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The Adoption of Smart Warehouse Technology in Thailand

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Abstract: The growth of advanced technologies has been rising in recent years, which affects business operations throughout the supply chain. The smart warehouse is one of many technologies that increase warehouse management efficiency, for instance, increasing accuracy and reducing operating costs and processing times. Smart warehouse technologies are expected to be critical factors for effectively entering the fourth industrial revolution in Thailand. Currently, the utilization of smart warehouses in Thailand is not widespread; however, many organizations view such technologies as integral parts that will change the entire industry in Thailand. This research project explores and analyzes innovative warehouse technologies and their requirements for various industry sectors in Thailand. In addition, both qualitative and quantitative methods are employed to gather data. In-depth interviews of executives and warehouse managers are conducted, together with self-administered questionnaire surveys, to both smart warehouse users and providers. TOWS Analysis is applied to identify appropriate strategic options. Policy recommendations to effectively improve the unitization of smart and innovative warehouse technologies are also discussed.

Keywords: Advanced Technology, Industry 4.0, Policy Recommendation, TOWS Analysis, Smart Warehouse.

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1. Introduction

With the advancement of technology, business operations require more modernization. Warehousing is essential in the supply chain (Berg and Zijm, 1999) as a place to store goods, raw materials, or fresh products before they are moved to different locations or delivered directly to customers. The smart warehouse is one of the technologies for making storage more efficient (Mostafa et al., 2018). The utilization of the internet has resulted in a connection between goods and logistics systems. Businesses such as online shopping have resulted in a leap in warehouse growth (Zuchowski, 2016). Smart warehouses will increase efficiency in inventory management by reducing lead times or using robots to move goods more accurately (Olofsson and Rylander, 2021). Besides the efficiency of inventory management, smart warehousing can also reduce operating costs (Olofsson and Rylander, 2021). For example, they use software for inventory management or the Internet of Things (IoT) for real-time viewing or controlling warehouse operations to reduce unnecessary accidents. Therefore, utilizing smart warehouse technologies such as IoT, QR codes, robots, and machines can contribute to more efficiency in warehouse management (Buntak et al., 2019).

2. Literature Review

The inefficiency of labor operation, reduction in labor, and the need for cost reduction in logistics have resulted in the development of traditional warehouses into smart warehouses (Geest et al., 2021). Using smart warehouse technology will increase efficiency, and the production capacity of the logistics system will be economically viable (Buntak et al., 2019). In the traditional warehouse system, inventory information is recorded. Therefore, the suppliers can use this information to develop the new smart warehouse system. Implementing smart warehouse technology is a long-term investment, and its benefits can far outweigh the initial investment.

Smart warehouse applications have been implemented since 1999 (Foote, 2016), with full implementation in 2008. China, one of the countries with the most extensive inventories in the world, is researching and investing in developing industrial robot applications and has seen tremendous growth since 2000 (Grau et al., 2017). Various industries have increased their operational efficiency with smart warehouse technology. For example, the automotive industry, one of the biggest industries

around the world, has historically accounted for 90% of its operations with robots (Grau et al., 2017). Overall, industrial applications of robots account for 50% of all industries worldwide and are expected to increase.

In addition to using robots, implementing IoT, such as RFID technology, in the traditional warehouse reduces the operating time and simplifies the logistics route for the manufacturer (Aamer and Sahara, 2021). Robots and RFID have been developed for utilization in warehouse systems through IoT and modern software to increase storage capacity, production capacity, efficiency, and effectiveness (Mostafa et al., 2018). Therefore, the applications of smart warehouse technology are becoming more diversified from the improvement and development of technology to suit industries worldwide. In addition, smart warehouse technology will be one of the factors that will increase the working capacity of the industry.

In 2020, due to the Covid-19 epidemic, the global logistics system declined (Twinn et al., 2020). The epidemic lockdown has also affected Thailand (Marome and Shaw, 2021). However, it is rapidly changing the lifestyle of people from traditional store shopping to online shopping. Therefore, developing smart warehouses and logistics in Thailand should focus on adopting technology and innovation to optimize service efficiency and management of warehousing and logistics.

Currently, the Thai economy is in intense competition (Puttanont, 2020). Consumers expect to receive goods and services faster. Therefore, modern and diverse technologies must be used to enhance the system's capabilities to be more efficient. According to NESDC (2020), government support is vital in the industrial development of smart warehouse applications. The policy and advocacy will be developed to support the implementation of smart warehouses and logistics.

