JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190, Special Issue, No.-13, June (2026) pp 48-57 ISSN (Print) 0973-8975

SMART WAREHOUSE: CURRENT SITUATION AND DEVELOPMENT SOLUTIONS IN VIETNAM

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https://doi.org/10.26782/jmcms.spl.13/2026.05.00005

(Received: February 13, 2026; Revised: April 30, 2026; Accepted: May 15, 2026)

Abstract

Warehousing is a crucial link in the supply chain, ensuring the storage and distribution of goods. In Vietnam, logistics costs account for about 16–18% of GDP, which is higher than the global average (10–12%), with warehousing contributing a significant proportion. The rapid growth of e-commerce, at a rate of over 20% per year, has exposed the limitations of traditional warehouses, such as reliance on manual management, low productivity, and a lack of data integration. This study aims to clarify the concept of smart warehouses, analyze the current situation, and propose solutions for logistics enterprises in Vietnam. The research methodology adopts a qualitative and conceptual approach based on secondary data analysis. SWOT analysis is employed to highlight the strengths and weaknesses of traditional warehouses, as well as the opportunities and challenges in developing smart warehouses in Vietnam. In line with this approach, the study focuses on a conceptual and policy-oriented analysis rather than developing mathematical or optimization models for warehouse operations. The study contributes by providing a theoretical basis and a framework for smart warehouses, thereby guiding investment strategies for enterprises and informing national logistics policies.

Keywords: Smart Warehouses; Warehouse Management System (WMS); Logistics; AI; IoT; E-commerce; Digital Transformation

I. Introduction

In the context of globalization, logistics plays a strategic role in promoting trade and enhancing national competitiveness. In many developed economies, logistics costs account for only 10–12% of GDP thanks to optimized infrastructure and technology, while in Vietnam, this ratio remains at approximately 16–18% of GDP, according to national logistics reports. Within the cost structure, warehousing and storage account for a large proportion, underscoring both their importance and existing shortcomings.

Warehouses, with functions of storage, preservation, sorting, and distribution, are increasingly under pressure from the boom of e-commerce, which has been growing at over 20% annually (2020–2024). Traditional warehouse systems reveal many limitations, such as dependence on manual labor, low productivity, and a lack of data connectivity. Meanwhile, a global digital transformation trend is taking place with AI, Big Data, robots, drones, and AR/VR, which help optimize goods flows, enhance productivity, and improve customer experience. Studies suggest that the application of WMS, IoT, and robotics can reduce costs by 15–20% and increase productivity by 25–30%.

In Vietnam, more than 80% of warehouses are still traditional, while the number of modern and smart warehouses remains limited, mainly driven by FDI investment. Some projects, such as Lazada Logistics Park and SLP Bac Ninh, have emerged, but academic research on barriers and suitable development roadmaps is still lacking. Therefore, it is necessary to conduct a comprehensive study to evaluate the current situation and propose feasible solutions.

This study aims to analyze the warehousing system in Vietnam, assess the readiness to adopt smart technologies, and propose solutions for developing smart warehouses in line with infrastructure, human resources, and policies. The research methodology adopts a qualitative and conceptual approach based on secondary data from the Ministry of Industry and Trade, VLA, and international studies. Key indicators such as operating costs, order processing time, inventory accuracy, and space utilization are used for comparative analysis between traditional and smart warehouses, while SWOT analysis is applied to highlight benefits, limitations, and development directions.

In this context, the study focuses on a conceptual and policy-oriented analysis of smart warehouse development in Vietnam. The objective is not to construct detailed mathematical or operational models, but to synthesize existing knowledge, assess structural challenges, and propose development solutions aligned with the current conditions of Vietnam's logistics sector. Accordingly, the research emphasizes strategic, managerial, and policy implications. Future research may extend this study by applying quantitative approaches or operational modeling to evaluate system performance in greater detail.

II. Theoretical Basis and Lessons Learned Related to Smart Warehouses

II.i. Smart Warehouse Management Technologies

A smart warehouse is a system that integrates information technology, automation, and data analytics, replacing manual models with real-time digital management. The core component is the Warehouse Management System (WMS), which enables end-to-end management of goods, integrated with barcodes, RFID, and IoT to improve inventory accuracy and optimize storage space, though implementation costs are high.

