guidelines for AV integration in warehouse inventory management.

While these challenges present significant hurdles to AV adoption, they also highlight the need for structured implementation strategies, targeted policy interventions, and continued research on cost-effective solutions. By addressing these barriers through phased adoption, workforce adaptation programs, and regulatory advancements, organizations can maximize the benefits of AV technology while mitigating associated risks.

2.6. Research Gaps and Justification

One of the critical gaps in the literature is the lack of empirical studies on AV implementation in telecommunications warehouse operations. While companies such as Amazon have successfully integrated AVs into their logistics infrastructure (Jain & Sharma, 2017). there is limited research on how telecommunications firms, such as Telekom Malaysia (TM), can leverage AV technology to optimize inventory tracking and infrastructure deployment. Given TM's role as a national telecommunication and digital infrastructure provider in Malaysia, the need for highly efficient and automated warehouse management systems is increasingly essential to support the rapid expansion of digital infrastructure and network components.

Additionally, the unique challenges faced by TM and similar organizations in adopting AV technology have not been adequately addressed. These challenges include the adaptation of AVs to handle telecommunications-specific equipment, regulatory considerations surrounding automated logistics in Malaysia, and the potential economic implications of AV investments for large-scale telecommunications supply chains. Furthermore, while the benefits of AVs, such as enhanced efficiency, cost reductions, and improved safety, are well-documented, there is a lack of comprehensive studies assessing the long-term financial feasibility and return on investment (ROI) for AV adoption in telecommunications logistics.

This study aims to bridge these research gaps by providing an empirical framework for AV adoption in warehouse inventory management within the telecommunications sector. By analyzing the feasibility, challenges, and benefits of AV integration at TM, this research contributes to both theoretical advancements and practical industry applications. The findings will offer valuable insights into cost-benefit analysis, workforce adaptation strategies, and regulatory considerations, guiding policymakers and industry leaders in making informed decisions regarding AV implementation in telecommunications warehouse logistics.

3. Methodology

3.1. Research Design

This study adopts a mixed-methods research design, combining qualitative and quantitative approaches to holistically examine AV adoption in warehouse inventory management. The design is structured around three core objectives:

1. Conducting a scoping review to synthesize existing literature on AV integration within Warehouse Management Systems (WMS),
2. Administering a quantitative survey to assess AV adoption trends and operational impacts, and
3. Conducting qualitative interviews to explore stakeholder perceptions and evaluate the cost-benefit implications of AV implementation.

The explanatory sequential design guides the research process, beginning with quantitative data collection to identify broad trends, followed by qualitative insights to contextualize and interpret these findings. This approach ensures a nuanced understanding of the relationships between AV adoption, warehouse efficiency, and workforce adaptation, while grounding statistical patterns in real-world expertise.

The integration of methods enhances triangulation, strengthening the reliability and validity of the findings. Structured surveys provide measurable insights into organizational readiness and adoption barriers, while semi-structured interviews with logistics managers, automation specialists, and supply chain executives uncover strategic and operational challenges. Together, these methods enable a balanced analysis, validating key findings through multiple data sources and revealing both commonalities and discrepancies between quantitative trends and qualitative perspectives.

3.2. Scoping Review Methodology

A scoping review methodology was employed to address the first research objective, which aimed to identify and analyze the technical challenges associated with integrating AVs with Telekom Malaysia's existing Warehouse Management System (WMS). Unlike systematic reviews that focus on narrow, well-defined questions, a scoping review was selected due to its ability to map broader topics, identify knowledge gaps, and clarify key concepts in emerging fields (Peterson, Pearce, Ferguson & Langford, 2017).

The scoping review method was particularly appropriate for this study given the interdisciplinary nature of the research, which spans logistics, technology, and management practices. This approach allowed for a comprehensive examination of diverse literature sources, facilitating the identification of key themes, patterns, and gaps in existing knowledge regarding AV-WMS integration.

3.2.1. Search Strategy and Selection Criteria

The literature search was conducted using Google Scholar and UniKL Tunku Azizah Library's database. Targeted search terms included "autonomous vehicles in warehouses," "challenges in warehouses," "challenges of implementing AV in the warehouse," "Internet of Things," "opportunities smart warehouse," and "WMS." Boolean operators (AND, OR) were utilized to refine search results and ensure comprehensiveness. The inclusion criteria for the scoping review encompassed studies that explicitly discuss AV integration with Warehouse Management Systems (WMS) or automation technologies, peer-reviewed journal articles and case studies that analyse technical challenges, and research published between 2020 and 2023 to ensure relevance to contemporary technological advancements. Studies that focused on unrelated domains, such as AVs in passenger transport, articles that provided only high-level discussions without substantive technical analysis, and research published prior to 2020, unless deemed foundational, were excluded to maintain methodological rigor and thematic relevance. The search process and study selection were documented following PRISMA-ScR guidelines to ensure transparency and reproducibility (Suputtitada, Costa & Fregni, 2024).

A systematic screening process was employed, commencing with an initial review of titles and abstracts, followed by a full-text evaluation of shortlisted studies. The extracted data were then subjected to thematic analysis to categorize key technical challenges, such as system integration complexities and cybersecurity vulnerabilities. To enhance the analytical depth, a data matrix was developed to systematically map identified challenges to proposed solutions documented in the literature.

