

Refining Warehouse Operations by Implementing Collaborative Robots and Automation: A Survey

Wang Yuan

School of Business
Singapore University of Social Sciences
Singapore 599494
wangyuan@suss.edu.sg

Zhao Qitong

School of Business
Singapore University of Social Sciences
Singapore 599494
qzhao@suss.edu.sg

Abstract

Traditionally, automation has been leveraged extensively in larger warehouses to streamline processes, reduce human error, and increase productivity. However, small-scale warehouses face unique challenges that complicate the adoption of such technologies. This research is structured around three critical questions: Firstly, it delves into the specific challenges these warehouses encounter in adopting automation. Secondly, it assesses the impact of various automation technologies, such as AGV robots, barcode systems, and OCR scanners, on improving efficiency and productivity. Thirdly, it explores effective strategies and best practices for seamlessly integrating these technologies into existing operations. By employing a comprehensive research methodology that includes surveys, interviews, observations, and leveraging the researcher's hands-on experience as a warehouse specialist, the study provides insightful analyses into the automation landscape for small-scale warehouses. The findings highlight significant barriers such as inadequate funding and disparities in access to technology, despite the pivotal role these facilities play in the logistics sector. The study proposes that government incentives or subsidies could facilitate a more equitable adoption of automation technologies. These insights offer practical recommendations for policymakers and warehouse owners, aiming to foster more efficient, less labor-intensive, and technologically advanced operations within these crucial logistics hubs.

Keywords

Robotics, Digital Transformation, Warehouse.

1. Introduction

Within the domain of warehouse operations, a lack of cutting-edge technologies frequently deprives small-scale facilities of the benefits that these innovations offer to improve operational efficiency. This evident disparity often originates from a variety of constraints, including financial limitations and challenges related to the allocation of resources (Horvath and Szabo, 2019). Therefore, smaller warehouses frequently fall behind their larger counterparts in adopting sophisticated technologies for their operations.

Undoubtedly warehousing is the essence of logistics. This assertion finds strong support in the data in Figure 1, which highlights the pivotal role of warehousing and storage within the broader logistics landscape. When examining the data through a quarter-on-quarter lens, it becomes evident that there has been a notable increase of 1.1% in the context

of warehousing and storing activities, as observed between the fourth quarter of 2022 and the first quarter of 2023. A more comprehensive view of this trend emerges when evaluating year-on-year changes, specifically comparing the first quarter of 2022 to the same period in 2023. In this comparison, the percentage change in warehousing and storing activities demonstrated a robust growth of 2.6%. The upward trends in both quarter-on-quarter and year-on-year measures substantiate the indispensable nature of warehousing in driving efficiency and economic growth within the logistics domain.

While the larger warehouse has seamlessly integrated high-tech innovations, the smaller warehouse predominantly relies on manual processes. This reliance on manual operations has resulted in heightened workloads and a backlog of tasks, such as the case for post-covid recovery period. Recognizing the potential for automation in every aspect of warehouse operations, there is a clear imperative for enhancements to be made.

A major issue arises from the absence of advanced warehouse management systems. Manual document handling is error-prone and time-consuming, the invoices are slotted in between the parcels (Figure 2) and sometimes when they are misplaced or missing, it affects the overall efficiency. Moreover, the failure to integrate with other systems and technologies results in missed opportunities for streamlined operations and data-driven decisions – Locating parcels becomes increasingly challenging, particularly when the designated location, such as the one depicted in Figure 2 labelled as "C-1-1," is absent from the system. This absence hinders the efficient retrieval of items when needed, often leading to last-minute searches and disruptions. This situation is further compounded when the responsible personnel is on medical leave, as they are the only one possessing the knowledge of parcel placement. As a result, discrepancies, order delays, and operational costs increase. If the items remain within the warehouse, costs continue to accumulate for inventory storage, and funds remain tied up. Addressing these issues is crucial as warehouses play a vital role in the supply chain, acting as central hubs for receiving, storing, and distributing electrical products to various sectors' customers.

