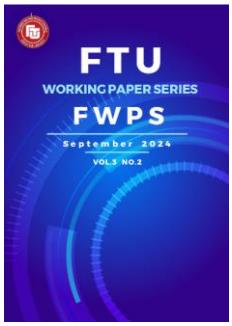

Working Paper 2024.3.2.4

- Vol 3, No 2

MÔ HÌNH DIGITAL TWINS VÀ TIỀM NĂNG ỨNG DỤNG TRONG VẬN HÀNH KHO HÀNG Ở VIỆT NAM

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Tóm tắt

Nghiên cứu này xem xét tính khả thi và đề xuất việc ứng dụng việc ứng dụng mô hình Digital Twins trong thiết kế và vận hành kho hàng tại Việt Nam nhằm theo kịp nhu cầu thị trường và ứng phó với các rủi ro phức tạp trong chuỗi cung ứng. Digital Twins vận hành bằng cách tạo ra các bản sao ảo của hệ thống vật lý, cung cấp ma trận thông tin thời gian thực, từ đó cho phép phân tích dữ liệu hiệu quả và cải thiện khả năng ra quyết định của cấp quản lý, đồng thời người vận hành hệ thống có thể kiểm soát, điều chỉnh trực tiếp lên vận hành kho (đặc biệt hệ thống tự động hóa). Nghiên cứu sử dụng phương pháp nghiên cứu tại bàn, nghiên cứu dựa trên dữ liệu thứ cấp từ các nguồn đáng tin cậy. Thông qua tìm hiểu kỹ lưỡng nền tảng lý thuyết của Digital Twins, nghiên cứu tập trung chỉ ra cơ hội, cách thức khi áp dụng công nghệ vào vận hành kho, bên cạnh đó đề xuất cách tiếp cận phù hợp với điều kiện chung của doanh nghiệp Việt. Tổng kết lại, Digital Twins là một khái niệm mới mẻ và chưa được ứng dụng phổ biến tại Việt Nam bởi một số rào cản khách quan và chủ quan. Tuy nhiên, với cách tiếp cận phù hợp, doanh nghiệp Việt Nam vẫn có thể tận dụng triệt để sức mạnh của Digital Twins, nâng cao chất lượng vận hành kho.

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Từ khóa: Digital Twins, vận hành kho, thời gian thực, phân tích dữ liệu, khả năng ra quyết định.

DIGITAL TWINS MODEL AND POTENTIAL APPLICATIONS IN WAREHOUSE OPERATIONS IN VIETNAM

Abstract

This research investigates the application of Digital Twins in Vietnam's warehouse operations, motivated by the need for enhanced efficiency and optimization in the country's expanding industrial landscape. Digital Twins, which create virtual replicas of physical systems, offer real-time insights, advanced data analytics, and improved decision-making. The study aims to transform warehouse operations by improving inventory management, space utilization, downtime reduction, and overall performance. The literature review underscores the advantages of Digital Twins in enhancing productivity, reducing costs, and supporting informed decision-making. The primary objectives are to understand the theoretical underpinnings of Digital Twins, evaluate the current state of Vietnamese warehouses, and explore the potential benefits and implementation challenges of this technology. Utilizing a desk-based research methodology, the study draws on secondary data from credible sources. It also highlights the importance of cybersecurity and government support for the adoption of Digital Twins. The research seeks to provide actionable recommendations for integrating Digital Twins into Vietnamese warehouses, fostering a more agile and competitive supply chain ecosystem.

Keywords: digital twins, warehouse operations, real-time insights, advanced data analytics, informed decision-making

1. Rationale of the research

The research on Digital Twins Model and its potential applications in warehouse operations in Vietnam is motivated by the increasing need for efficiency, accuracy, and optimization in supply chain management within the country's rapidly growing industrial landscape. By exploring the concept of digital twins, which involves creating virtual replicas of physical assets or systems, this research aims to revolutionize warehouse operations by providing real-time insights, predictive analytics, and enhanced decision-making capabilities. In Vietnam, where logistics play a pivotal role in economic development, adopting digital twin technologies promises to streamline inventory management, optimize space utilization, minimize downtime, and ultimately improve overall operational performance. Through this study, stakeholders seek to harness the transformative potential of digital twins to address the unique challenges faced by warehouse operators in Vietnam, paving the way for a more agile, responsive, and competitive supply chain ecosystem.

2. Literature review

2.1. Previous research on the application of Digital Twins models

In recent years, optimizing operations and improving the efficiency of supply chain activities has been a major concern for many businesses, and optimizing warehouse operations through the application of Digital Twins is one of the ways to achieve this. In the study of Baruffaldi, Accorsi and Manzini (2019), the authors demonstrated that through the use of

Digital Twins, warehouse managers can determine the best management scenario that maximizes productivity, minimizes picking and storage costs, and has the quickest payback period by measuring the short- and mid-term effects of implementing new WMS features. In Industry 4.0, a WMS Digital Twin helps the 3PL build reliable added-value connections with their clients by raising awareness and visibility. By using Digital Twins in warehouse management to simulate possible scenarios and consequences, warehouse operators will be significantly supported in making operational decisions, ensuring that those decisions are more accurate and objective.

With its capacity to create warehousing plans with the aid of potent warehouse real-time data analysis that optimize the packing solution for conserving carton resources, the Digital Twin technique can maximize the utilization and efficiency of large-scale automated high-rise warehouses (Leng et al., 2019). The potential of Digital Twin in supporting the order picking process in terms of picking tour size, human resource planning, and order-release strategy adjustments was also highlighted by Kauke, Galka and Fottner (2021) in their research paper illustrating the implementation of a Digital Twin system by a logistics service provider. Furthermore, the Digital Twin, which contains up-to-date information about the physical locations of goods and forklifts in the warehouse, can quickly generate new alternative scenarios, optimize warehouse allocation, and determine which routes the forklifts should take to reduce overall warehouse management costs (Braglia et al., 2019). Similarly, the optimal location of the products on the warehouse shelves may be determined by a warehouse management system using an unmanned aerial vehicle (UAV) based on digital twin and 5G technology, as the system can alert the operator to any anomalous data that is found (Chen et al., 2020). It can be seen that the application of Digital Twins, in addition to supporting the decision-making process in warehouse management, also has the ability to increase the efficiency of many main activities in the warehouse such as picking and storage, ensuring accuracy and optimizing time and cost.

2.2. Research gaps, research objectives and research questions

Despite increased global interest in Digital Twin technology and its applications in various industries, there has been little to no study on its applicability in Vietnamese warehouse operations. This gap indicates an important topic of research, since investigating the possibilities of Digital Twins in this context might provide substantial insights into boosting efficiency and solving present operating issues in Vietnamese warehouses.