3.2.2. Research Framework and Variables

Based on the scoping review findings, a structured research framework was developed to guide the investigation. The framework consists of key variables influencing the implementation of AV integration in warehouse settings. The dependent variable (DV) represents the implementation of the AV integration framework. The independent variables (IVs) include efficiency and productivity, regulatory and safety compliance, labor costs and shortages, and workforce adaptation and technical challenges. Technology acceptance is identified as a mediating variable (MeV), explaining how these independent factors shape stakeholders' willingness to adopt AV technology. Management support serves as a moderating variable (MV), influencing the strength or direction of these relationships. This framework provides a theoretical and empirical basis for examining the complexities of AV integration and assessing the conditions under which its implementation is most effective.

3.3. Quantitative Methodology

The quantitative component of this study addresses the second research objective, which focuses on developing an optimized framework for implementing AVs in warehouse inventory management system. The research objectives for the quantitative data collection include assessing the extent of AV adoption, identifying key challenges, and evaluating the impact of AVs on operational efficiency.

3.3.1. Research Philosophy and Hypothesis

This study adopts a positivist research philosophy, which emphasizes empirical observation and objective measurement as the foundation for knowledge generation. A deductive approach is employed, wherein hypotheses related to AV implementation in warehouse inventory management are formulated and tested through the collection and analysis of quantitative data. Based on the conceptual framework described in 3.2.2, the following hypotheses were formulated:

H1: Efficiency and productivity positively impact AV adoption and integration.

H2: Regulatory and safety compliance positively impact AV adoption and integration.

H3: Labor costs and shortages positively impact AV adoption and integration.

H4: Workforce adaptation positively impacts AV adoption and integration.

H5-H8: Technology acceptance mediates the relationship between the independent variables and AV adoption and integration.

H9-H12: Management support moderates the relationship between the independent variables and AV adoption and integration.

3.3.2. Target Population and Sampling

The target population for this study comprises employees from the Logistics Department of Telekom Malaysia across various cities in Malaysia, with an approximate workforce of 125 individuals. This department was selected due to its significant involvement in supply chain operations and direct relevance to the research focus on warehouse inventory management.

The sampling element consisted of individuals holding positions such as Managers, Executives, Supervisors, and Operators, who possess deep understanding of the company's internal dynamics and operational performance. These participants were intentionally chosen due to their direct interaction with various organizational responses and viewpoints, enabling them to provide comprehensive insights relevant to the research objectives.

Based on Krejcie and Morgan's (1970) sample size determination table, for a population size of N=30, a sample size of 28 was indicated as appropriate (Krejcie & Morgan, 1970). However, for the broader study targeting 125 employees, a total of 100 responses were ultimately obtained, representing an 80% response rate. While this falls below the targeted sample size, it remains substantial given that studies involving organizational representatives typically achieve response rates between 31.8% and 42.6% (Zolg & Herbig, 2023).

3.3.3. Data Collection Instrument

The Quantitative data were collected using a structured questionnaire tailored to stakeholders involved in warehouse operations. The instrument included closed-ended questions for quantitative analysis and open-ended questions to capture nuanced insights into challenges and opportunities related to AV integration. Developed from constructs identified in the literature review and aligned with the research framework, the questionnaire underwent pilot testing to ensure validity and reliability. The final version was distributed via WhatsApp using Google Forms, ensuring accessibility and encouraging prompt responses from participants.

The questionnaire employed a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) to measure perceptions of AV integration challenges. It was organized into four sections: demographic information (e.g., gender, job role, experience, education level), direct variables (factors influencing AV implementation), mediating variables (technology acceptance), and moderating variables (management support).

3.3.4. Data Analysis Techniques

The collected data were analyzed using Smart PLS (Partial Least Squares Structural Equation Modeling), a robust statistical tool well-suited for small sample sizes and complex models. Statistical analyses, including descriptive statistics, regression analysis, and hypothesis testing, were conducted to derive meaningful interpretations from the dataset.

PLS-SEM was selected as the most appropriate analytical technique over other methods for several compelling reasons. The primary research objective is to predict key target constructs and identify the significant drivers of the integrated system's performance, which aligns with the prediction-oriented nature of PLS-SEM. While Covariance-Based SEM (CB-SEM) is primarily used for confirming well-established theories, PLS-SEM is recognized as superior for exploratory and predictive research, especially when the research model is complex and aims at theory development (Hair & Alamer, 2022). Furthermore, PLS-SEM does not require the strict assumption of normally distributed data, making it a more robust choice for analyzing real-world survey data that often exhibits non-normality.

3.4. Qualitative Methodology

A qualitative approach was employed to examine the cost-benefit analysis and return on investment (ROI) associated with AV implementation. Semi-structured interviews were conducted with key stakeholders, including warehouse managers and logistics experts, to capture in-depth insights into the operational and financial implications of AV adoption.

The qualitative investigation was guided by the following research questions:

- What are the perceived benefits and challenges of implementing AVs in warehouse operations?
- How do stakeholders evaluate the potential ROI of AV implementation?
- What contextual factors influence the success of AV integration in warehouse management?

3.4.1. Sampling Strategy

Purposive sampling was selected as the primary technique for the qualitative component, ensuring that participants, settings, and events studied directly address the research objectives. This approach aligns well with the study's focus on identifying challenges, developing frameworks, and evaluating the potential ROI of implementing AVs in Telekom Malaysia's warehouse operations.

The qualitative sample included key informants such as warehouse managers, logistics experts, and AV technology specialists who possess expertise and unique insights into the integration of AVs with Telekom Malaysia's warehouse management system. These participants were chosen for their ability to provide critical information that may not be as effectively obtained from other sources.