In China, policies have focused on tax privileges, land policy, technological innovations, and agricultural logistics (Similan Technology, 2021). These policies may also increase incentives for logistics companies due to tax exemption and promotion. In addition, foreign companies have an excellent opportunity for logistics growth from China's logistics support. Thailand is also one of the countries that benefit from China's transport and logistics infrastructure to support the country's prosperity (Atikins, 2021).

In 2004, the Thai government passed a resolution to develop the country's logistics system by creating a Logistics Roadmap to develop the infrastructure related to the logistics system (Loetyingyot and Dhebpanya, 2015). Thailand has adopted many approaches to the development of logistics and warehousing systems, such as encouraging entrepreneurs to develop new technology and innovation, increasing the efficiency of logistics and warehousing systems, and changing the way of doing business through online channels to support commerce in the form of electronic commerce (E-Commerce). For example, the Thai government supports the industries listed in the Eastern Economic Corridor (EEC) in terms of a tax deduction (Phuangketkeow, 2020). The support focuses on the company's adoption of smart warehouses and innovation (Sorat, 2012). Therefore, it will optimize logistics and warehouse operations for the industries in EEC (Department of Land Transport, 2013). In addition, the Thai government is establishing a logistics clinic committee to disseminate knowledge and understanding of the process implementation of the logistics management system and consulting with SMEs in Thailand (Loetyingyot and Dhebpanya, 2015). Therefore, the government support policies will focus on the infrastructure of logistics systems which will affect the development of smart warehouses, including utilization of international standards to build a warehouse infrastructure, tax deductions, and privileges for the company that develops smart warehouses and logistics systems.

Today, smart warehouse technology has been developed in various ways to be fully utilized for maximum benefits. The technologies involved in smart warehouse and logistics systems have been reviewed from literature and open-source data from companies worldwide.

3. Methodology

Data was collected from both secondary and primary sources and divided into three parts: general information, information about technologies used in smart warehouses, and problems from smart warehouse utilization. All three parts focused on current technology utilization and its challenges, especially in terms of technical capability to respond to tasks or needs in the warehouse. The authors conducted in-depth interviews with 27 companies: 22 companies that currently utilize smart warehouse technology (Users) and 5 technology or service providers (Providers). Data were then analyzed using Threats, Opportunities, Weaknesses, and Strengths (TOWS) analysis to develop four strategy types, namely maxi-maxi strategy (utilization of strengths and opportunities), mini-maxi strategy (use opportunities to minimize weaknesses), maxi-mini strategy (use strengths to deal with threats), and mini-mini strategy (minimize weaknesses and avoid threats) (Aslan et al., 2012). TOWS analysis allowed assessment of the strengths and weaknesses of the current internal environment of the smart warehouse in Thailand, including opportunities and threats from the external environment, as well as the impact on all types of business. In addition, frequency analysis was utilized to summarize the critical factors of the technology used in the smart warehouse. Policies and guidelines that will benefit both companies and the Thai government were developed to adopt smart warehouse technology in the future.

4. Results

Current technologies utilized in the industry around the world were collected from literature reviews and company reports. They demonstrate the diversity and development of technology to increase the efficiency of the smart warehouse. From a total of 61 technologies collected, they are divided into seven groups as follows:

1. Automation system: Any system or mechanism that can run the assigned program, such as automatic cranes that bring goods into storage or take goods off the shelf. Such systems can be used as operational tools or electronic control devices that operate according to the assigned tasks or are programmed by humans.

2. Digital software and technology: Computer systems, communication systems, software systems, or other related systems which utilize the data or history information to maximize the efficiency of the system to allow people and organizations to interact in the digital world. They also are utilized in procuring, storing, creating, and using data for utility in the warehouse.

3. Robots: Automatic machines which are designed to perform specific human tasks. Robots work with the same commands in a complex and flexible way. In addition, they can be modified to operate in a specific environment and make their own decisions.

4. Internet of Things (IoT): Objects, devices, vehicles, and other artificial things with embedded electronic circuits, software, sensors, and network connections that can store and exchange data.

5. Smart warehouse and logistics facility: A facility that facilitates logistics and smart warehousing operations for placing, storing, holding, and distributing goods or products.

6. Controller: A device that controls the operation of machines or processes in the warehouse, with human operators controlling or instructing which had a processing chip (microprocessor) as a brain that commands and helps to process work functions.

7. Security and safety technology: Technology or systems that ensure safety in smart warehouses.

The 22 users have been categorized into nine industries: petrochemical products, machinery and equipment, food and beverages, retail, automotive, E-commerce, chemical products, agricultural products, and courier. Large-sized companies accounted for 63.64% of users of smart warehouse technology, while small and medium-sized companies accounted for 18.18% of each. The technology utilization of users and providers is summarized in Figure 1.