WAREHOUSING & STORAGE PRICE INDEX (2021=100)																		
Price Index	Weights	2019				2020				2021				2022				2023
		1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q
WAREHOUSING & STORAGE	10,000	92.9	93.3	93.4	93.7	95.4	96.3	96.7	96.6	99.9	99.8	100.1	100.2	100.2	100.4	101.2	101.8	102.9
General & Refrigerated Warehousing	5,538	99.5	99.7	100.1	100.0	100.1	100.2	99.8	99.7	100.0	100.0	99.9	100.1	100.2	100.6	102.3	103.1	103.9
Dangerous Goods Storage	4,462	88.5	89.1	89.1	89.5	92.4	93.8	94.6	94.6	99.7	99.7	100.3	100.3	100.3	100.2	99.7	100.2	101.6
Quarter-on-Quarter Percentage Change																		
WAREHOUSING & STORAGE	10,000	-1.4	0.5	0.1	0.3	1.9	0.9	0.3	0.0	3.3	0.0	0.2	0.1	0.0	0.2	0.8	0.6	1.1
General & Refrigerated Warehousing	5,538	-0.4	0.3	0.3	-0.1	0.1	0.1	-0.4	-0.1	0.3	0.0	0.0	0.2	0.1	0.4	1.7	0.8	0.8
Dangerous Goods Storage	4,462	-2.1	0.7	-0.1	0.5	3.2	1.5	0.9	0.0	5.4	0.0	0.6	0.1	0.0	-0.1	-0.5	0.5	1.4
Year-on-Year Percentage Change																		
WAREHOUSING & STORAGE	10,000	-1.1	-0.5	-1.1	-0.5	2.8	3.2	3.4	3.1	4.6	3.6	3.5	3.7	0.4	0.6	1.1	1.6	2.6
General & Refrigerated Warehousing	5,538	0.6	0.7	-0.7	0.1	0.6	0.5	-0.3	-0.3	-0.1	-0.2	0.2	0.5	0.2	0.6	2.4	3.0	3.7
Dangerous Goods Storage	4,462	-2.3	-1.4	-1.4	-1.0	4.4	5.3	6.2	5.7	7.9	6.3	6.0	6.0	0.6	0.5	-0.5	-0.1	1.3

Figure 1. WSPI index 2019-2021 (Services Producer Price Indices, 2023)



Figure 2. The slotted invoices in between and location of items

By integrating automation technologies significantly manual intervention can be seen for both inbound and outbound processes, thus the shorter process flows whilst becoming more simplified. This not only enhances operational efficiency but also allows the workforce to focus on value-added tasks, ultimately leading to increased productivity and improved overall performance.

1.1 Objectives

The proposed study seeks to tackle a significant challenge within the realm of supply chain warehousing logistics. The central focus will be on the introduction of automation technologies in smaller, middle-scale warehouse enterprises. While the primary research data will be on a specific organization, it will leverage a diverse range of online data sources from multiple small-scale entities to ensure a comprehensive analysis. The investigation's scope will encompass operational scales spanning from local to regional and global contexts, thereby offering insights across a broad spectrum. The study will emphasize downstream supply chain activities, whilst acknowledging aspects of end-to-end processes. Essentially, the research will adopt a balanced perspective by examining both challenges and opportunities associated with automation, alternately from the viewpoints of shippers and carriers. This inclusive approach aims to foster a holistic comprehension of the intricate dynamics entailed in effectively integrating automation technologies across varied scales and viewpoints within the ever-evolving landscape of supply chain warehousing logistics.

2. Literature Review

Warehouse automation has become increasingly important for improving efficiency and meeting customer demands, especially in light of recent market changes (Glynn & Cook, 2022; Bogue, 2016). Automated systems can enhance storage density, productivity, and flexibility in warehouse operations (Baker & Halim, 2007; Koster & René, 2018). Various robotic systems have emerged, including shuttle-based storage and retrieval systems, compact storage systems, and mobile fulfillment systems (Azadeh et al., 2019). Recent advancements in artificial intelligence have enabled robots to perform complex tasks such as mixed product picking, sorting, and kitting. As robotic technologies continue to evolve, warehouses are moving towards higher levels of automation (Bogue, 2021). Horvath and Szabo (2019) seek to comprehend how different automation technologies contribute to efficiency improvement. The paper provides perspectives on the elements that catalyze or hinder the integration of automation technologies by analyzing the driving forces and hurdles of Industry 4.0 adoption across both SMEs and MNEs. It does not, however, delve fully into the various benefits of individual automation systems, which might constitute to a valuable feature for my study to examine. Thus, to supplement this, a deeper analysis of how various automation technologies contribute to efficiency and productivity gains, drawing similarities between (SME)s and (MNE)s should be demonstrated in the study.