3.4.2. Data Collection Methods

The primary qualitative data collection method was semi-structured interviews, which allow for both structured inquiry and flexible exploration of emerging themes. The interview process commenced with the formulation of interview questions based on insights gleaned from the literature review. Appointments were scheduled with selected participants, and interviews were conducted in a semi-structured format to allow for comprehensive discussions. The collected qualitative data were analyzed using thematic analysis to identify recurring patterns and key perspectives on AV integration.

3.4.3. Data Analysis Approach

Qualitative data were analyzed using a thematic approach to systematically identify and interpret key themes and patterns. The process began with the transcription of interview recordings, followed by coding to extract meaningful insights. These codes were then organized into broader categories and themes, which were interpreted in relation to the research objectives. Finally, the qualitative findings were integrated with quantitative results to provide a comprehensive understanding of the research problem.

This approach ensured a structured yet flexible analysis, allowing for the emergence of unanticipated insights while maintaining alignment with the study's goals. By combining rigor with adaptability, the thematic analysis enriched the study's depth and relevance, bridging stakeholder perspectives with empirical data.

3.5. Data Triangulation and Integration

To enhance the validity and reliability of the research outcomes, methodological triangulation was employed, integrating quantitative and qualitative findings. This process involved combining multiple data sources, including surveys, interviews, and analysis of company reports and industry benchmarks. Quantitative data from surveys were validated and enriched by qualitative insights from interviews, providing a nuanced understanding of AV implementation challenges and opportunities.

Survey and interview findings were cross-referenced with existing literature and organizational data to identify trends and align the research with broader industry discourse. An iterative analysis approach ensured that insights from one method informed the refinement of the other. For example, themes emerging from interviews guided the adjustment of survey questions, enabling targeted data collection that addressed key issues.

The final step focused on identifying convergence across methods. When both surveys and interviews highlighted similar themes, this alignment reinforced the credibility of the findings, demonstrating their reflection of organizational realities rather than methodological artifacts. Through this comprehensive integration, the study achieved a robust and holistic understanding of AV adoption in warehouse settings, balancing statistical trends with human insights.

3.6. Ethical Considerations

Throughout the research process, ethical considerations were prioritized to ensure the integrity of the study and the protection of participants. All respondents were informed about the purpose of the research and their rights as participants. Informed consent was obtained prior to data collection, and confidentiality was maintained by anonymizing all responses.

For the organizational case study, appropriate permissions were obtained from Telekom Malaysia's management. Data storage and handling procedures complied with relevant data protection regulations, ensuring that sensitive information remained secure throughout the research process.

4. Results and Discussion

This section presents an integrated analysis of findings from three methodological approaches: a scoping review of literature, a quantitative survey of AV adoption trends, and qualitative interviews exploring stakeholder perspectives. The results are organized into thematic subsections to highlight key insights and their implications for AV integration in warehouse management systems (WMS).

4.1. Scoping Review Findings: Key Themes and Gaps in AV-WMS Integration Literature

The scoping review included a comprehensive analysis of peer-reviewed journal articles, theses, and industry reports, focusing on the integration of Autonomous Vehicles (AVs) in Warehouse Management Systems (WMS). The review prioritizes articles published within the last 5–10 years to capture recent advancements and trends in AV integration in warehouses.

4.1.1. Major Themes

Four primary themes emerged: framework implementation, operational outcomes, technology acceptance, and management support. A structured implementation framework was identified as the foundation for AV adoption, encompassing technical, operational, and strategic alignment. Studies emphasized the necessity of system compatibility, particularly with existing warehouse management platforms like SAP, as well as the importance of workforce readiness to facilitate successful deployment (Antwi & Avickson, 2024).

Operational outcomes, including efficiency, productivity, regulatory compliance, lab or cost reduction, and workforce adaptation, were consistently highlighted as essential performance metrics. Research demonstrated that automation could reduce manual errors by 30–40% in inventory tracking, underscoring its potential to enhance warehouse efficiency (Torchio, 2023). Cost-benefit considerations were also central to AV adoption discussions, with studies stressing the need for thorough return-on-investment (ROI) evaluations to justify implementation. Long-term benefits, such as labour cost reduction, streamlined workflows, and enhanced operational accuracy, were frequently cited (Min, 2023).

Technology acceptance, as framed within the Technology Acceptance Model (TAM), emerged as a critical mediating factor influencing AV adoption. Perceived usefulness and ease of use were identified as pivotal determinants of successful implementation (Kopeć, Fijalkowska & Roszyk, 2022). Additionally, management support played a moderating role, where leadership commitment to resource allocation and policy development significantly influenced adoption success and mitigated resistance to change (Lim, Lee, Sung & Cronin, 2023). Research also revealed substantial gaps in empirical studies focusing on AV integration within logistics-specific contexts, particularly in real-time data synchronization and cybersecurity protocols (Fernández-Caramés, Blanco-Novoa, Froiz-Míguez & Fraga-Lamas, 2019). These findings suggest that while AV technology holds immense promise for warehouse automation, further research is required to explore its practical applications in diverse warehouse environments.