The figure shows that digital software and technology had the highest frequency of usage among the users, followed by IoT, security and safety technology, smart logistics and warehousing facility, controller, automation, and robotics, respectively. Digital software and technology are at the top rank due to the current operations that require storing and retrieving data in digital forms for future analyses, such as the number of products in stock, information on goods entering or leaving, and the current income and expenditure. In addition, users said that technology providers in Thailand focus mainly on software development rather than machinery and equipment. Digital software and technology are used in a total of eight out of nine industries accounting for 88.89% of the total industry group, followed by IoT at 87.31%, security, and safety technology at 85.71%, and logistics facilities and smart warehousing at 52.38%, respectively, which is similar to the data from providers as shown in Figure 1.

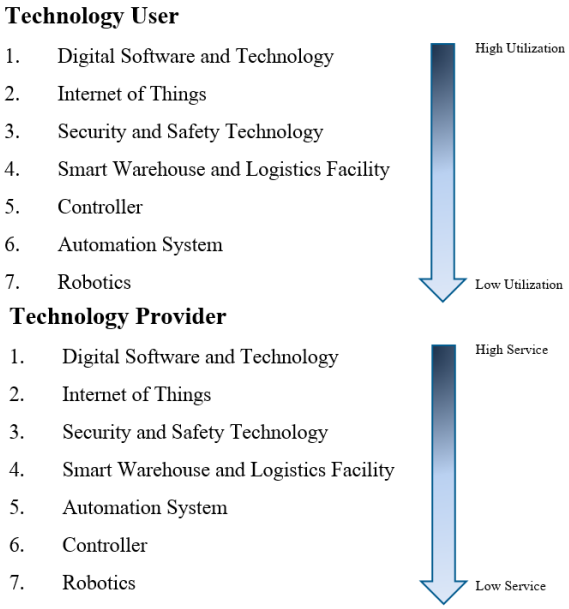

Fig. 1. The technology utilization by users and providers

In digital software and technology, the information on technology usage is consistent between users and providers. The use of an order management system is necessary to increase efficiency in the warehouse in handling orders from customers. Currently, the growth in online shopping has increased significantly. Therefore, focusing on developing an order management system will drive more utilization of this software, and it can increase the level of efficiency in warehouse operations.

For the IoT group, providers have not entirely focused on track and trace technologies and weight checks. In the future, the providers may develop or import technology involving these technologies to meet the demand of the users. In security and safety technology, both users and providers have the same corresponding data: video surveillance system, finger scanner, and face ID entrance control, respectively. Therefore, providers should balance the supply for optimal performance.

The remaining groups are smart warehouse and logistics facilities, controllers, automation systems, and robots, which are relatively uncommon in Thailand due to the high investment, including specific applications. However, the utilization of these technologies will be increased in the future due to technology's rapid adoption and development. In addition, the labor will be inefficient compared to artificial systems or mechanisms. Therefore, support from the government will play an essential role in overcoming barriers to smart warehouse technology adoption.

According to the interviews, it was found that the barriers to smart warehouse technology can be divided into seven topics:

1. Investment aspect: The main problem is the worthiness of investment in technology for its implementation.
2. System of the organization: Currently, labor is more efficient than technology and has a lower cost. In addition, the number of products (SKUs) needs to be increased for the cost-effective use of technologies, including warehouse layout and warehouse standards, and the nature of the product is not suitable for using the technologies.
3. Worker standards: The language barrier and the knowledge base of technology workers are the biggest problems for the preparation of technology utilization. In addition, most workers need more time to learn to operate new technologies.
4. Relationship with stakeholders: The main problem is that there must be more communication channels with technology providers. The stakeholders, such as suppliers and consumers, are not ready to change or adjust the current operating system, and more than a variety of products is needed to suit the system. As a result, there is no need for technology.
5. Direction of the organization: The management teams or directors do not support the utilization of new technologies, or the use of various technologies must depend on the parent company abroad.
6. Technology limitations: Major issues included the maintenance of machinery or technology that can take a long time and negatively affect the operation or the downtime of the machine
7. Disasters and Diseases: Major problems include Covid-19, and flooding, which affected the logistic systems.

According to interviews, investment is the critical barrier that affects the implementation of smart warehouse technology. Investing in modern technology is expensive and may not be worth a short-term investment. In addition, organizational systems and worker standards are obstacles for the companies to adopt the technology. Currently, the use of labor is more efficient and cost-effective than the use of technology. In addition, the working system in the organization is also more conducive to the use of labor, for example, inventory counting and order packing. However, the users mentioned that future operations will require these technologies because the expense of hiring workers may be higher in the future.