IoT and smart sensors support monitoring of temperature, humidity, and goods location, which is particularly important in cold storage; however, they require stable network infrastructure and high security. AI and Big Data enable demand forecasting, slotting optimization, and the reduction of excess inventory, but are limited by the need for standardized data and skilled analytical personnel.

Robots and material handling systems (AGV/AMR, ASRS, conveyors, sorters) can increase productivity by 25–30% [III] and reduce labor costs by 15–20%, but require standardized warehouse space and substantial capital investment. RFID, QR codes, drones, and AI-powered cameras allow rapid inventory checks and improve accuracy to over 98%, though RFID costs remain high and drones face difficulties in confined spaces. However, automation investments do not always deliver expected outcomes due to operational and strategic uncertainties, highlighting the need for careful technology selection and implementation [VII].

In addition, AR/VR supports vision picking (increasing productivity by 20–25% with error rates below 0.5%) and workforce training, while BMS, solar power, and LED lighting can reduce energy costs by 15–20%, contributing to green logistics development [II].

Warehouse operations such as receiving, picking, sorting, and dispatching can be conceptualized as queue-based processes. System performance depends on the relationship between arrival rates (λ) and service rates (μ), commonly reflected in the utilization level ($\rho = \lambda/\mu$). As utilization increases, congestion effects intensify, leading to longer waiting times and reduced throughput. This issue is particularly relevant in highly automated warehouse environments, where demand variability and system interdependencies may amplify bottlenecks. Therefore, capacity buffers and effective coordination are essential to maintain operational stability, especially during peak demand periods, highlighting the need for continuous process optimization and coordination in warehouse operations [VI].

Demand forecasting and inventory management are closely interconnected within smart warehouse systems. Inventory decisions are typically associated with a total cost structure comprising holding costs, ordering costs, and stockout (shortage) costs. The choice of inventory policy is therefore strongly influenced by forecast accuracy, as forecast errors can result in excessive inventory, stockouts, or higher operational costs. Demand uncertainty also affects safety stock requirements and cost trade-offs. These considerations highlight the importance of integrating forecasting and inventory control into a unified decision-making framework and point to a relevant direction for future quantitative research.

System reliability and operational risk are important aspects of smart warehouse performance. Smart warehouses can be viewed as cyber-physical systems characterized by reliability metrics such as failure rate, mean time to failure (MTTF), mean time to repair (MTTR), and system availability. Disruptions caused by equipment failures, system integration issues, or data transmission problems may affect operational continuity and overall performance. In highly integrated environments, failures can propagate across interconnected subsystems, leading to cascading effects and broader system risks. This issue is particularly relevant in the context of Vietnam, where infrastructure conditions and system integration capabilities are still evolving, highlighting the need to consider resilience in the design and operation of smart warehouse systems.

II.ii. International Experience in Smart Warehouse Development

Over the past decade, global warehouse management has undergone a significant transformation thanks to digital technologies. According to McKinsey reports, smart warehouses help enterprises reduce operating costs by 15–20%, increase productivity by 30–35%, and shorten delivery times by 40–50%, establishing a new benchmark for operational efficiency.

In the United States, Amazon operates more than 1,100 logistics centers, of which approximately 55% are equipped with automated robotic systems, including over one million Kiva and Proteus units. Processing speed has tripled, warehousing costs have decreased by 20% per order, and logistics profits have increased by 15% annually. Investment in an automated warehouse ranges from USD 100–300 million, with a payback period of 3–5 years.

In China, companies such as Cainiao and JD Logistics have rapidly expanded smart warehouse systems. Cainiao operates more than 220 smart warehouses, including one in Hangzhou, deploying 800 AGVs to process over one million orders per day. Labor costs have decreased by 35–40%, and productivity is nearly double that of semi-automated warehouses. JD Logistics has expanded automated warehouses in five cities, achieving 2.5 times the productivity of traditional warehouses and increasing profits by 25–30% annually (2021–2025).