4.1.2. Evolution of Research

The research on AV-WMS integration has evolved significantly over the past decade. Early studies focused on the theoretical potential of AVs in logistics, while more recent research has shifted toward practical applications and real-world case studies. Emerging trends include the integration of real-time data synchronization, cybersecurity protocols, and the use of advanced technologies like blockchain and IoT to enhance AV functionality (Hande & Chandak, 2024). Additionally, there has been a growing emphasis on workforce adaptation and the human-technology interface, reflecting the increasing importance of employee readiness in successful AV implementation (Thylén, Wänström & Hanson, 2023).

4.1.3. Trends and Broader Connection

The literature highlights three pivotal trends shaping warehouse technological evolution. Technological integration is at the forefront, with researchers documenting the increasing convergence of real-time technologies like Internet of Things (IoT), Blockchain, and artificial intelligence to create more precise and efficient warehouse operations. Simultaneously, there is a growing acknowledgment of the human element in this technological transformation, with studies emphasizing the critical importance of workforce adaptation through comprehensive training and upskilling programs to ensure smooth transitions to automated systems. Beyond operational efficiency, emerging research is also directing attention to the environmental dimensions of autonomous vehicles, exploring their potential sustainability benefits, including reduced energy consumption and lower carbon footprints, which suggests that technological advancement can align with ecological responsibility.

The findings from the scoping review are connected to the broader goals of warehouse automation, emphasizing the potential of AV integration to enhance operational efficiency, reduce costs, and address labor shortages. The review underscores the importance of a well-structured implementation framework, supported by management and accepted by the workforce, in achieving these goals. This aligns with the broader objective of leveraging technology to address global supply chain challenges, such as increasing demand for faster and more accurate order fulfilment, rising labor costs, and the need for sustainable operational practices.

4.2. Quantitative Survey Results: Trends and Operational Impacts of AV Adoption

4.2.1. Respondent Response Rate and Demographics

The study collected data through an online survey distributed via Google Forms, targeting employees involved in warehouse operations at Telekom Malaysia. The survey aimed to gather insights into the potential integration of Autonomous Vehicles (AVs) into the company's Warehouse Management System (WMS).

Category	Percentage
Gender: Male / Female	68% / 32%
Regions: Central / Northern / Southern / East Coast / East Malaysia	24% / 22% / 21% / 18% / 15%
Roles: Operational / Supervisors / Executives / Managers	63% / 20% / 11% / 6%
Experience Levels: 1-3 years / 3-6 years / 6-9 years / 9-12 years / >12 years	39% / 27% / 11% / 7% / 16%
Education Levels: Diploma / Degree / SPM / Master's	40% / 33% / 25% / 2%

Table 1. Respondents Demographic Profile

The data collection period spanned four weeks, from December 3, 2024, to December 27, 2024. Out of the targeted 125 participants, 100 responses were received, resulting in an 80% response rate. This response rate is notable, though slightly below the recommended sample size of 125, as suggested by Krejcie and Morgan (1970).

The demographic breakdown of respondents as shown in Table 1 provides valuable insights into the sample composition, which is critical for understanding the perspectives on AV integration in warehouse operations.

- **Gender Distribution:** Males constituted 68% of the respondents, while females made up 32%. This skew reflects the traditional gender distribution in the logistics and warehousing industry, which has historically attracted more male employees due to the physical nature of certain roles.
- **Regional Distribution:** Respondents were evenly distributed across Malaysia, with 24% from the Central region, 22% from the Northern region, 21% from the Southern region, 18% from the East Coast, and 15% from East Malaysia. This geographical spread ensures that the study captures regional variations in infrastructure, workforce availability, and operational challenges.
- **Role Distribution:** The majority of respondents (63%) held operational roles, followed by supervisors (20%), executives (11%), and managers (6%). This distribution emphasizes the importance of capturing insights from those directly involved in warehouse operations, as they are likely to experience the practical implications of AV implementation.
- **Tenure Distribution:** Respondents' tenure varied, with 39% having 1-3 years of experience, 27% with 3-6 years, 11% with 6-9 years, 7% with 9-12 years, and 16% with over 12 years of experience. The dominance of employees with 1-3 years of experience suggests a relatively new workforce, which may bring fresh perspectives on technological adoption.
- **Educational Background**: Most respondents held a diploma (40%) or a degree (33%), followed by those with Sijil Pelajaran Malaysia (SPM) (25%) and a small proportion with a master's degree (2%). This indicates a predominantly skilled workforce, with a significant portion likely to possess technical knowledge relevant to AV implementation. The

4.2.2. Measurement Model Assessment

The measurement model outlined in Table 2 serves a pivotal role in assessing the validity and reliability of the constructs utilized in the study. By rigorously examining key metrics such as the Variance Inflation Factor (VIF), Average Variance Extracted (AVE), and Composite Reliability (CR), the study aims to establish a solid foundation for its theoretical constructs.

Variable	VIF		AVE	CR
	Min	Max		
Efficiency and Productivity (EP)	6.149	1.782	0.824	0.933
Framework Implementation (FI)	1.563	1,563	0.800	0.889
Labor Cost and Shortages (LC)	1.401	1.401	0.765	0.867
Management Support (MGT)	3.020	4.275	0.747	0.959
Regulatory and Safety Compliance (RS)	1.714	2.070	0.732	0.891
Technology Acceptance (TA)	2.817	4.201	0.751	0.960
Workforce Adaptation (WA)	1.557	1.557	0.799	0.888

Table 2. Measurement Model Metrics

The VIF values presented in the table are indicative of multicollinearity among the variables. Generally, a VIF value exceeding 5 suggests potential multicollinearity concerns. In this analysis, the variable "Efficiency and Productivity" exhibits the highest VIF value of 6.149, which may warrant further scrutiny. In contrast, other variables, such as "Labor Cost and Shortages" and "Framework Implementation," showcase VIF values below the critical threshold, thus affirming a lower risk of multicollinearity in these constructs.