Government support is essential for developing smart warehouses in Thailand to solve these problems. In addition to the investment in smart warehouse technology, users need help accessing providers and new emerging technologies. There still needs to be more connection between users and providers. Therefore, the government can play a role as an assistant in collecting such data and links between users and providers. It will also be able to promote the use of smart warehouse technology. According to the interviews, government support can be divided into three groups as follows:

1. Tax exemption/reduction: The government may support import tax exemption/reduction in smart warehouse technology as well as exemption/reduction of import duty on machinery and equipment and exemption/reduction of import duty on raw materials
2. Utilization promotion: The government may disseminate information of providers to users, organize a seminar on smart warehouse technology, educate users about the importance of smart warehouse technology, and support smart warehouse technology trials.
3. Investment promotion: The government may reduce the process/time in applying for investment promotion (BOI), promoting the use of technology produced by Thai companies, and reducing innovation and patent entry requirements.

According to the interviews, the users want to reduce costs and increase the ROI of technology investments through the government's tax exemption or tax reduction policy. In addition, the government's role as an intermediator would facilitate contact between the users and providers and jointly develop new warehouse technology in which the government may choose users' representatives to pilot new technologies and disseminate the results among other users. In this way, government can provide guidelines to effectively plan for such technologies.

Application for investment promotion through the Board of Investment (BOI) is often delayed, preventing users from investing in the technology on time. The government should improve the process or set a specific time so users can plan the investment schedule. In addition, the inability to enter the Thai innovation list is also one of the barriers because of monopolized technology knowledge. In Thailand, smart warehouse technology is still in the early adoption stage and has few developers; the developer may be the only one with the technical know-how. The government should reduce the list entry requirements until the emergence of technology utilization.

Other promotions, such as promoting the use of technology produced by Thai companies, would be beneficial. It could also reduce costs for the users because foreign technology is expensive due to the import tax. Government support would help Thai users utilize smart warehouse technology and develop higher warehouse standards in Thailand.

Therefore, with the data from the technologies utilization in Thai industries (see Appendix), the barriers to technologies adoption in Thailand, and Thai government supports, the TOWS analysis will be utilized to develop various strategies to set guidelines for the smart warehouse in Thailand.

5. Discussion

This research explored and analyzed smart warehouse technologies, including the need to set guidelines for adopting smart warehouses in Thailand. According to the study, there is currently a high demand for smart warehouse technology in Thai

industries due to the cost of warehouse operation, which has increased from various factors such as labor costs, storage costs, or transportation costs.

Data collection shows that digital software and technology have the highest utilization, accounting for 88.89%, because of digital operations' convenience, speed, and efficiency. In addition, the technical data from the users is also consistent with the providers who focused mainly on digital software technology development rather than machinery and equipment. Users still want to use the order management system. Therefore, it is suggested that providers continue to develop this software to gain a market share from imported technologies.

The IoT and security and safety technologies are among the most commonly utilized technologies. They have utilization rates as high as 87.31% and 85.71%, respectively. Both are also essential warehouse technologies for higher operational efficiency. They still have gaps where the providers can fill the users' needs, for example with track and trace technologies and weight checks from IoT, which providers still need to respond to the market demand. In the future, providers should focus more on this aspect in response to market demand. However, the security and safety technology are very consistent between users and providers which indicates that both share the same importance; this should be maintained for maximum efficiency.

Although technologies such as smart logistics and warehousing facilities and controllers have less demand than the top three, with utilization rates of 52.38% and 50.79%, these two technologies are just as crucial as IoT or security and safety technologies and are essential for smart warehouse adoption. The analysis revealed that there are still gaps to be filled. With technology rankings in smart logistics and warehousing functions, the providers are encouraged to focus on cold storage because of the high demand from the users. The users are interested in virtual dashboards, among other technologies, based on the current information. Therefore, it is recommended that the providers offer more products in this group.

The last group of technologies, automation, and robots are the least utilized among smart warehouse technology, with utilization rates of 50.79% and 26.98%, respectively, resulting in less attention in Thai industries. Thai companies still need to be able to utilize these technologies to the maximum extent. However, a low number of products (SKU) or employees who lack the knowledge necessary to use the technologies will negatively impact the worthiness of the investment. In addition, the data shows that the providers need to focus on providing technologies or services in this group. These technology groups are technologies that have a very high investment. Therefore, government support is essential for the implementation of smart warehouse technology.