The primary goal of this study is to investigate the concept of Digital Twins, understand its theoretical foundation, and assess the potential applications of Digital Twins in improving Vietnamese warehouse operations, with an emphasis on outcomes such as increased efficiency, real-time monitoring, predictive maintenance, and improved management. This is due to the fact that there are relatively few studies on the possibilities of using Digital Twin in warehouse operations in Vietnam. Based on this, the report proposes suggestions for industry stakeholders to encourage the adoption of Digital Twins in warehouse operations, as well as ways for efficiently integrating this technology.

In order to accomplish these goals, the study will tackle some important questions:

1. What is the concept and theoretical foundation of the Digital Twin model, and what are its essential elements and features?

2. What is the current condition of Vietnamese warehouse operations, and what are the common problems and inefficiencies?

3. How might Digital Twins be deployed in Vietnamese warehouses, and in what ways could this model improve productivity, control, and maintenance?

4. What are the potential obstacles to implementing the Digital Twin model in Vietnamese warehouses?

5. How can Vietnam's warehouse operations be revolutionized by the Digital Twin model, and what practical suggestions can be made for its effective implementation?

3. Methodology

In this study, the authors use a desk-based research method, drawing on secondary data and information from credible publications, journals, and other scholarly sources. This technique was selected since there is little previous research on the use of Digital Twin model in warehouse operations in Vietnam, necessitating a thorough examination of the relevant literature to provide a solid theoretical framework.

4. Theoretical framework

4.1. Digital twins models

A digital twin is a virtual representation of an object or system designed to reflect a physical object accurately. It spans the object's lifecycle, is updated from real-time data and uses simulation, machine learning and reasoning to help make decisions (IBM, 2022).

4.1.1. Characteristics

Digital twins transcend static models, acting as dynamic companions to real-world objects (Jones, 2022). There are some characteristics of the digital twins model which prove the potential of the application.

Firstly, the capacity of connectivity, the digital twins can interface with their physical counterpart effortlessly, seamlessly exchanging data in real time. This allows them to constantly monitor and reflect the physical system's behavior (Attaran, Attaran and Celik, 2024).

Secondly, the realism and accuracy of this model, a successful digital twin aims to accurately replicate the actual item or procedure. This means that it can provide a near approximation to reality by properly reflecting the properties and behavior of the physical system (Attaran, Attaran and Celik, 2024). Furthermore, unlike a normal blueprint, the digital twins also can reprogram smarter than those. They are meant to be flexible, in contrast to static models. They may be updated with fresh data and regulations, enabling simulations and forecasting depending on shifting circumstances. They are ideal for changing circumstances because of their dynamic character.

Last but not least, the predictive capabilities. By analyzing historical and real-time data, digital twins can predict future behavior of the physical system. This allows for proactive

maintenance, identifying potential issues before they occur, and optimizing performance (Mitrofanskiy, 2024).

Finally, modularity is a hallmark of digital twins. They are built with interchangeable components that enable customization to fit specific application needs and simplify integration with existing systems (van Schalkwyk, 2023). The interchangeable components are the parts or modules that are designed to be easily swapped with others of the same kind. They are typically used in physical systems to allow for flexibility, repairs, or upgrades. For example, Virtual Robot Modules in a Manufacturing Plant's Digital Twin. The digital twin of a manufacturing plant can be significantly enhanced by utilizing virtual robot modules. These modules simulate real-world industrial robots, allowing engineers and plant managers to simulate, optimize, and control the production process more effectively.

4.1.2. Model application

The theoretical framework for the model application of digital twins models involves using digital replicas to simulate, analyze, and optimize real-world systems and processes. In practice, digital twins serve as a bridge between the physical and digital worlds, enabling continuous monitoring and simulation of systems under various conditions.

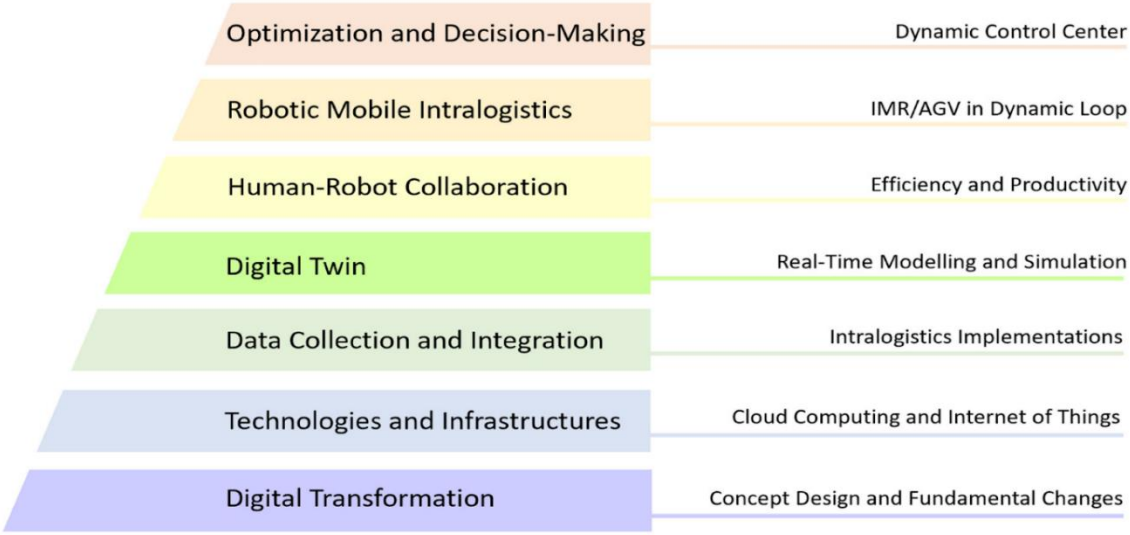


Figure 1. Hierarchy of digital transformation (DTR) based on digital twins (DTs)

Source: Rahmani, Jesus and Lopes, 2024

The figure above depicts a pyramid that illustrates the six levels of digital transformation based on the DTM (digital twins model) in a factory setting, with the most fundamental level at the bottom and the most strategic level at the top. By applying the digital twins and mobile intralogistics represent specific areas of focus within the transformation, and all these components collectively contribute to optimization and decision-making at the highest level in model application (Rahmani, Jesus and Lopes, 2024). As we all know that, to apply DTM in Vietnam will need a huge investment. Only giant enterprises can invest in digital transformation and in this model. From the pyramid above, small-to-medium enterprises in Vietnam can utilize and optimize the advantages of this model by splitting it into small levels.

By bridging the physical and digital worlds, digital twins offer a powerful tool for optimizing and managing physical systems, leading to significant advancements in various fields.

a. **Physical System:**

All of the information is connected by Internet of Things (IOT) technology to collect and integrate the data of the physical world. The foundation of the framework is the physical system itself. This can encompass anything from a single machine or product to a complex factory or even an entire city (IBM, 2022). Sensors and Internet of Things (IoT) devices are attached to the physical system, continuously collecting data on its state, behavior, and performance. This data can include parameters like temperature, pressure, vibration, location, and resource consumption (EI, 2024).

b. Data Acquisition and Integration

The head of any digital twins model lies in the data that bridges the physical world with its virtual counterpart is the data acquisition and integration.