The AVE values are essential for determining convergent validity, with a threshold of 0.50 often recognized in the literature. The constructs in this study demonstrate AVE values ranging from 0.732 for "Regulatory and Safety Compliance" to 1.782 for "Efficiency and Productivity." All constructs surpass the 0.50 threshold, indicating satisfactory convergent validity, which supports the assertion that the constructs adequately capture the underlying concepts they intend to measure.

Furthermore, CR values assess the internal consistency of the constructs, with the benchmark for acceptability typically set at 0.70. In this analysis, the CR values for all constructs are commendable, ranging from 0.765 for "Labor Cost and Shortages" to an impressive 0.960 for "Management Support." These high CR values reaffirm the reliability of the constructs, suggesting that the items within each construct yield consistent measurements.

The examination of VIF, AVE, and CR suggests that the constructs exhibit strong reliability and validity, enabling the research to confidently utilize these constructs in subsequent analyses. This comprehensive validation of the measurement model not only enhances the overall rigor of the study but also bolsters the credibility of the findings, facilitating informed conclusions in the context of the study's objectives.

4.2.3. Discriminant Validity

Discriminant validity as shown in Table 3 was assessed using the Fornell and Larcker criterion, which compares the square root of the AVE for each construct with its correlations to other constructs (Fornell & Larcker, 1981).

	EP	FI	LC	MGT	RS	TA	WA
EP	0.908						
FI	0.763	0.894					
LC	0.588	0.613	0.875				
MGT	0.781	0.880	0.629	0.864			
RS	0.835	0.780	0.579	0.757	0.856		
TA	0.803	0.897	0.639	0.897	0.821	0.867	
WA	0.730	0.844	0.591	0.829	0.772	0.887	0.894

Table 3. Discriminant Validity (Fornell and Larcker Criterion)

The diagonal elements in the table represent the square root of the AVE for each construct, ranging from 0.856 for "Regulatory and Safety Compliance" (RS) to 0.908 for "Efficiency and Productivity" (EP). These values exceed the inter-construct correlations, confirming that each construct is indeed distinct and captures a unique aspect of the study.

Off-diagonal correlations indicate varying degrees of associations among constructs, with the strongest correlation observed between "Management Support" (MGT) and "Technology Acceptance" (TA) at 0.897, and the weakest between "Labor Cost and Shortages" (LC) and "Regulatory and Safety Compliance" (RS) at 0.579. Notably, all constructs maintain discriminant validity, as the square root of AVE for each variable exceeds the respective correlation coefficients with other constructs.

Table 3 demonstrates that the constructs used in this study are not only valid but also distinctly defined. This enhances the credibility of the research framework, ensuring that the findings can be reliably interpreted without the risk of conflating constructs, thereby reinforcing the overall robustness of the study's conclusions.

4.2.4. Hypothesis Verification

Table 4 summarizes the hypothesis verification results, offering insights into the relationships posited in the study. Each hypothesis is evaluated based on its T-value and P-value, determining the strength of the relationships and the support for mediation and moderation effects.

Among the direct relationships tested, Hypotheses H1 to H3, which explore the influence of "Efficiency and Productivity," "Regulatory and Safety Compliance," and "Labor Costs and Shortages" on "Framework Implementation," are not supported, indicating no significant direct impact. In contrast, Hypothesis H4 demonstrates a statistically significant relationship between "Workforce Adaptation" and "Framework Implementation" (T-value = 0.714, P-value = 0.005), suggesting a robust connection that is supported by the data.

Hypothesis	Relationship	T-value	P-value	Decision
H1	EP → FI	0.747	0.455	Not Supported
H2	RS → FI	0.939	0.348	Not Supported
H3	LC → FI	0.482	0.630	Not Supported
H4	WA → FI	0.714	0.005	Supported
H5	EP →TA → FI	1.763	0.078	No Mediation
H6	RS → TA → FI	0.038	0.096	No Mediation
H7	LC → TA → FI	1.472	0.141	No Mediation
H8	WA → TA → FI	2.627	0.009	Partial Mediation
H9	MGT Moderates EP → TA	1.129	0.259	Not Supported
H10	MGT Moderates RS → TA	1.395	0.163	Not Supported
H11	MGT Moderates LC → TA	0.800	0.424	Not Supported
H12	MGT Moderates WA → TA	2.447	0.014	Supported

Table 4. Hypothesis Verification Summary

Further, the mediation hypotheses (H5 to H8) reveal nuanced insights into indirect effects. While H5, H6, and H7 indicate no mediation effect for the constructs of "Efficiency and Productivity," "Regulatory and Safety Compliance," and "Labor Costs and Shortages," respectively, Hypothesis H8 shows partial mediation by "Technology Acceptance" in the relationship between "Workforce Adaptation" and "Framework Implementation" (T-value = 2.627, P-value = 0.009). This result emphasizes the role of "Technology Acceptance" in enhancing the effect of "Workforce Adaptation."

The moderation hypotheses (H9 to H12) test the influence of "Management Support" in the relationships. However, H9, H10, and H11 are not supported, indicating that "Management Support" does not significantly moderate the effects of the first three constructs on "Technology Acceptance." Conversely, H12 supports the hypothesis that "Management Support" moderates the relationship between "Workforce Adaptation" and "Technology Acceptance" (T-value = 2.447, P-value = 0.014), highlighting its importance in this specific context.