From the data collection and interviews, it was found that investment is one of the barriers that users perceive as having the most significant impact on technology usage. In this respect, the government can help users by discussing problems and issuing policies consistent with the users' demands. Tax exemptions or reductions can help users reduce total costs. In addition, the government can promote the use of technology by being an intermediary between the users and the providers or even among users to show the importance of smart warehouse technologies and share experiences. In the short term, the government may reduce the conditions for technology development to support the emergence of smart warehouse technology that belongs to Thai companies. The government may encourage the providers to be listed in the Thai innovation list by adjusting the conditions required for listing based on the providers' needs to promote future development. In addition to reducing the conditions, the government should streamline the procedure or specify a specific time for requesting government support for convenience and efficiency for the users in Thailand.

In the TOWS analysis of smart warehouse technology applications in Thailand, the researcher has chosen the theory of SWOT analysis to identify strengths, weaknesses, opportunities, and threats based on the data collected from interviews with 22 Thai users and 5 Thai providers. It was found that the fundamental strength of the industry in Thailand is that the demand for smart warehouse technology usage is similar to that offered by providers. The users have a variety of options in choosing the technology they want. In addition, the providers in Thailand can also provide services and adapt their technology to meet users' needs.

However, smart warehouse technology is still in the early development stage for Thai industries. As a result, the current operation of some organizations is not suitable for utilizing smart warehouse technology such as labor readiness, the goods in storage or sorting, investment capital, or readiness of stakeholders. All of the above factors affect the adoption of smart warehouse technology. According to data collection, online shopping in Thailand is growing, increasing warehouse growth rates. In the future, using smart warehouse technology can reduce the costs that would otherwise increase in warehouse operations. With the internet and online media, it is easier for users to access technology and knowledge and promote the development and potential of workers, which can create opportunities for the utilization of smart warehouses in Thai industries.

The threat from foreign providers is a factor that the providers in Thailand still need to consider. The foreign providers are more prepared and available than the providers in Thailand, both in terms of their variety of technologies and experiences. In addition, developing and producing new technologies in Thailand could be more conducive, considering taxes and technology's high price. Therefore, the government should help users and providers adopt smart warehouse technology in Thailand.

The internal and external factors of the organization will be determined through the SWOT analysis. Strategies for implementing smart warehouse technology in Thailand can be built using TOWS Analysis, as shown in Table 1.

Table 1. TOWS Analysis of Smart Warehouse Technology in Thailand

Factor	Strategy
Threat (T)	**T1**: Foreign smart warehouse technology/service providers are entering the warehouse market in Thailand. **T2**: There are too many obstacles in producing smart warehouse technology. **T3**: Tax on smart warehouse technology is too much for users/providers.
Opportunity (O)	**O1**: Thai online trading is trending upward in the past few years, increasing the warehouse growth rate yearly. **O2**: Using technology can reduce long-term costs from higher labor costs in the future. **O3**: Access to technology and knowledge is now more convenient, creating opportunities for smart warehousing in the Thai industry. **O4**: Promoting the development and capacity of workers from the public and private sectors can create opportunities for the use of smart warehouses in Thai industries.
Strength (S)	**S1**: User demand for smart warehouse technology matches with providers in Thailand. **S2**: The Thailand providers can provide precise service and solutions according to customer needs. **S3**: Users recognize the importance of technology.
Weakness (W)	**W1**: The organizational operation could be more suitable for using some smart warehouse technologies. **W2**: Workers need more time to learn smart warehouse technology due to language barriers or lack of knowledge. **W3**: The users need more time to be ready to change or adjust the organizational operating system. **W4**: Thailand's industrial model is unsuitable for some types of smart warehouse technologies, such as robots or automation. **W5**: Small and medium-sized users need more time to be ready to invest in smart warehouse technology, such as insufficient investment or too small a customer base.
Threat-Strength (TS)	**T1S1**: Thailand's government, service users, and service providers unite to formulate policies to drive technology produced by the Thai people jointly. **T3S1**: Determine tax policy for high-demand smart warehouse technology in response to the Thai market. **T2S2**: The government, users, and providers in Thailand cooperate in developing specialized technologies that can solve problems within the industry.
Threat-Weakness (TW)	**T1W2**: Maintain customer relationships. **T3W1**: Develop enterprise systems by enlisting government assistance before losing the market share to foreign providers. **T3W5**: Study and contact governments, providers, and other users to increase the opportunity to use technology to develop the foundation of the organization
Opportunity-Strength (OS)	**O1S3**: Develop an organization to achieve the standard of the smart warehouse in response to the growth rate of the warehouse in Thailand. **O2S3**: Motivate and empower executives to use technology for long-term investment. **O3S1**: Government is the middleman linking smart warehouse technology data between providers and users to have greater access to information about technology.
Opportunity-Weakness (OW)	**O3W3**: Share and promote education on smart warehouse technology with corporate stakeholders. **O4W1**: Study the budgeting and organizational foundation development approach from experienced users who use smart warehouse technology. **O4W2**: The government organizes a meeting between users in Thailand to share innovation and technology education. **O4W5**: The government acts as an intermediary between service providers and users to drive small and medium-sized users.