- **Data acquisition**: is involved in understanding needs, sensor selection and deployment. Understanding needs is the first step to define the purpose of the digital twin, what aspects of the physical system (products, process,..). After that, the model with select sensors is deployed on the physical system to capture the chosen data points. These sensors can be pre-existing or require additional installation, depending on the system and desired data.

- **Data integration**: is the tool that supports data acquisitions. The model will address heterogeneity; the data may come from diverse sources with varying formats and protocols. The framework needs mechanisms to standardize and pre-process this data for seamless integration. Another point is the data storage and management, the platform stores the acquired data securely and efficiently. Techniques like data warehousing and time-series databases are often used for this purpose (Merino et al., 2023).

c. Model-Data Synchronization

In the digital twins framework, maintaining consistency between the physical system and its virtual model is vital. This is achieved through mode-data synchronization, a process that can ensure the digital twin reflects the latest state of the physical counterpart. The data is fed into the digital twin, keeping it informed about the machine's current state. This tool is called "two-way street": the digital twin can analyze the data and recommend ways to optimize the machine's performance, which can then be implemented in the real world. The key is finding the right update frequency. While frequent updates ensure the digital model is always current, they can be overwhelming. On the other hand, infrequent updates can make the digital model outdated. To address this, different strategies are employed. Some involve updating the model at set intervals, while others update only when significant changes occur. Additionally, techniques like data filtering ensure the information fed into the model is accurate and relevant. By maintaining effective model-data synchronization, the digital twin remains a powerful tool for monitoring, analyzing, and ultimately, optimizing the performance of the physical system it represents (Tan and Matta, 2023).

d. Model Analytics and Insights:

The digital twin framework goes beyond simply mirroring the physical system. By leveraging data and advanced analytics, it unlocks a treasure trove of insights that can be categorized as descriptive, predictive, diagnostic, and prescriptive:

- **Descriptive Analytics:**
    - **Understanding Current State:** This is the foundation, providing a real-time view of the physical system's performance. Sensor data from the physical system is visualized and analyzed to understand its current operating conditions (e.g., temperature, pressure, energy consumption).
- **Predictive Analytics:**
    - **Forecasting:** By analyzing historical data and trends, the digital twin can predict future behavior of the physical system. This allows for proactive maintenance, preventing potential failures before they occur. (e.g., predicting when a machine component might need replacement based on wear and tear data) (Mitrofanskiy, 2024)
- **Diagnostic Analytics:**
    - **Root Cause Analysis:** When an issue arises in the physical system, the digital twin can be used to diagnose the root cause. By analyzing sensor data and model simulations, the framework can pinpoint the source of the problem, enabling faster and more targeted troubleshooting. (e.g., identifying the faulty sensor causing a malfunction in a machine) (Zhang et al., 2021).
- **Prescriptive Analytics:**
    - **Taking Action:** This is the pinnacle of digital twin analytics. The framework goes beyond diagnostics and suggests corrective actions or optimizations for the physical system. This can involve adjusting operating parameters, scheduling maintenance tasks, or even re-designing components based on the insights gleaned from the model. (e.g., recommending adjustments to machine settings to improve efficiency or reduce energy consumption)

4.2. Warehousing

In the context of Vietnam's burgeoning industrial and e-commerce landscape, where spatial constraints and logistical exigencies frequently intersect, the efficiency of warehouse design assumes heightened significance. This efficiency delineates the parameters for effective inventory management and logistical throughput.

Warehouse efficiency refers to the ability of a warehouse to optimize its operations and resources to achieve the desired level of performance in terms of speed, accuracy, and cost-effectiveness (Kłodawski et al., 2017).

The relationship between warehouse efficiency and warehouse attributes has been extensively researched. According to Guliti et al. (2019), warehouse layout along with other attributes significantly impact warehouse efficiency. This is corroborated by the study conducted by Halawa et al. (2019), which emphasizes the importance of warehouse location, warehouse design, and warehouse management in achieving optimal efficiency.

In addition to the warehouse layout, the operational processes within the warehouse are crucial for enhancing overall performance. Effective and efficient warehouse operations require consideration of numerous design elements and resources. These include the physical layout, such as dock placement, aisle configuration, lane depth, and stack height, as well as storage and handling equipment, including various types of racks and forklifts, and automation solutions like conveyors and robots.

The synergy between layout and operations is critical for the overall efficiency of a supply chain warehouse. Without a well-designed and effectively managed warehouse, enhancing warehouse efficiency and consequently the performance of the company is challenging (Kłodawski et al., 2017).

4.2.1. Warehouse Design

Warehouse layout constitutes a pivotal aspect within warehousing operations. This facet encompasses the strategic orchestration of spatial configurations and logistical infrastructure to optimize resource utilization and streamline operational processes. Paramount considerations within warehouse layout entail judicious site selection, meticulous floor planning, integration of advanced storage systems, and the adept incorporation of emerging technological solutions.

Richards (2014) recommends that the optimal warehouse layout maximizes spatial efficiency while minimizing travel time and the number of points of contact. Effective warehouse design should prioritize flexibility, accessibility, and efficiency, while simultaneously reducing non-value-adding activities (Abushaikha, Salhieh and Towers, 2018).

In Vietnam, the rapid rise of e-commerce and industrial demands has exerted considerable pressure on the warehousing system to accommodate a diverse array of goods. Consequently, warehousing operators must deploy numerous operational processes and specifications to adapt to evolving customer demands. Traditional layouts (such as U-shaped or L-shaped configurations) and conventional slotting methods (based on ABC analysis, item types, and volumes,..), even when enhanced with Industry 4.0 technological advancements, frequently fall short in addressing the increasing complexity of customer order specifications and delivery times, particularly in the e-commerce sector. This issue is especially pronounced during peak seasonal periods, when commodities are dispersed across warehouse lanes and aisles, causing workers (pickers, packers, etc.) to struggle in completing their tasks efficiently. This situation underscores the need for more dynamic approaches.

In response to these challenges, Amazon has developed one of the world's most efficient warehouses by embracing a system of organized chaos (Kessler, 2018). Amazon's approach involves the strategic use of randomness in warehouse organization, which contrasts with traditional orderly methods. This system is supported by extensive automation and information systems that provide strict monitoring, insightful analytics, and streamlined operations, thereby maintaining efficiency despite apparent randomness.

In Vietnam, there is very promising for the adoption of similar cost-effective initiatives that align with this strategy.

4.2.2. Warehouse activities

A warehouse is a complex environment involving various tasks and operations, such as picking, storing, scheduling, and routing. Achieving warehouse efficiency necessitates the arrangement of all activities in a streamlined and optimized manner.