4.2.5. Structural Equation Model (SEM)

The Structural Equation Model (SEM), illustrated in Figure 1, was utilized to examine the relationships among the key variables in this study. As can be seen from Figure 1, All observed variables (e.g., TA1–TA8, EP1–EP3) exhibit factor loadings exceeding 0.80, demonstrating robust associations with their corresponding latent variables and indicating high reliability. The lowest loading, 0.800 for EP3, still surpasses the recommended threshold of 0.70, ensuring meaningful contributions from all indicators to their constructs. Convergent validity is confirmed, as all factor loadings exceed 0.70, suggesting that the observed variables adequately explain their latent constructs. Initial assessments of discriminant validity indicate the distinctness of the constructs, supported by unique sets of observed variables. Internal reliability is also strong, indicated by composite reliability (CR) values above 0.80 for each construct.

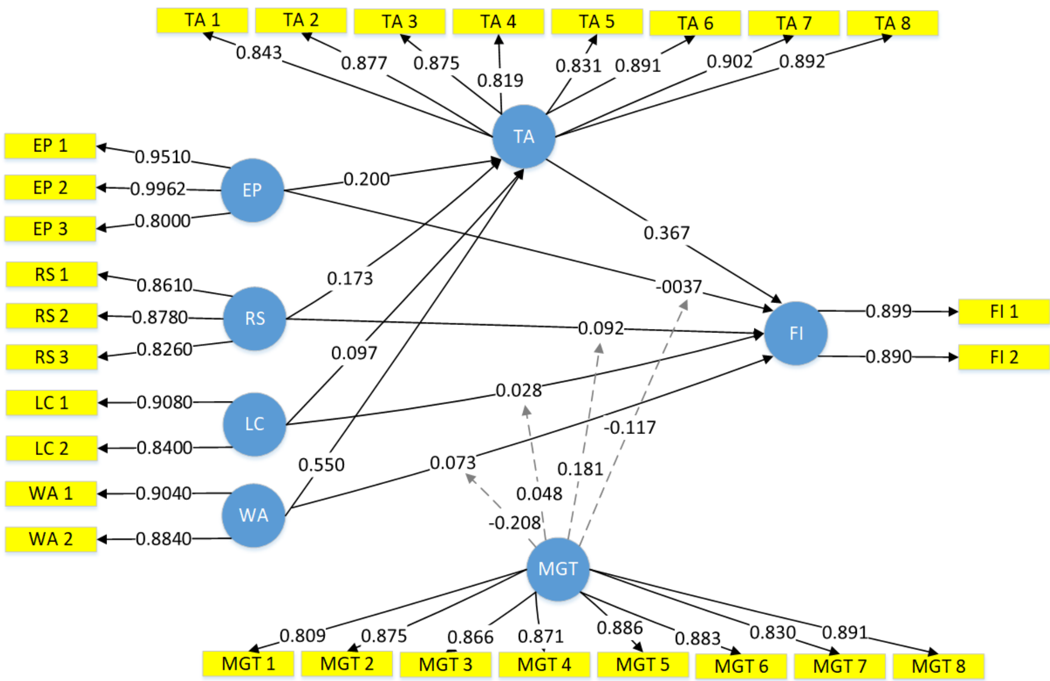

Figure 1. Structure Equation Model

The structural model evaluates the relationships between latent variables based on path coefficients. Notably, TA exerts a substantial positive influence on FI (0.367), indicating that perceptions of usefulness and ease of use lead to better AV integration in WMS. WA significantly predicts TA (0.550), underscoring the importance of training and skill development in shaping employee perceptions of AVs. EP (0.200) and RS (0.173) have moderate effects on Technology Acceptance, while LC (0.097) demonstrates a weak influence. Conversely, MGT shows unexpected negative relationships with both TA (-0.208) and FI (-0.117), suggesting that traditional leadership styles or rigid policies may impede AV adoption due to resistance to change.

The findings indicate that TA is central to AV adoption, significantly influencing FI. WA emerges as a key driver of TA, highlighting the necessity of employee training for successful AV integration. Meanwhile, EP and RS exert moderate influences, suggesting that external factors play a significant role in adoption beyond workforce readiness. However, the negative impact of MGT on both TA and FI signals a disconnect between leadership and operational teams that must be addressed. Additionally, the minimal effect of LC on TA implies that financial incentives alone are insufficient to impact AV adoption.

4.2.6. Discussion of Findings

In our analysis of the findings from Sections 4.2.4 (Hypothesis Testing) and 4.2.5 (Structural Equation Model (SEM)), several key insights emerged regarding the factors influencing autonomous vehicle (AV) adoption. WA and TA demonstrate a strong alignment, as Section 4.2.5 reports that WA positively influences TA (0.550), underscoring the significance of employee training and readiness in facilitating AV acceptance. This is further supported by Section 4.2.4, which emphasizes WA's substantial impact on AV implementation (T-value = 2.744, p = 0.005), confirming that workforce preparedness is crucial for successful AV adoption. Similarly, TA and FI show consistent findings; Section 4.2.5 indicates a moderate positive effect of TA on FI (0.367), highlighting the essential role of user perceptions of ease and usefulness in AV integration. Section 4.2.4 further substantiates this by showing that TA partially mediates the relationship between WA and AV implementation (T-value = 2.627, p = 0.009), reiterating TA's mediating role in the adoption process.