According to Table 1, four main strategies are developed as follows:

1. Strategies for cooperation between governments, users, and providers (Threat-strength strategy): Some Thai users choose new technology from overseas because of foreign providers. The Thai government should find a way to support providers in Thailand to prevent the benefits from using the technology falling into the hands of foreign providers. The obstacles (T1, T2, and T3) and strengths (S1 and S2), the strategies are analyzed. Advantages of strategies for cooperation between governments, users, and providers are as follows:

- There must be a policy that is consistent with the market demand.
- The government must be able to support both the public and private sectors.
- The benefits from smart warehouse utilization will be local and affect the total GDP in Thailand.

Disadvantages of strategies for cooperation between government, service users, and service providers are as follows:

- It is necessary to understand the work of all public and private sectors.
- Finding the equilibrium point requires time to study the real benefits of the policy.

2. Strategy for building relationships between organizations (Threat-weakness strategy): Nowadays, connecting and communicating through online systems makes business more convenient and it is suitable for the development of the country. However, the easy accessibility of foreign companies to the Thai market has resulted in a massive loss to the Thai industry. Therefore, it is imperative for companies to maintain their customer base in the global marketplace. In addition, different parties cooperating to help both in terms of development and promoting each other will increase the chances of using technology in the future. The obstacles (T1 and T3) and weaknesses (W1, W2, and W5), the strategies are analyzed. Advantages of the strategy for building relationships between organizations are as follows:

- Learning from each other can develop a good relationship that can help each party.
- Maintaining customer relationships is essential to developing the foundation of an organization.

Disadvantages of strategy for building relationships between organizations are as follows:

- If there is knowledge inaccessibility or poor cooperation, the development or implementation of smart warehouse technology will not happen in Thailand or will be delayed.
- Strong support from the government is crucial to link stakeholders and create the smart warehouse community.

3. Organizational development strategy (Opportunity-strength strategy): Organizational development, whether it is the development of skills and knowledge, policies, or management's mindset, can increase the likelihood of future applications of smart warehouse technology. The users should adapt to the working culture of organizations. According to TOWS analysis, opportunities (O1, O2, and O3) and the strengths (S1 and S3) are analyzed. Advantages of organizational development strategy are as follows:

- Reduce the risk of losing opportunities for organizational development in the future.
- Enhance the organization's potential for future use of new technologies.

Disadvantages of organizational development strategy are as follows:

- Must rely on the government to coordinate information between providers and users.
- There must be improvements, developments, and upgrades of standards and services to collaborate with new technology.
- A limited budget will be one of the barriers to following the plan in the short term. This strategy is used to solve long-term problems.

4. Technology and innovation strategy (Opportunity-weakness strategy): It is a strategy to raise the user's awareness of smart warehouse technology in Thai industries to minimize organization's weaknesses. Nowadays, accessing online media and linking between providers and users are convenient and fast. Organizations can use this opportunity to share knowledge and realize the importance of technology. The opportunities (O3 and O4) and weaknesses (W1, W2, W3, and W5) are analyzed. Advantages of technology and innovation strategy are as follows:

- Increase knowledge in the organization for a solid foundation.
- Help promote development for stakeholders.
- Increase the competitiveness in the market.

Disadvantages of technology and innovation strategy are as follows:

- Must rely on many sectors, such as experienced users, government sectors, or providers, to learn.
- It takes time to study for knowledge because warehouse technology is a technology that is in the developing stage in Thailand.

6. Conclusion

This research explores and analyzes smart warehouse technology, including the demand for smart warehouses. The Thai government or related industries can use the findings to set guidelines for developing smart warehouses in Thailand. The results of the study show that there is currently a high demand for smart warehouse technology in Thailand due to increasing warehouse costs from factors such as labor cost, storage cost, and transportation costs. According to the data collection, smart warehouse technologies can be divided into seven categories: digital software and technology, IoT, security and safety technology, smart warehouse and logistics facility, automation system, controllers, and robots.