Figure 2 illustrates one possible layout of these functions within a warehouse. Each task is typically confined to its designated zone, functioning as a node within a broader network. Given the numerous flows of goods in a warehouse, aligning these with multiple processes introduces a high level of complexity, necessitating optimal process selection (Kłodawski et al., 2017).

Figure 3 presents a network of material handling costs, one of the predominant expenses in warehouse operations. This cost factor is crucial in selecting appropriate processes for warehouse operations. In addition to cost considerations, other elements such as labor, technology, and organizational factors are also taken into account.

Figure 4 demonstrates a binary decision-making tree for selecting warehouse operation processes, showcasing the probability of choosing the optimal operation strategy. Models similar to this can cover dimensions beyond binary possibilities (yes/no) to determine the most efficient processes.

Three pictures showcase each stage on how to choose operation strategy from: network's outline, deep-dive analysis of each factor, simulation tests. However, the practical applicability of any model hinges on the reliability of the data used, which must be updated and effective in reflecting real-world conditions.

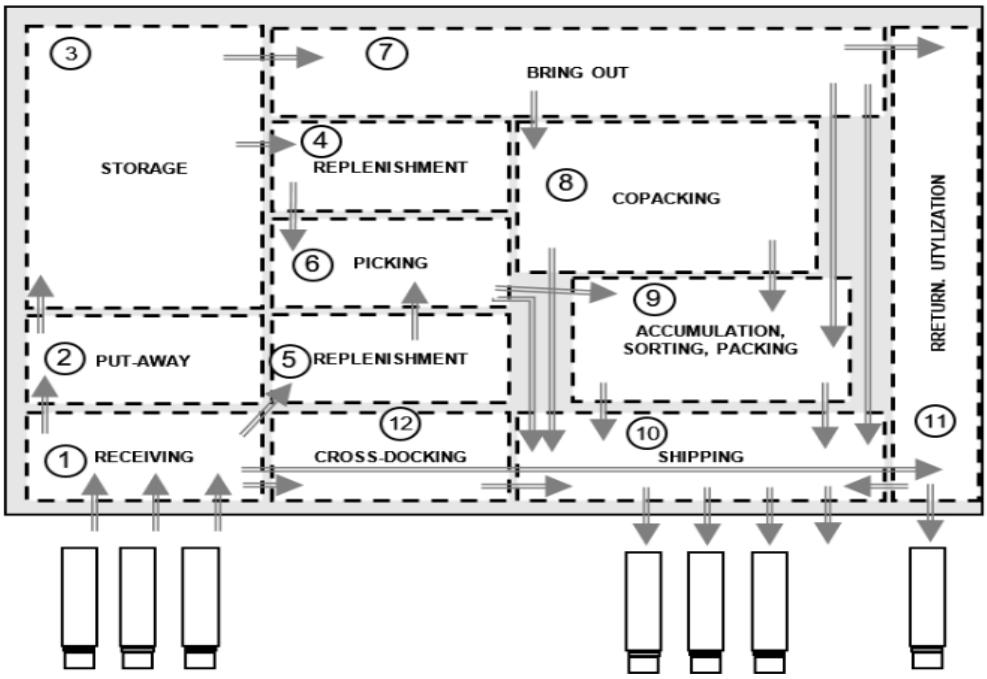


Figure 2. Functional area and sub-processes of warehousing

Source: Kłodawski et al., 2017

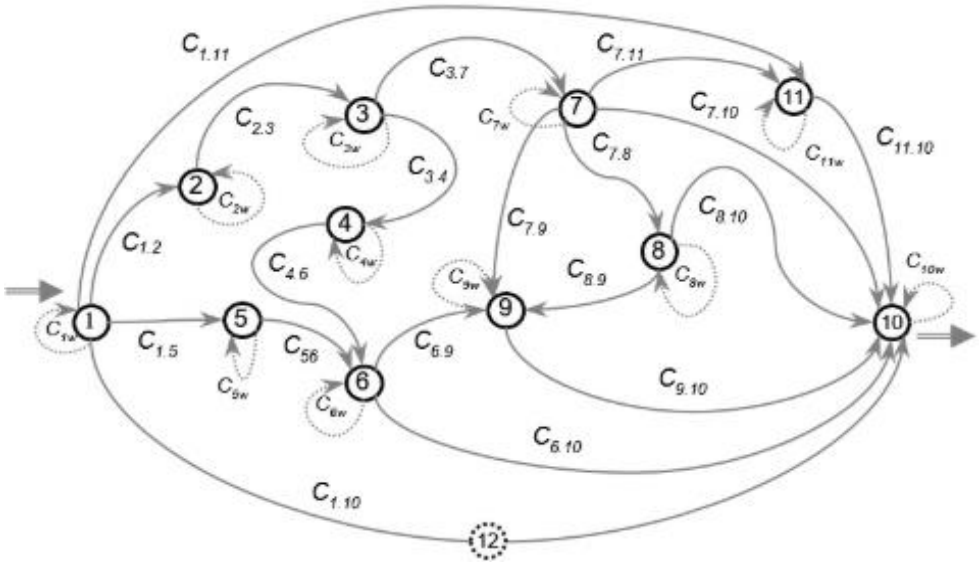


Figure 3. Graph of warehouse strategy costs

Source: Kłodawski et al., 2017

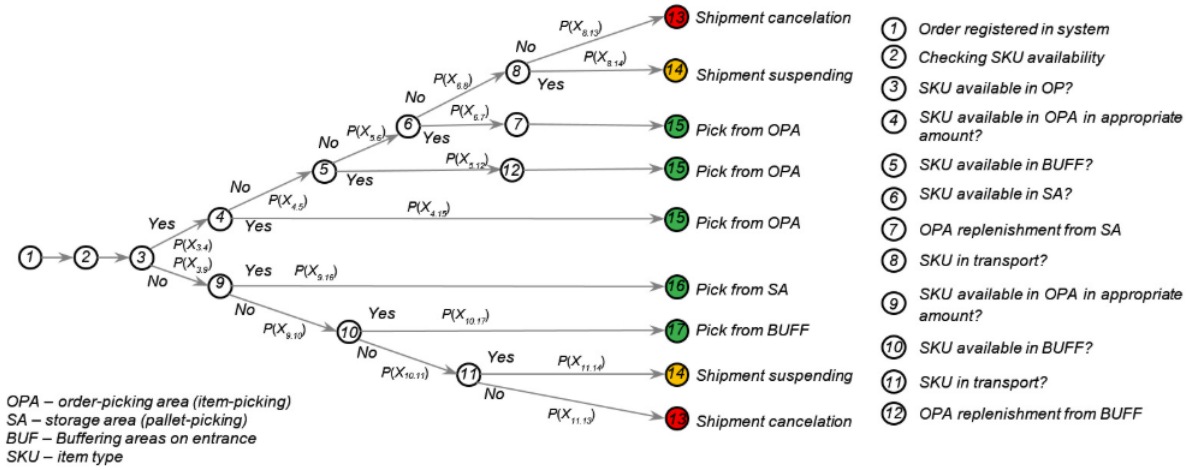


Figure 4. Binary decision-making tree of warehouse operations strategy selection .