In Germany, DHL has integrated automation with green logistics initiatives: DHL applies AR vision picking to increase productivity by 25% with an error rate below 0.5%. AMR systems and smart conveyors reduce processing time by 35–40%. By 2025, more than 65% of DHL warehouses will be equipped with solar panels and BMS, reducing energy costs by 15–20%, with revenue from green logistics accounting for nearly 27%.

These international experiences suggest that the development of smart warehouses depends not only on technology adoption but also on system integration, operational coordination, and long-term strategic investment. In particular, the interaction between automation, data analytics, and system reliability plays a critical role in achieving sustainable performance improvements.

For Vietnam, it is essential to develop a synchronized ecosystem combining technology, strategy, and policy. First, core technologies (WMS, IoT, AI) should be adopted for digitalization, followed by expanded automation (AGV/AMR, drones, ASRS). At the same time, logistics infrastructure must be developed to be “ready-for-automation,” while enhancing digital workforce training and issuing supportive policies (tax incentives, green credit, technical standards). Vietnam can leverage the Logistics Development Strategy to 2030 (reducing costs to ≤16% of GDP, establishing 50 logistics centers) to promote smart warehouse adoption.

III. Current Situation of the Warehousing System in Vietnam

III.i. Current Status of the Warehousing System

By 2024, Vietnam’s logistics sector reached a scale of more than USD 45 billion, with an average annual growth rate of 14–15%. However, costs still accounted for 16.8% of GDP, higher than the global average of 10–12%. Within the cost structure, warehousing and storage represent a large share, reflecting both their central role and infrastructure shortcomings.

According to the Vietnam Logistics Business Association (VLA), about 82% of warehouses remain traditional, mostly small in scale (2,000–5,000 m^2), with low mechanization. Inventory management is still manual or based on basic software, with an accuracy rate of only 85–90%. Limitations include low productivity, inventory discrepancies, peak-season congestion, high labor costs, and occupational safety risks, making this type unsuitable for the fast-growing e-commerce sector.

In contrast, 18% of warehouses are modern, of which less than 5% are truly smart warehouses, mainly developed by foreign direct investment (FDI) enterprises. These warehouses deploy WMS, RFID, IoT, conveyors, and in some cases AGVs, AMRs, and drones. Their advantages are high productivity and inventory accuracy above 98%, with the flexibility to meet fluctuating demand. However, they require large investments (tens of millions of USD), have a payback period of 3–5 years, face shortages of high-tech personnel, and are vulnerable to disruptions when infrastructure failures occur.

In terms of distribution, warehouses are concentrated in two key economic regions. In the North: Hanoi, Bac Ninh, Hai Phong, and Hung Yen; in the South: Ho Chi Minh City, Binh Duong, Dong Nai, and Long An — serving as the country's main distribution hubs. The Central and Central Highlands regions are limited in both scale and quality, with facilities scattered only in Da Nang and Khanh Hoa.

Cold storage is the fastest-growing segment, driven by seafood, agricultural products, and modern retail. In 2024, total capacity reached about 900,000 pallets, of which 75% served seafood and fresh food, concentrated in the Mekong Delta, Ho Chi Minh City, Binh Duong, and Hai Phong, while other regions faced severe shortages.

In summary, as of 2024, Vietnam's warehousing system remains dominated by traditional warehouses with many limitations, while the number of modern and smart warehouses is still limited and unevenly distributed. This highlights the need to accelerate investment and digital transformation to reduce logistics costs to 16% of GDP and improve the country's Logistics Performance Index (LPI) ranking by 2030.

III.ii. SWOT Analysis of Vietnam's Warehousing System

Table 1 highlights a clear contrast between the favorable factors and the existing limitations of Vietnam's warehousing system. In terms of Strengths, the logistics industry has maintained a relatively high growth rate of 14–15% per year with a market size of USD 45–50 billion. Vietnam also enjoys a significant geographical advantage as an international trade gateway, supported by more than 290 industrial zones currently in operation. In addition, strong FDI inflows into industrial real estate have driven the development of many modern warehouse projects.

However, the Weaknesses reveal major bottlenecks of the system. Most warehouses (82%) remain traditional, with low mechanization and manual management, while modern warehouses account for only 18% and smart warehouses less than 5%. The shortage of highly skilled logistics personnel further hinders the operation of advanced technologies. Moreover, the distribution density of warehouses across Vietnam is regionally imbalanced, and warehouse infrastructure is still inadequate, leading to uneven development among regions.