From interviews and company reports, it was found that the industry in Thailand has the highest demand for digital software and technology since the operations focus on collecting and retrieving data. The collected data are used to analyze the market for maximum benefit. The benefits of using digital software are convenience, speed, and efficiency. In addition, the technology supply from the providers is consistent with demand from the users who focus mainly on digital software and technology development rather than machinery or automation systems.

According to the interviews with users in Thailand, there are seven barriers to smart warehouse technology adoption, namely: investment aspect, system of organization, worker standards, relationship with stakeholders, direction of the organization, technology limitations, and disasters and diseases. Users feel that investment is the main obstacle to the adoption of smart warehouse technology. Therefore, the government must support users by discussing problems and developing policies consistent with the users' demands. According to the interviews, government support is divided into three groups: tax exemption or reduction, utilization promotion, and investment promotion.

Tax exemptions or reductions can reduce the users' total costs and also increase the cost-effectiveness of technology investments, resulting in more applications of smart warehouse technology. The government can promote the utilization of technology by being an intermediary between users and providers to increase awareness of smart warehouse technology and share experiences. In the short term, the government may reduce the conditions for technology development, such as the condition of the innovation list to support the emergence of Thai smart warehouse technology. In addition to reducing the conditions, the government should reduce the procedure or specify a specific time for requesting government support funds for efficiency. Therefore, the users and providers can fully adopt the smart warehouse technology long-term.

The plans and strategies in various fields are developed to support the users' and providers' smart warehouse technology adoption in Thailand by analyzing the data obtained using TOWS analysis. There are four strategies: an organizational development strategy; a technology and innovation strategy; strategies for cooperation between governments, users, and providers; and a strategy for building relationships between organizations.

For organizational development, developing the organizational standard is essential to achieve the standard of the smart warehouse in response to the growth rate of the warehouse in Thailand. In addition, the government can be an intermediary between users and providers to have more access to information about smart warehouse technology. In the long term, the company's executives may set the direction for smart warehouse technology for long-term investment.

Technology and innovation are also the routes to achieving a higher potential in the market. The emergence of online media and the internet develops the connection between users and providers, creating the opportunity to study new technologies and share knowledge. On the other hand, the government can be a moderator among experienced users to encourage smart warehouse technology utilization in small and medium-sized users.

Foreign companies are currently taking the market share from Thai providers. The government must develop policies to prevent market takeover from other countries, such as promoting innovation from Thai companies, tax reduction for high-demand smart warehouse technology, or developing specific technologies that can solve current problems in Thai industries.

Nowadays, accessing information and communication through the online system is convenient for business development. Although it is increasing the development in the country, it also makes the Thai warehouse market accessibile to foreign companies. Therefore, it is essential for companies to maintain good relationships with their customer. In addition, the cooperation among the users, providers, and government can support each other and increase the chances of smart warehouse technology utilization in the future.

The study results may be a guideline for companies worldwide to plan for the shift to smart warehouses. Asia, in specific, is the region with high productivity growth in the future. It is necessary to have guidelines for warehouse management to increase the world’s competitive advantages. Even though some policy results may be incompatible with other countries, they can adjust their policies to suit their practices. For example, the barriers to smart warehouse adoption can be categorized based on seven barriers. However, the barriers can be adjusted based on different working cultures or countries. In addition, the analysis results in this study may be used as a guideline for other industries to apply the TOWS analysis to develop various strategies to enhance their work effectiveness.

7. Limitation

The research on smart warehouse adoption in Thailand faces several limitations. Firstly, the study's data collection was based on a relatively small sample size, consisting of only 22 users and five service providers. This limited sample may not adequately represent the diverse perspectives and experiences of all stakeholders involved in smart warehouse management in Thailand. Secondly, since the utilization of smart warehouses in Thailand is still in its early stages, there is a scarcity of comprehensive and accurate data specific to the Thai context. Consequently, some of the data used in the study may have been adjusted or borrowed from other countries. As the adoption of smart warehouse technologies is influenced by various local factors, relying on data from other regions may not fully reflect the unique challenges and opportunities faced by

Thailand in implementing and adopting smart warehouse solutions. Given these limitations, it is crucial to recognize the need for further research in this field. Future studies should aim to overcome the limitations by collecting data from a larger and more diverse sample, including stakeholders from various sectors and regions within Thailand. Additionally, conducting longitudinal studies to capture the dynamic nature of smart warehouse adoption and regularly updating the research with the latest technological advancements and market trends will help ensure the findings remain relevant and accurate. By addressing these limitations, researchers can enhance the understanding of smart warehouse adoption in Thailand and provide valuable insights for policymakers and industry practitioners.