Source: Kłodawski et al., 2017.

5. Technology adoption in warehouse operation in Vietnam and potentials for Digital Twins applications

5.1. Level of Technology Adoption in Vietnam's Warehouses

5.1.1. The Range of Technologies

Vietnam's warehousing sector is undergoing a digital transformation driven by e-commerce growth and a burgeoning manufacturing industry. Here's a breakdown of technology adoption across virtual and physical aspects, with insights on strategy, scale, and popularity:

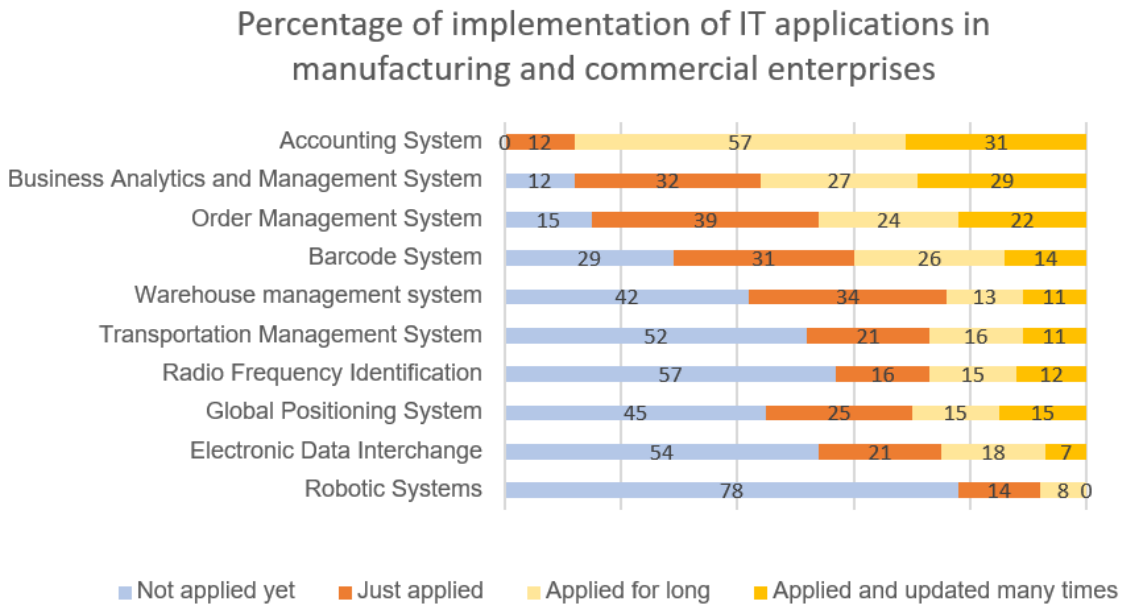
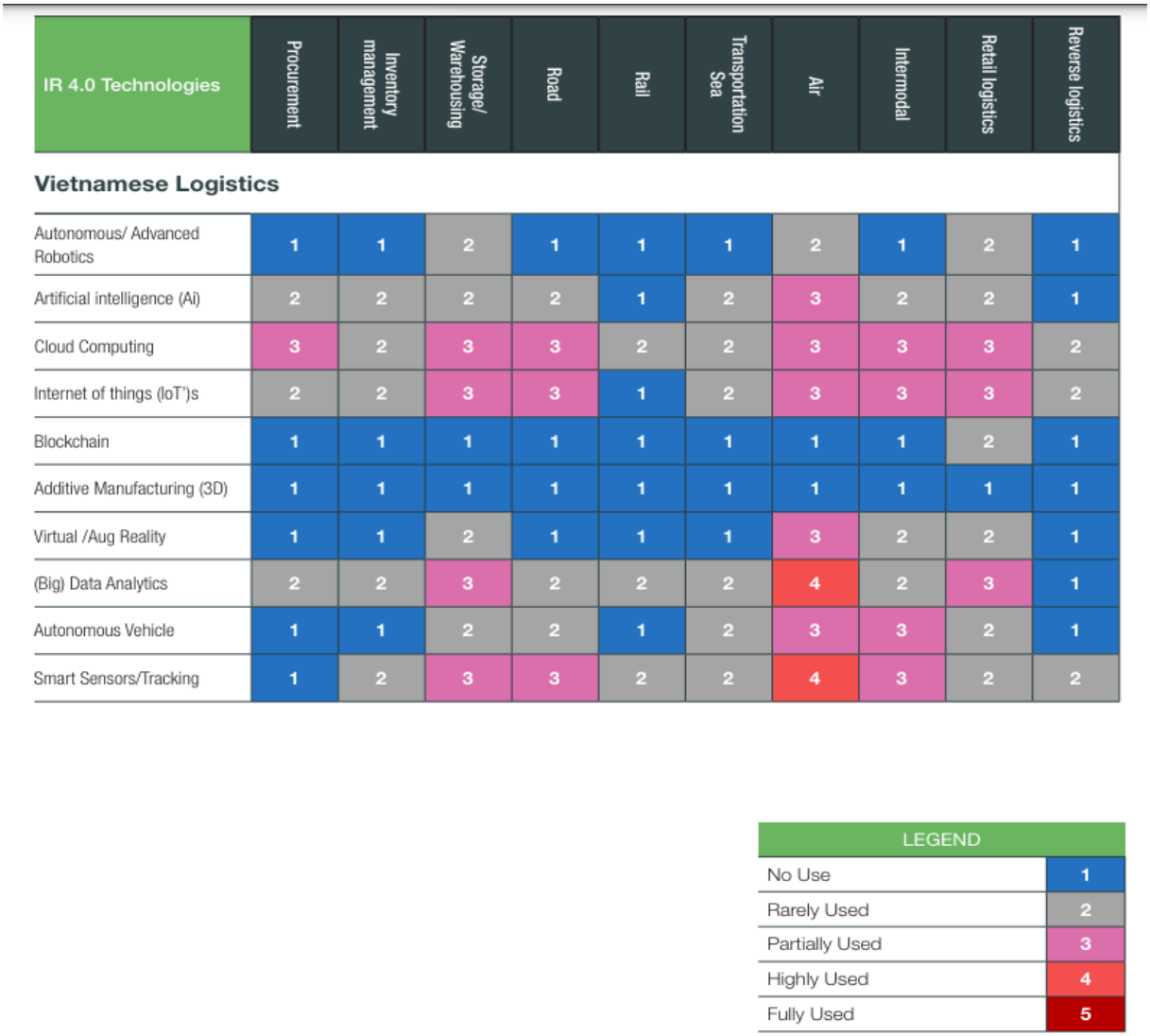


Figure 5. Percentage of implementation of IT applications in manufacturing and commercial enterprises.

Source: Vietnam Logistics Report, 2023.