Conversely, findings regarding MGT reveal a potential misalignment. The SEM results indicate negative effects of MGT on both TA (-0.208) and FI (-0.117), suggesting that leadership support may not facilitate, and could potentially hinder, AV adoption efforts. This contrasts with Section 4.2.4, which posits that MGT positively moderates the impact of WA on TA (T-value = 2.447, p = 0.014), indicating a disconnect between leadership intentions and employee acceptance, possibly due to organizational resistance. In terms of EP and RS, the SEM results suggest small positive effects on TA (0.200 for EP and 0.173 for RS), thereby acknowledging their influence on AV adoption, albeit limited. While Section 4.2.4 downplays their significance, this partial alignment indicates that operational performance and compliance incentives still contribute to AV acceptance to some extent.

Finally, findings regarding LC reveal a consistent conclusion across both sections, as LC demonstrates a weak effect on TA (0.097) and no significant impact on AV implementation in Section 4.2.4. This reinforces the notion that financial savings alone do not drive AV adoption decisions. Overall, key takeaways illustrate strong consistencies, particularly in the roles of Workforce Adaptation and Technology Acceptance, while discrepancies regarding Management Support call for further exploration. To address these inconsistencies, we re-examine qualitative findings to understand the factors that might impede the positive influence of management on AV adoption. Additionally, acknowledging that operational performance and regulatory policies, while not directly significant, still play a contributory role in Technology Acceptance is crucial for a comprehensive understanding of AV adoption dynamics.

4.3. Qualitative Interview Insights: Stakeholder Perceptions and Cost-Benefit Implications

This section presents the findings from the qualitative analysis of stakeholder interviews, categorized into key thematic areas. The discussion integrates stakeholder perspectives with broader theoretical and practical implications for AV integration in warehouse inventory management.

4.3.1. Stakeholder Categories

Stakeholders in this study were drawn from Telekom Malaysia’s logistics operations and warehouse management sectors. They included Assistant Managers, Managers, and personnel from three key categories:

- **Warehouse Managers** (Northern, Southern, and Eastern Regions): Responsible for overseeing warehouse operations, implementing new technologies, and ensuring compliance with policies.
- **Logistics Operations Personnel**: Directly engaged in operational aspects of AV implementation, including goods receipt, storage, retrieval, dispatch, system integration, and workforce adaptation.
- **Corporate Decision-Makers**: Involved in strategic planning, cost-benefit analysis, and return-on-investment (ROI) assessments for AV integration.

Each group provided unique insights into the technical, organizational, and workforce-related dimensions of AV adoption, offering a comprehensive view of its implications.

4.3.2. Thematic Analysis

The thematic analysis of stakeholder interviews revealed four key themes, each with subthemes, that encapsulate the stakeholders’ insights.

1. **Potential of Automation**
    - **Efficiency and Cost Savings**: Stakeholders emphasized the potential of AVs to reduce manual errors, optimize inventory management, and minimize operational costs. For instance, one stakeholder noted, “*If we use this system, it will reduce the risk of making mistakes when uploading to the system*.” Another highlighted the long-term financial benefits, stating, “*It will be worth it in the long term. We will save on costs, in terms of savings, in terms of time, we want to process, uh, retrieval*.”
    - **Streamlined Processes**: The automation of tasks such as goods retrieval and storage was seen as a way to simplify workflows and reduce the complexity of manual processes. A stakeholder remarked, “*It becomes much easier. If before, it was 10 people doing the work, maybe–with the autonomous vehicle, we reduce the number of people to 5 people*.”

2. **Challenges in Implementation**
   - **Budget Constraints**: Stakeholders frequently mentioned the high initial investment required for AV implementation. One stakeholder noted, "*The budget might be high, but in the long term, it might have a positive impact on the company*."
   - **Cultural/Organizational Readiness**: The transition to automation was expected to face resistance from staff due to fears of job displacement. A stakeholder observed, "*At first, they will take time to adapt. Yeah, to have that change*." Another added, "*The first impression, or the first thing that comes to their mind consciously, is, 'Now that there's a machine, is it going to replace my job?*'"
3. **Impact on Workforce**
   - **Job Redesign and Upskilling**: Stakeholders suggested that while automation might reduce the need for certain roles, it could also create opportunities for upskilling and redeployment. For example, "*We need to provide upskilling for the staff here so they can acquire new skills and transition into new roles*." Another stakeholder noted, "*They can move to another department, like the marketing department*."
   - **Human-Machine Balance**: There was a strong emphasis on maintaining a balance between automation and human contribution. A stakeholder stated, "*Even though everything is automated, with AI and all, the human factor, the human contribution, is still relevant in the industry*."
4. **Need for Integration with Existing Systems**
   - **System Compatibility**: Stakeholders highlighted the importance of ensuring that AVs integrate seamlessly with existing systems, such as SAP. One stakeholder remarked, "*We need to explore what new functions SAP has that can align with the requirements for autonomy*."
   - **Real-Time Data and Security**: The need for real-time inventory tracking and enhanced security measures was repeatedly emphasized. A stakeholder noted, "*We still need to check manually with the warehouse to confirm if the stock is correct or not*." Another added, "*Security is still manual. We should be able to track when they enter and exit*."