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Author Contributions

Anatawat Chayutthanabun contributes to methodology, literature review, in-depth interviews, TOWS analysis, manuscript editing, and policy recommendations. Thanwadee Chinda contributes to conceptualization, methodology, technical data, in-depth interviews, TOWS analysis, supervision and manuscript editing. Suthathip Suanmali contributes to conceptualization, methodology, in-depth interviews, TOWS analysis, draft preparation, supervision, manuscript editing, and policy recommendation. All authors have read and agreed with the manuscript before its submission and publication.

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Appendix

Data of Each Technology Utilized by Users and Providers in Thailand

Technology	Number of Users	Technology	Number of Providers
Digital Software and Technology			
Warehouse Management System	18	Warehouse Management System	4
Order Management System	18	Enterprise Resource Planning	4
Enterprise Resource Planning	15	Data Management System	4

Data Management System	14	Supervisory Control and Data Acquisition Systems	4
Machine Monitoring and Reporting	12	Cloud Technology	4
Supervisory Control and Data Acquisition Systems	11	Machine Monitoring and Reporting	3
Cloud Technology	11	Block Chain	3
Product Life Cycle Management System	10	Artificial Intelligence	3
Logistic Management System	10	Product Life Cycle Management System	3
Web-enabled Technologies	8	Logistic Management System	3
Big Data Analytic	8	Web-enabled Technologies	3
Industrial 5G	5	Big Data Analytic	3
Block Chain	5	Digital Twin	3
Artificial Intelligence	4	Order Management System	2
Computer-based Process Control System	4	Industrial 5G	2
Process Field Net	3	Computer-based Process Control System	2
Computer-Aided Manufacturing Technology	3	Process Field Net	2
Digital Twin	2	Computer-Aided Manufacturing Technology	1
Warehouse Navigation	2	3D Visual Warehouse	1
3D Visual Warehouse	1	Warehouse Navigation	0
IoT			
Barcode	19	Barcode	3
Track and Trace Technologies	11	QR Code	3
Weight Check	10	Alarm Troubleshooting	3
QR Code	9	Radio Shuttle Car	3
Alarm Troubleshooting	8	Track and Trace Technologies	2
RFID	8	Weight Check	2
Text Recognition	3	RFID	2
Virtual Reality	1	Text Recognition	2
Voice Picking	1	Virtual Reality	2
Object Recognition	1	Voice Picking	2
Radio Shuttle Car	0	Object Recognition	2
3D Visual Recognition Technology	0	3D Visual Recognition Technology	0
Security and Safety Technology			
Video Surveillance System	16	Video Surveillance System	3
Finger Scanner	7	Finger Scanner	2
Face ID Entrance Control	3	Face ID Entrance Control	1
Smart warehouse and logistics facility			
Distribution Center	9	Distribution Center	3
Built to Suit Warehouse	4	Built to Suit Warehouse	3
Ready-built Warehouse	4	Cold Storage	2
Cold Storage	4	Ready-built Warehouse	1
Dark Warehouse	0	Dark Warehouse	1

Controllers			
Virtual Dashboard	10	Virtual Dashboard	2
Distributed Controllers	4	Distributed Controllers	2
Remote Terminal Units	2	Remote Terminal Units	2
Programmable Logic Controller	2	Programmable Logic Controller	2
Automation System			
Conveyer Belt	9	Conveyer Belt	3
Light Picking Technology	4	Direct Put Wall	3
Temperature Regulated Handling	3	Automated Storage/Retrieval System (AS/RS)	3
Automated Stacker Crane	3	Light Picking Technology	2
Customized Machine with Autonomous System	3	Temperature Regulated Handling	2
Scanning Tunnel	2	Automated Stacker Crane	2
Automated Storage/Retrieval System (AS/RS)	2	Horizontal Carousel	2
Palletizer	1	Connected Vehicle Technology	2
System Vehicle Loop	1	Scanning Tunnel	1
Horizontal Carousel	1	Palletizer	1
Connected Vehicle Technology	1	System Vehicle Loop	1
Direct Put Wall	1	Tilt Tray System	1
Tilt Tray System	1	Autostore	1
Autostore	0	Cardboard-box Closing Machine	0
Robots			
Autonomous Guided Vehicle	2	Autonomous Guided Vehicle	2
Robotic Arms	1	Robotic Arms	1
Computer Numerical Control System	0	Computer Numerical Control System	0