According to the Vietnam Logistics Report (2023), the logistics industry in Vietnam features a range of technologies, particularly in warehousing, which is the field with the most prolonged applications and upgrades with solutions such as WMS, Barcode, Order Management Systems, and Accounting Systems. This underscores opportunities for the feasibility and scalability of technology application in Vietnam's warehouses (Vietnam Logistics Report, 2023).



IR 4.0 Technologies	Procurement	Inventory management	Storage/ Warehousing	Road	Rail	Transportation Sea	Air	Intermodal	Retail logistics	Reverse logistics
Vietnamese Logistics										
Autonomous/ Advanced Robotics	1	1	2	1	1	1	2	1	2	1
Artificial intelligence (Ai)	2	2	2	2	1	2	3	2	2	1
Cloud Computing	3	2	3	3	2	2	3	3	3	2
Internet of things (IoT')s	2	2	3	3	1	2	3	3	3	2
Blockchain	1	1	1	1	1	1	1	1	2	1
Additive Manufacturing (3D)	1	1	1	1	1	1	1	1	1	1
Virtual /Aug Reality	1	1	2	1	1	1	3	2	2	1
(Big) Data Analytics	2	2	3	2	2	2	4	2	3	1
Autonomous Vehicle	1	1	2	2	1	2	3	3	2	1
Smart Sensors/Tracking	1	2	3	3	2	2	4	3	2	2

LEGEND	
No Use	1
Rarely Used	2
Partially Used	3
Highly Used	4
Fully Used	5

Figure 6. Strengthening Victoria's Connections with Southeast Asia: Industry 4.0 in Viet Nam Opportunities for Australian Business

Source: RMIT University, 2022

Further analysis from the report "Strengthening Victoria's Connections with Southeast Asia: Industry 4.0 in Viet Nam Opportunities for Australian Business" reveals that in the field of inventory management and storage/warehousing, most 4.0 technologies range from no use to partial use. Prominent examples of active use of advanced technology applications include Cloud Computing, IoT, Big Data Analytics, Smart Sensors/Tracking, and Autonomous Vehicles. This foundation supports higher-level integration between physical and virtual operations in Vietnam's warehouses (RMIT University, 2022).

5.1.2. Characteristics of Application by Size of Enterprises

Only large enterprises such as Tan Cang Company, Gemadept, Vinafco, U&I, TBS, Transimex, and Sotrans have the resources to develop OMS, WMS, TMS applications for data synchronization across departments, inventory management, and financial accounting (Hoa et al., 2023).

- **Multinationals and E-commerce:** These companies tend to be early adopters of both virtual and physical technologies due to larger budgets and a focus on efficiency. They leverage

WMS, AI assistants, AMRs, AS/RS, and conveyors, with strict requirements for supply chain stakeholders' participation to maximize automation and streamline operations.

- **Medium Third-Party Logistics and Local Manufacturers**: These businesses, which account for 90% of logistics enterprises, usually outsource virtual technologies like basic WMS for inventory management and explore cost-effective automation solutions like cobots (collaborative robots) or RaaS (Robot-as-a-Service) for specific tasks.

- **Small Enterprises**: Due to constraints in business scale and resources, small enterprises tend to maintain small in-house warehouses and rely heavily on manual operations. However, they can apply limited solutions such as basic warehouse management software and semi-automated solutions like mobile barcode scanners for better inventory control.

5.1.3. Overall assessment of Vietnam's Warehouse Technology Applications

a. General Barriers

The Vietnam Logistics Report (2023) identifies major barriers in digital transformation:

- **ROI Returns**: One major barrier in digital transformation is the investment and implementation costs, which deter medium and small businesses from adopting digital solutions internally. About 30% of businesses express concerns about uncertain ROI, which discourages bold investments in digital transformation (Vietnam Logistics Report, 2023). Moreover, operators often overlook the hidden costs of not automating, such as persistent labor shortages, increased labor costs, hiring, turnover, training, and the impact on site productivity and worker safety (Malloy, 2023).

- **Resource and Space Constraints for Automation**: Many businesses believe that high investment costs and the need for comprehensive digital transformation leave them lacking resources and initiative, especially small and medium enterprises (Vietnam Logistics Report, 2023). Smaller centers may find the logistics of overhauling existing workflows daunting, opting to continue with mostly manual workflows despite their limitations. However, modern automation, including micro-workflows and RaaS (Robot-as-a-service), can drive productivity even in budget-constrained warehouses (Malloy, 2023).

- **Employee Resistance**: Employees in Vietnam's logistics sector feel that their jobs are threatened by technology deployment, leading to resistance against new HR policies introduced alongside technological adoption (Hoa et al., 2023).

b. Operation's Limitations

- **Real-time Requirements and Stakeholder Collaboration**: Synchronized software and practices across departments are crucial. However, outsourcing, fragmented investments, and varying processes complicate comprehensive evaluations, especially amid supply chain disruptions.

- **Workforce Issues**: The logistics industry in Vietnam suffers from a lack of skilled workforce, with only about 4% proficient in English and 30% of businesses needing to retrain their employees (Musa and Bin, 2019). The demand for qualified ICT employees is projected to be about 300,000 by 2025 out of approximately 1.2 million people working in logistics (Nguyen, 2020).

- **Security Concerns**: Inadequate encryption and security protections pose risks to data integrity and system reliability. Viettel Cyber Security (2023) reports that retailing and manufacturing sectors are highly vulnerable to cyberattacks, with numerous cases of data breaches and internal account thefts (Viettel Cyber Security, 2023).

In the context of a more disruptive supply chain, real-time execution is essential to effectively react to sudden events (Truong, 2023). A similar view is that real-time visibility are important foundations for improving supply chain resilience (Wyciślak, 2024). Such viewpoint has been confirmed by a Gartner report that 60% of Chief Supply Chain Officers (CSCOs) are expected to make faster, more accurate, and consistent decisions in real-time (Gartner, 2022). In Vietnam, technologies such as RFID, EDI, GPS, and cloud-based solutions are actively implemented, particularly in transportation and warehousing. Beside real-time supported technologies, data analytics can help to make empower proactive adjustments in the supply chain, countering disruptions and improving resilience (Wyciślak, 2024).

An approach that provides up-to-date, reliable, comprehensive inputs for intensive, **in-depth data analytics (descriptive, predictive, diagnostic, prescriptive), robust decision-making, and holistic risk management**, while being **affordable, scalable, user-friendly, and secure**, is necessary for the successful technology adoption of Vietnam's warehousing sector.