Various robotic systems are being implemented, including automated guided vehicles, autonomous mobile robots, and shuttle-based storage systems (Dhaliwal, 2020). These technologies offer benefits such as increased productivity, flexibility, and improved workplace morale. Drawing insights from the comprehensive literature review article authored by Sun, X. et al. (2022), twelve pivotal Industry 4.0 technologies have been outlined in their review along with their benefits. The review emphasizes how these Industry 4.0 technologies can be integrated into small-scale warehouse operations to enhance efficiency. For instance, the integration of IoT sensors with AI-driven predictive maintenance systems can minimize downtime, while autonomous robots can optimize picking routes based on real-time demand data. However, the rapid adoption of these new systems presents challenges in system design, integration, and operational control, necessitating new research models and methods. When implementing warehouse automation, companies should develop strategic plans, justify the system, and conduct thorough equipment analysis, testing, and training (Adams, 1996). This thereby lays the foundation for our exploration of effective strategies and recommended best practices for successful automation implementation as per the project scope.

Fager, P. et al. (2021) explicitly addresses the role of automation technologies in improving productivity in small-scale warehouses. This study corresponds with the project's emphasis on refining warehouse operations through the adoption of collaborative robots and automation by exploring the economic consequences of integrating collaborative robots (cobots) into sorting procedures. The study compares the costs of human sorting vs cobot-supported sorting options, considering factors such as personnel, equipment, and quality. It provides useful insights into the benefits of cobot sorting, such as enhanced productivity and improved error detection. The authors present a concrete example of how particular automation technologies can contribute to increased efficiency, which could be correlated along with

the project ideation to improve the practical applicability of the project. However, this study focuses on economic implications, aspects of the implementation process, such as problems encountered, successful integration tactics, and the significance of human-machine collaboration can be addressed in our study.

Ali and Kaur (2022) present a thorough examination of technology's consequences for small-scale warehouses, including both benefits and drawbacks. The paper provides a core understanding of the impact of technology on small-scale warehouses. Based on this foundation, the project can delve into the unique challenges and opportunities that come with automating such warehouses.

In conclusion, the literature provides a variety of insights on the challenges, contributions, and techniques for automation and optimization in small-scale warehouses. With the various authors' conducted studies, it collectively addresses aspects related to the adoption of Industry 4.0 technologies, driving forces and barriers, the impact of technology, and the economic implications of automation integration. However, there is still a need for more research that thoroughly investigates the specific factors driving technology adoption, thoroughly analyses the benefits of various automation technologies, and provides actionable strategies for successful automation implementation to optimize processes in small-scale warehouses.

3. Methods

The research will employ the Google Forms survey platform for data collection, ensuring participants provide informed consent before participating. The collected data will be meticulously analyzed using Excel's pivot tables, descriptive statistics, and correlations. Data privacy and security will be maintained, adhering to regulations and participants' rights. A random sampling approach will target working adults with warehouse experience. Distribution will utilize social media, WhatsApp, and personal networks. Response validation will prevent duplications.

For the data collection phase of the project, a comprehensive approach will be taken to gather relevant insights regarding the implementation of barcode technology to relieve the warehouse from manual processes. This will involve a combination of in-person observation and face-to-face interviews with the current warehouse personnel, ensuring a holistic understanding of the current practices and potential improvements. The study will encompass a mix of experimental and survey methods to capture both immediate changes and longitudinal trends.

- In-Person Observation: The project will involve in-depth in-person observation conducted by the researcher. The focus will be on closely monitoring the various aspects of the inventory management workflow. Key measurements will include tracking inventory movement, observing data entry and recording methods, identifying instances of errors, monitoring manual tracking and searching processes, noting communication and coordination methods among the team, recording instances of handling delays, identifying bottlenecks and constraints in the workflow, assessing employee experiences with current practices, evaluating physical space utilization, and measuring order fulfilment time. These observations will provide real-time insights into the intricacies of the warehouse's operations.

- Face-to-Face Interviews: To complement the observational data, face-to-face interviews will be conducted with the current warehouse personnel. These interviews will provide an opportunity to delve into their experiences, challenges, and perceptions related to manual processes and the potential benefits of using automation. The interviews will be guided by a semi-structured approach, allowing for flexibility to explore different perspectives. The interviews are expected to last approximately 20 minutes, depending on the depth and detail the participants are willing to share.