Table 1: Comparative Table of Strengths and Weaknesses in Vietnam's Warehouse System

Strengths (S)	Weaknesses (W)
The logistics industry grows 14–15% annually, market ~USD 45–50 billion.	82% of warehouses are traditional, low mechanization, manual management.
Favorable location as an international trade gateway, 290+ industrial zones.	Modern warehouses are only 18%; smart warehouses <5%.
Strong FDI inflows into industrial real estate → modern warehouse projects.	Shortage of skilled logistics personnel for advanced systems.
	The distribution density of warehouses in Vietnam is unbalanced, and warehouse infrastructure is inadequate.

Table 2 shows the coexistence of development opportunities and major challenges for Vietnam's warehousing system.

Opportunities include the boom of e-commerce, projected to reach USD 39–40 billion by 2025, creating strong demand for urban warehouses and cold storage. The Government's 2030 targets of reducing logistics costs to ≤16% of GDP and improving the Logistics Performance Index (LPI) into the world's top 50 serve as important drivers for modernization. The development plan for at least 50 regional and national logistics centers by 2030 provides clear growth space. The trend of digital transformation and green logistics also offers favorable conditions for technology adoption.

Threats highlight significant risks and barriers. Competition from international corporations with superior capital and technology poses difficulties for domestic enterprises. High investment costs for smart warehouses with slow payback periods of 3–5 years are major obstacles. The legal framework and technical standards for smart warehouses remain incomplete and inconsistent, which may hinder implementation. Cybersecurity risks and dependence on imported equipment further increase the vulnerability of the warehousing system.

Table 2: Comparative Table of Opportunities and Threats in Vietnam's Warehouse System.

Opportunities (O)	Threats (T)
E-commerce projected at USD 39–40 billion by 2025 → strong demand for urban warehouses & cold storage.	Competition from international corporations with superior capital & technology.

Opportunities (O)	Threats (T)
Government 2030 target: logistics costs ≤16% GDP; LPI top 50 globally.	High investment costs for smart warehouses, payback 3–5 years.
Development plan: ≥50 regional/national logistics centers by 2030.	An incomplete legal framework & technical standards for smart warehouses.
Digital transformation & green logistics trend support technology adoption.	Cybersecurity risks & dependence on imported equipment.

IV. Solutions for Developing Smart Warehouses in Vietnam

IV.i. Solutions for Enterprises

Given the operational challenges identified in Sections 2 and 3, particularly bottlenecks in processing flows, mismatches between demand forecasting and inventory management, and system reliability issues, enterprises need to adopt a phased approach to smart warehouse development.

As the direct operators of warehouses, enterprises should develop implementation roadmaps that align with their financial capacity and operational scale. For small and medium-sized enterprises, instead of investing immediately in full automation, the initial step can be digitalizing management with a basic WMS combined with barcodes and RFID to improve inventory accuracy and reduce losses. This is a practical solution to overcome the limitations of traditional warehouses, which still account for more than 80% of the current system.

In the next stage, semi-automation can be introduced with conveyors, pick-to-light systems, or sensor-equipped electric forklifts, aiming to reduce manual labor and increase processing speed. Once enterprises gain sufficient scale and experience, they can move toward advanced automation with AGVs/AMRs, drones for inventory management, and AI for demand forecasting. This step-by-step roadmap minimizes financial risks while facilitating gradual adaptation to technology and workforce requirements.

Another important factor is the development of digital human resources. Enterprises should invest in training employees in high-tech operations, collaborate with universities and research institutes to implement “Logistics 4.0” programs, and shift from experience-based management to data-driven decision-making.

Finally, enterprises should strengthen value chain linkages by forming alliances to jointly invest in large-scale smart warehouses, sharing costs and data. This approach enhances the competitiveness of domestic enterprises against international corporations.

IV.ii. Solutions for Infrastructure and Technology

From a system perspective, the effectiveness of smart warehouses depends not only on individual technologies but also on the integration of infrastructure and data systems to address operational coordination, demand variability, and system reliability.