5.2. Opportunities for Digital Twins applications in Vietnam

5.2.1. The young development of logistics sectors

Logistics has been significantly focused for such a long time in many developed countries. However, this field has just developed remarkably in Vietnam recently. This is a challenge, but also a chance for many 3PLs companies to develop and stabilize their position in critical aspects, particularly warehousing. According to Vietnam Briefing (2020), World Bank rankings in 2018, Vietnam demonstrated a significant improvement in its Logistics Performance Index (LPI). It ranked 39 out of the 160 countries, rising 25 places above its position in 2016. Data from the Ministry of Industry and Trade showed that Vietnam's logistics sector grew by over 12 percent in 2018. These statistics show the potential to continue to develop and invest in this field. Logistics companies can experiment and call for FDI to apply the most advanced technology, in this case Digital Twins Models, without hesitation from the out-of-date working concept. It is clear that logistics is a dynamic sector, which has many potentials to invest in and develop new technology, from which gain a significant profit and contribute to the economy of our country. If the implementation and operation of Digital Twins are proved to be effective and lucrative, the potential to continue to expand this model is really high.

5.2.2. Young workforces with the progressive learning attitude

The new generation is considered open-minded and willing to learn new technology. With a progressive learning attitude and the ability to acquire IT knowledge, it is easier for warehouse staff to innovate their working process and apply the Digital Twins Model in the most effective way.

We can take a vivid example of application from game to work for the young. Nowadays, many young people have a passion for 3D gaming. Thanks to the early approach to these platforms, when they join the workforce, it is easier for them to design totally 3D virtual warehousing. Moreover, the early access to an friendly cyber environment in gaming will create

a habit of requiring a user-friendly interface, resulting in development of a user-friendly warehousing visualization.

5.2.3. The discovery of new warehousing solutions

It is known that Digital Twins is a new technology, therefore, the application of this model can bring about new warehousing management for the enterprises. By applying the Digital Twin model into every micro-operation, warehouse staff will have chances to discover the problem from a new vision, leading to the new warehousing solution.

Here are some opportunities that Digital Twins creates for enterprises:

a. Receiving

In the receiving process, there are some problems that warehouse staff have to face such as monitoring the flow and number of goods into the warehouse, time consuming, inefficient labor,... especially when the operation in Vietnam's warehouse is manual, companies have not applied much technology and automation into this chain. Therefore, Digital Twins Model will help warehousing staff to have an effective real-time monitor and visibility by providing virtual representation of physical assets and processes. In this situation, Digital Twins will provide a real time 3D simulation of the physical warehouse, showing workflow, staff allocation, how busy or full the facility is, and location of highest pick activity. This means the monitoring process can be continuous and the discrepancies detection can happen without disruption. Furthermore, the warehouse manager can grasp all the process of receiving and make timely decisions to support their staff. Having a virtual receiving process will improve accuracy and efficiency when Digital Twins can streamline this process by automating tasks, reducing human errors and ensuring the inventory count is accurate.

b. Put-away

One of the problems in the put-away process is that goods are not timely and accurately stored. As in WERC's Annual Warehousing and Distribution Center Operations Survey, 69% of warehouses reported issues with inventory accuracy, leading to problems such as lost inventory and inaccurate counting. The goods, after being received, are counted, inspected and then moved to the storage location. However, during the process, many issues may happen. For example, different types of goods will require different time and ways of storage, otherwise, their quality can greatly reduce. With the help of Digital Twins models, warehousing managers can track all the information of the inventory from the receiving process, therefore effectively control the put away procedures. By providing visual tracking and updated data of the goods condition, it is more efficient to maintain the quality of inventory. During the put-away process, losing track of goods and missing location of the inventory is a regular problem. According to Ghiani, Laporte and Musmanno (2003), 43% of small businesses either don't track their inventory or use a manual process, leading to frequent issues such as lost goods and mislocated inventory. That is the reason why warehousing managers should apply Digital Twins into this process because the virtual image of goods as well as the necessary data will constantly check the information of the goods and immediately notify the staff about the discrepancy error.

Last but not least, warehousing layout has always been a challenge for the put-away process. Warehouses with suboptimal layouts experience an average of 30% longer put-away times compared to those with optimized layouts, as studied by Edgar E. Blanco. Numerous

warehouses in Vietnam are designed in an ineffective way, which makes it time-consuming while handling and moving goods from receiving area to storage area. Digital Twins Models will provide a virtual and vivid replica of the warehouse, which helps managers to test critical pathways such as facilitating virtual simulation and analysis of materials flow during picking. In this case, warehousing staff can identify inefficiencies, optimize pick paths, therefore ensure smoother material handling.

c. Storage

Storage is an essential procedure in warehousing management. However, during this process, many problems may happen such as losing inventory, inaccurate counting, critical mishaps and unplanned inventory during downtime,... In "Warehouse Performance Measurement", Gong and de Koster (2011) have indicated that warehouses often struggle with inventory accuracy, noting that average cycle counting accuracy ranges from 85-95%, leaving room for significant errors and lost inventory. The most important function of Digital Twins is to enhance the inventory management. The data integrated in the cyber warehouse helps managing staff control the flow of information in an optimal way like always keeping track of the number, the conditions and the location of goods. Thanks to these benefits, decision-making will be greatly enhanced. All the data about inventory management, resources allocations and workflow optimization are recorded and vividly visualized, remarkably boosting the efficiency of the decision-making process.

Especially during a fluctuating period, there may be extremely high or low demand for one type of merchandise. In these situations, applying Digital Twins models may pave the way for data analytics, from which warehousing staff can have better predictions and make optimal decisions. It is critical that every warehouse avoid mishaps and prevent unplanned downtime, and the data integrated can improve this process. Consequently, the risks of downtime can be remarkably minimized and costs can be maintained.

d. Picking

Regarding the picking process, similar to the put-away process, warehouse managers can visualize the optimal paths for pickers, identify bottlenecks, and allocate resources effectively thanks to Digital Twins. This fluent flow of goods in the warehouse will significantly save time, labor and money for the whole procedure.

It seems that many warehouses have not got used to the paperless working environment, especially in this technology-changing era. That is also one factor leading to the late response when there is any question from customers. With the virtual replica of a real-time, 3D simulation of a real-life environment, such as a warehouse, the response time to the customer can be reduced because all the information that customer requires stays updated, and it takes just a few to check data and respond to the consumer. As a result, the operation with the help of Digital Twin model will gradually be fast and lean.

5.2.4. New approaches for Vietnamese SMEs

It is known that it takes a huge investment for the operation of Digital Twins. Therefore, only big enterprises have the ability to afford this technology. In Vietnam, 95% of enterprises are small-to-medium enterprises, and only some leading enterprises pioneer in implementing Digital Twin are Viettel, Vinfast,... However, with the analysis in each micro process of the

warehouse as mentioned above (picking, receiving, put-away, storage,...), small companies may have chances to approach this advanced technology. By breaking into small functions of Digital Twins, the cost of operation for this model can be greatly reduced. Companies can analyze the strength and weakness in their warehousing management, from that learn to apply Digital Twin in just the needed process. These strategies not only can optimize warehousing activities but also save budgets for the developing companies.