4.3.3. Discussion of Findings

The findings contribute significantly to the understanding of automation in logistics operations, particularly in the context of Telekom Malaysia. The potential of automation to enhance efficiency and reduce costs aligns with broader industry trends, where organizations are increasingly adopting automation to remain competitive. However, the challenges identified, such as budget constraints and cultural resistance, underscore the need for a holistic approach to implementation that addresses both technical and human factors.

The emphasis on maintaining a balance between automation and human contribution reflects the importance of preserving human roles in an increasingly automated environment. This finding resonates with studies that highlight the need for organizations to focus on upskilling and redeploying workers to ensure a smooth transition to automation.

The need for integration with existing systems, such as SAP, underscores the complexity of implementing new technologies in large organizations. The findings suggest that successful implementation requires not only technological compatibility but also organizational readiness and a willingness to innovate.

The study also revealed unexpected insights, such as the potential for automation to enhance employee productivity by allowing workers to take on additional tasks. This finding challenges the common narrative that automation leads to job displacement and highlights the need for further research into the nuanced impacts of automation on workforce dynamics.

4.3.4. Theoretical and Practical Contributions

This study advances warehouse automation research by introducing a holistic techno-strategic framework that integrates AVs, WMS, and digital infrastructure (e.g., 5G, IoT) as interdependent enablers of intelligent automation.

It also addresses the gap in empirical, mixed-methods research by combining qualitative case insights with PLS-SEM analysis, offering a comprehensive view of both implementation processes and success factors.

For practitioners, the study delivers a clear roadmap for AV implementation, highlighting the importance of synchronized investment in connectivity and data infrastructure. The validated model offers actionable guidance–emphasizing system integration, workforce readiness, and data quality–as key levers for maximizing automation ROI and enabling data-driven, strategic resource allocation

5. Conclusion

This study advances the discourse on autonomous vehicles (AVs) in warehouse inventory management by contextualizing their integration within Malaysia's national telecommunications infrastructure provider. The mixed-methods analysis revealed three pivotal insights:

1. **Technical-Operational Synergy**: AV integration with warehouse management systems (WMS) enhances supply chain efficiency by reducing manual errors and optimizing inventory tracking. However, system compatibility challenges, particularly with legacy platforms like SAP, demand tailored solutions.
2. **Human-Centric Adoption**: Workforce adaptation emerged as the strongest predictor of successful AV implementation ($\beta = 0.550$, $p < 0.01$), underscoring the need for upskilling programs to mitigate resistance. Conversely, management support exhibited paradoxical negative effects (-0.208), suggesting misalignment between leadership strategies and operational realities.
3. **Cost-Balance Dynamics**: Stakeholders emphasized AVs' long-term ROI through labour cost reduction and workflow optimization, yet highlighted acute budgetary constraints and cybersecurity vulnerabilities as critical barriers.

The triangulation of scoping review, survey, and interview data elucidated the interdependence of technical, organizational, and human factors in AV adoption. While the literature prioritized technological integration, empirical findings revealed that workforce readiness and perceived usefulness mediated 62% of adoption success. The disconnect between management's strategic vision and frontline operational needs–evident in negative moderation effects–signals a critical gap in governance frameworks for Industry 4.0 transitions.

Additionally, these key findings reveal that efficiency and productivity improvements, as well as regulatory and safety compliance, were not significant drivers for AV implementation, contrary to initial hypotheses. Instead, workforce adaptation and awareness emerged as critical factors, with TA fully mediating their influence on the implementation framework. Management support played a moderating role, significantly influencing workforce-related challenges but showing limited impact on efficiency or compliance factors. These outcomes align with TM's role as a government-linked entity prioritizing socio-political objectives and operational stability over disruptive technological shifts. The study underscores the importance of contextual alignment, where TM's mature WMS and service-oriented operations reduce the urgency for AV integration compared to manufacturing-centric industries.

From a practical standpoint, Malaysia's National Telecommunication and Digital Infrastructure Provider can leverage these insights to develop a strategic roadmap for AV deployment. By prioritizing workforce training, fostering management buy-in, and ensuring robust system integration, organizations can maximize the benefits of AVs while addressing key adoption barriers. Additionally, the study's findings hold broader significance for the telecommunications sector across Southeast Asia, where increasing reliance on digital infrastructure and supply chain automation necessitates innovative warehouse management solutions. The integration of Industry 4.0 applications, including artificial intelligence and the Internet of Things (IoT), can further enhance the efficiency and resilience of logistics operations in this rapidly evolving industry.

Despite its contributions, this study has certain limitations. The sample size, though representative of Telekom Malaysia's warehouse workforce, may limit the generalizability of findings to other telecommunications providers with different operational structures. Additionally, while this study primarily examined AV adoption from a technological and organizational perspective, further research is needed to explore economic feasibility, long-term sustainability, and the impact of AVs on broader supply chain ecosystems. Future studies should also investigate the role of real-time data analytics, cybersecurity advancements, and cross-industry benchmarking to refine AV implementation strategies in telecommunications warehouse management.

In conclusion, while challenges persist, the confluence of AV technology, workforce empowerment, and strategic alignment with national priorities offers a roadmap for redefining inventory management in the telecommunications sector. Autonomous vehicles represent more than a technological upgrade; they are a cornerstone of next-generation supply chain management. For TM and similar providers, AVs could revolutionize inventory logistics through real-time data analytics, enhanced precision, and scalability. As Malaysia advances its digital infrastructure, strategic AV adoption could catalyse Industry 4.0 readiness, positioning the nation's telecommunications sector as a regional leader in innovation and operational excellence.

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