Experience from advanced economies shows that smart warehouses can only develop within a synchronized infrastructure ecosystem [VIII]. For Vietnam, priority should be given to planning logistics zones connected with seaports, airports, ICDs, and railways to facilitate multimodal transport, reducing costs and time. New warehouse projects should be designed according to "ready-for-automation" standards, with racks 11–12 meters high, floor load capacity compatible with robots, and stable network infrastructure for IoT [I].

In terms of technology, enterprises should deploy next-generation WMS integrated with TMS and ERP to synchronize data from production to consumption. IoT and sensors must be widely used to monitor temperature, humidity, and goods location, particularly in cold storage [IV]. AI and Big Data can support demand forecasting, optimize slotting, and assist in delivery planning [X, IX].

At the same time, Vietnam should develop a national logistics data center to leverage big data, apply AI in planning and supply chain management, and thereby optimize the entire logistics ecosystem.

Ultimately, the goal is green and sustainable logistics. New warehouses should adopt LED lighting, BMS, and rooftop solar energy, which both reduce long-term costs and comply with ESG standards, aligning with the Government's orientation toward green logistics development.

IV.iii. Policy Solutions Green Warehouses

At the policy level, the development of smart warehouses needs to address not only structural limitations but also operational challenges such as coordination inefficiencies, demand fluctuations, and system reliability risks identified in earlier sections.

In this context, the State plays a pivotal role in guiding and creating an enabling environment for smart warehouse development, particularly through improving logistics infrastructure to attract investment [IV].

The legal framework and technical standards need to be completed. Currently, Vietnam only has general regulations on warehouses and fire protection, but no specific standards for automated warehouses, IoT warehouses, or data security. It is necessary to issue a set of TCVN/QCVN standards for smart warehouses, drawing on experiences from Germany and the EU, to ensure harmonization and attract international investment.

Financial incentives should be introduced, such as reduced import taxes on equipment, interest rate support for green logistics projects, or the establishment of a digital transformation support fund. Lessons from China show that strong government support enabled Alibaba and JD to build comprehensive automated warehouse systems.

The National Logistics Strategy (Decision No. 221/QĐ-TTg, 2021) should be implemented, with the goal of establishing at least 50 regional and national logistics centers by 2030. These centers must be designed to be "ready for automation," with priority investments directed to the Central and Central Highlands regions to address regional imbalances.

In addition, international cooperation in technology and workforce training with the United States, Germany, and Japan should be strengthened to both acquire advanced technologies and address the shortage of high-quality logistics professionals.

V. Conclusion

By 2024, Vietnam’s warehousing system will still rely primarily on traditional models, accounting for more than 80% of total warehouses, while modern warehouses make up only about 18% and smart warehouses less than 5%. This reflects a significant disparity between the rapid growth of the logistics sector and the requirements for technological and managerial innovation. The SWOT analysis reveals a twofold picture: Vietnam enjoys many advantages from the strong development of e-commerce, its strategic geographical location, and increasing FDI inflows, yet it continues to face limitations in terms of highly skilled human resources, investment capital, uneven warehouse distribution, and an incomplete legal framework.

This study contributes to clarifying the concept of smart warehouses and their key components, from warehouse management systems (WMS), IoT, and AI to automation solutions. The comparison between traditional warehouses and technology-driven models, combined with qualitative analysis within the SWOT framework, provides a theoretical foundation for further research in logistics and digital transformation. In addition, the study highlights key operational aspects of smart warehouse systems, including process coordination, the integration of demand forecasting with inventory management, and system reliability considerations.

The study proposes a development roadmap suitable for enterprises, starting with the digitalization of warehouse management, gradually applying semi-automation, and eventually moving toward fully automated models. At the same time, policy recommendations are proposed, such as establishing national standards for smart warehouses, creating financial incentives for technology investment, planning regional and national logistics centers on a “ready-for-automation” basis, and promoting the adoption of green technologies (BMS, LED lighting, solar energy) to support sustainable development.

Overall, the study provides both theoretical insights and practical implications for the development of smart warehouses in Vietnam. By integrating international experience with domestic conditions, it contributes to supporting the transition toward more efficient, technology-driven, and sustainable logistics systems.

Conflict of Interest:

The authors declare that there is no conflict of interest regarding this article.

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