Here are 3 levels of Digital Twins Model application that developing companies can implement, depending on their development strategies:

Table 1. Supply Chain Digital Twins: Opportunities and Challenges Beyond the Hype

Level	**Unit ops (purely technical system)**	**Plant/ facility (mostly technical system)**	**Supply chain (socio-technical system)**
Monitor/control (dynamic)	Cyber-physical 'mirror" of individual equipment	Architecture of connected 'things'	Control tower with multi echelon 'data trigger'
Design (static)	One-off physical asset optimisation (warehouse layout,...)	One-off process or line optimization (master schedule,...)	One-off supply chain network design (location decision, safety stock optimization,..)

Source: Srai et al., 2019.

5.3. Challenges for Digital Twins applications in Vietnam

5.3.1. The cost of implementation and operation

It is known that the cost to implement and operate a whole Digital Twin system is extremely expensive, even for a big enterprise. According to RisingMax (2024), it takes from 45,000USD to 90,000USD to implement and operate a system of Digital Twin Models for small and big companies respectively. This is considered a huge investment, especially just for a chain-warehousing in total supply chain activities. Managers can gain profit gradually after a certain period of time, but still they will have to feel some hesitation to invest in such a high initial cost. Even though optimized in an economical way as applying for certain levels of company's demand, the cost to operate this advanced technology is too challenging to afford.

5.3.2. Deficiency of skilled labor in both technology and warehousing management

Implementing and maintaining Digital Twins warehousing requires specialized knowledge in fields like loT, data analytics and cybersecurity. However, logistics in Vietnam, though known from many years ago, has just been focused and strongly developed recently. Therefore, the main labor in this field is the older generation with deep warehousing understanding and

knowledge but little skill in technology. Consequently, it is challenging to integrate technology, from which we can build up Digital Twin Models and maintain an effective warehousing system with this quality of workforces. According to Dương (2022), a survey from Vietnam Industrial Research and Consulting Company, from 60% to 80% interviewed companies stated the ability of logistics workforces, including the working staff and managing positions) just stay at the medium level and need to be improved.

5.3.3. Predominant paper-based procedures

The procedures in Vietnam's warehousing environment is mainly paper-based, which can be a challenge for applying virtual warehouses, especially in the process of synchronizing information from real warehouses with the virtual one. The process of shifting from a manual and mainly paper-based working environment into a paperless and automation warehousing may take a lot of effort and time, especially money. Furthermore, data integration from various sources, such as loT devices, sensors, ERP systems, legacy systems, real-time condition of inventory can be a huge hindrance for applying Digital Twin Models in warehousing management. This is also a challenging factor for companies, particularly developing companies to consider implementing the Digital Twins Models.

5.3.4. Cybersecurity and data privacy

One of the most concerning problems relating to the Digital Twins model is cybersecurity and data privacy. The system and the data network is graded as vulnerable for hackers and the rivals to leak the information for illegal purposes. Furthermore, warehousing staff, due to their less access to advanced information technology, do not have enough protocols as well as awareness to secure the data in the Digital Twins Warehousing from harmful factors. As Vietnam National Cyber Security Technology Joint Stock Company (NCS) (2023) has stated: “In Vietnam, approximately 13,900 cyberattacks were reported targeting systems nationwide. Over the past five years, more than 83,000 computers and servers fell victim to attacks involving encryption ransomware in 2023. Most cyberattacks targeted businesses operating in the digital environment or offering online services, such as those in finance, e-commerce, telecommunications, and technology, such as securities firms, banks, and IT companies.

6. Suggestions for digital Twins applications in Vietnam's warehouses

6.1. Proper financial plan and implementation

The cost of implementing this Digital Model is rather high but warehousing is also a pivotal process in the whole production chain of the company. Therefore, to balance investment between warehousing and other production processes, companies should create a proper and detailed financial implementation plan. This technology is advanced and new for the whole supply chain in general, leading to the undeniable high cost. The market price for this model cannot be modified at this time, so each enterprise must have their own strategies to manage these cost issues. For example, instead of investing in the whole Digital Twins model from the beginning, companies can define the most critical phases in warehousing, from this making some experiments in applying this system. If production companies find it effective to utilize

this technology, they can gradually invest more into this. The approach will help them to significantly reduce the initial cost for the advanced model.

6.2. Skills development

As mentioned above, one of the problems in the applying Digital Twin model in warehousing is the deficiency of skilled workforce.

We are in the era of technology, it is recommended to educate a new generation which acquires knowledge and experience to master these IT developments. For example, the youth can have chances to get access to information technology from the early age.

Besides, comprehensive training and lessons should be regularly provided for warehousing staff so that they can stay updated and apply the state-of-art technology in warehousing management as well as the digital twins model.

Especially in warehousing aspect, each kind of goods will require a different characteristics and design warehouse for better storage. Each enterprises will have a different warehouse layout and procedures, which leads to different approaches for Digital Twin model. Therefore, it is recommended that companies develop their own internal training packages and distribute or sponsor these for the warehousing staff. The hands-on experience combined with the practical working environment will greatly boost the knowledge and skills of staff there.

6.3. Government support and policies

Government should promote the development of digital twins in warehousing by making advantageous policies to encourage IT companies. By investing in warehouse-developing and information technology projects, the government will be able to encourage experts in warehousing as well as technology aspects to continue to do research and apply their achievements in managing digital twins models.

Furthermore, the procedure in customs and warehousing should be simplified, making advantages for the application of digital twins in warehousing, especially for a country which has not complete information synchronizing processes as Vietnam.

6.4. Cybersecurity Measurement

Cybersecurity is a critical aspect of implementing a Digital Twin model, especially in warehousing where sensitive data and operational continuity are paramount. Therefore, each enterprise should pay close attention and have measurements to secure data in Digital Twin.

There are numerous tools that can be applied to prevent data leak and errors during the operation of Digital Twins Warehouse. For example, by setting multi factor authentication (MFA), experts can add extra layers of security, ensuring that only authorized personnel can get access to the digital twin system. Moreover, with the implementation of Role-Based Access Control (RBAC), each user will only have access to the information and systems necessary for their role, minimizing the risks of insider threat. Besides, the utilization of secure software development lifecycle (Code reviews and testing, patch management,..), threat detection and response (Real-time Monitoring, Incident Response Plan,..) are also recommended.

Conclusion

The digital twin model presents a transformative opportunity for warehouse operations in Vietnam. By creating a virtual replica of a physical warehouse, businesses can gain real-time insights, optimize workflows, and improve efficiency. From optimizing layout and picking routes to predicting equipment failures and ensuring safety, digital twins offer a comprehensive approach to warehouse management.

Vietnam's growing e-commerce sector and focus on Industry 4.0 make it fertile ground for adopting digital twin technology. As Vietnamese businesses look to enhance their supply chains and compete globally, digital twins can be a key differentiator. While initial investment costs exist, the potential return on investment in terms of cost savings, improved efficiency, and enhanced customer satisfaction makes digital twins a compelling solution for Vietnamese warehouses.

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