4. Data Collection

The data collected for the project will encompass various forms:

- Primary Data: The data collected will be specific to the project's objectives and will directly contribute to the analysis and conclusions.

- Quantitative and Qualitative Data: Both numeric (quantitative) and non-numeric (qualitative) data will be gathered from the surveys. This diverse dataset will allow for a well-rounded exploration of the project's research questions.

- Cross-Sectional and Longitudinal Data: The project will utilize cross-sectional data, providing a snapshot of the current situation i.e., Company A, as well as longitudinal data, allowing for the tracking of changes and trends over time. This combination will offer insights into immediate improvements and evolving patterns.

The project will investigate a range of KPIs and metrics, including process time, inventory accuracy, error rates, resource allocation efficiency, order fulfilment time, and more. Weekly data from Company A will be collected, particularly focusing on bulk shipments from logistics partners such as Bollore and FedEx. The face-to-face interviews will be directed towards warehouse personnel, ensuring that their first-hand experiences and insights contribute significantly to the understanding of the current processes and potential areas for improvement.

By employing a comprehensive data collection approach that involves both observation and direct engagement with personnel, the project aims to generate a well-rounded dataset that serves as the foundation for the subsequent analysis and conclusions regarding the benefits of using barcode technology to streamline warehouse processes.

The primary objective is to optimize warehouse operations through the implementation of automation technologies. Given the nature of logistics projects and the availability of quantitative data, the analysis will focus on processing the collected data to extract valuable information, aligning with research questions and objectives as follows.

The survey questions aim to comprehensively explore the challenges and opportunities associated with the adoption of automation technologies, specifically collaborative robots (cobots) and barcode scanning systems, in small and middle-scale logistics and warehousing enterprises. This study seeks to identify the primary obstacles faced by these enterprises in their quest for automation-driven process optimization. By examining the challenges, the study intends to offer insights into potential hurdles and recommend strategies to facilitate successful adoption, by focusing on the contributions of various automation technologies to enhance efficiency and productivity in these settings. It also aims to measure the potential benefits of implementing these technologies, providing a holistic understanding of their favorable outcomes in diverse operational contexts. Lastly, the study aims to identify, analyze, and consolidate a range of strategies for seamless automation technology integration, emphasizing the achievement of successful implementation and process optimization. The ultimate goal of this survey is to offer actionable insights that can empower small and middle-scale logistics and warehousing enterprises to harness the benefits of automation, thereby addressing their operational challenges and enhancing their competitiveness.

This survey successfully collected responses from a total of 62 participants. The primary objective of this research was to gain valuable insights into the potential implications of utilizing collaborative robots and automation technologies, particularly Industry 4.0 technologies like automated guided vehicles (AGVs) and automated storage and retrieval systems (AS/RS), in the context of refining warehouse operations within small and middle-scale warehouses in Singapore.

The survey encompassed four distinct sections, which include:

- General Awareness, aimed to gauge respondents' awareness of automation technologies and their relevance to modern industries, specifically within the logistics sector.
- Perceptions on Automation: In this section, respondents were asked to express their thoughts and opinions regarding the adoption of automation technologies in small and middle-scale warehouses.
- Warehouse Operations, delving into the current operational aspects of small and middle-scale warehouses, exploring manual processes, challenges, and the potential for automation.
- Impact and Strategies, focused on understanding how respondents perceived the impact of automation in warehouse operations and their ideas for effective implementation and strategies for overcoming challenges.

5. Results and Discussion

5.1 Results

For respondents' awareness of small and middle-scale logistics enterprises utilizing collaborative robots (cobots) or automation technologies in their warehouse operations, Figure 3 shows the results indicating that a majority of respondents, approximately 95.1% (59 out of 62), expressed their lack of awareness in this regard.

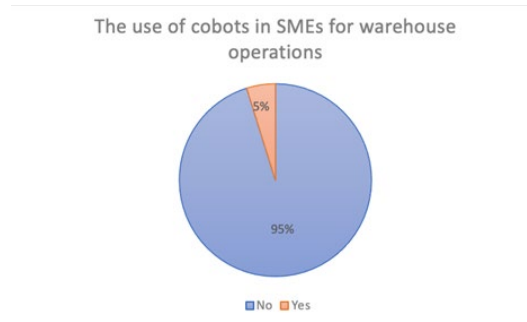


Figure 3. Awareness on the usage of cobots in SMEs for the warehouse operations

Among the remaining respondents who reported being aware of such enterprises, a few specific company names were provided. Notably, Shopee, Taobao Cainiao, and Alibaba were mentioned. The mentioning of prominent companies like Taobao Cainiao and Alibaba indicates a degree of awareness of significant players in the logistics industry, albeit with varying levels of engagement and operation scales. These survey results highlight the need for increased awareness and understanding of the role of automation technologies within logistics, especially in the context of smaller enterprises.

On to the perceptions regarding the adoption of autonomous technologies, such as cobots and automation, and how they might impact the efficiency of resource allocation in small and middle-scale warehouses.

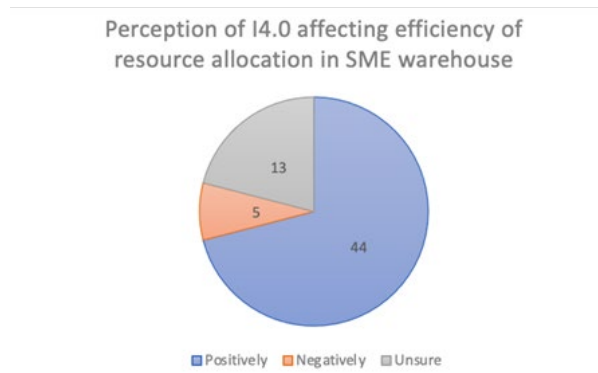


Figure 4. Perception of respondents regarding the effects of I4.0 and the efficiency of resource allocation in SME warehouse

As depicted in Figure 4, out of the total respondents, a significant portion, consisting of 44 individuals, expressed a positive view regarding the adoption of autonomous technologies and how it could enhance the efficiency of resource allocation. These individuals likely believe that these technologies can lead to more efficient utilization of budget and manpower in warehouse operations.

Delving into the factors that respondents believe might pose hindrances to the successful implementation of collaborative robots and automation in small and middle-scale warehouse operations. The survey offered several options for consideration, which respondents could select more than one of as depicted in the line graph, Figure 5.

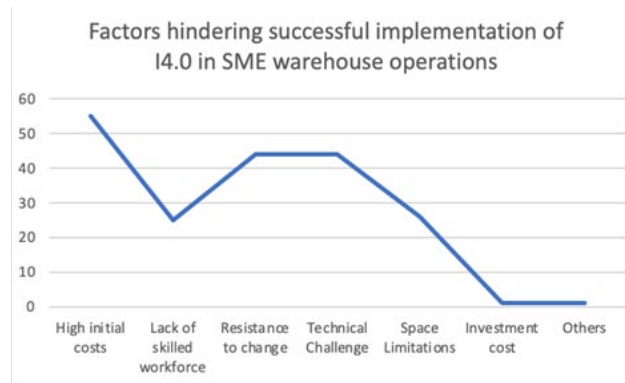


Figure 5. Respondents perception on which factors affects successful implementation of I4.0 in SME warehouse operations

The factor that garnered the highest count, with 55 respondents selecting it, was the high initial costs associated with implementing collaborative robots and automation. This result indicates that many respondents are acutely aware of the financial challenges posed by the adoption of such technologies.

Tied at 44 responses each, resistance to change and technical challenges emerge as significant concerns. These selections signify that a substantial portion of the respondents perceives resistance from the workforce and technical hurdles as potential roadblocks.

Space limitations and the lack of a skilled workforce received 26 and 25 selections, respectively. These concerns reflect apprehensions about the physical constraints within warehouse settings and the importance of a competent workforce for handling advanced technologies.

One respondent elaborated on potential hindrances by mentioning regulatory constraints, compatibility issues with existing systems, and the need for regular maintenance. This expanded perspective underscores the multifaceted nature of the challenges that might impede the successful integration of collaborative robots and automation in small and middle-scale warehouses.

Based on the results, it shows that respondents are particularly mindful of the financial demands and challenges related to workforce dynamics and technology. The additional insights provided by one of the respondents further underscore the complexity of this issue, suggesting that a comprehensive approach is needed to address potential hindrances effectively.

The survey then delved into the perception of whether large-scale enterprises hold a competitive advantage over their small and middle-scale counterparts due to specific factors. Respondents had various factors to choose from and could also provide additional insights as in the line graph in Figure 6.

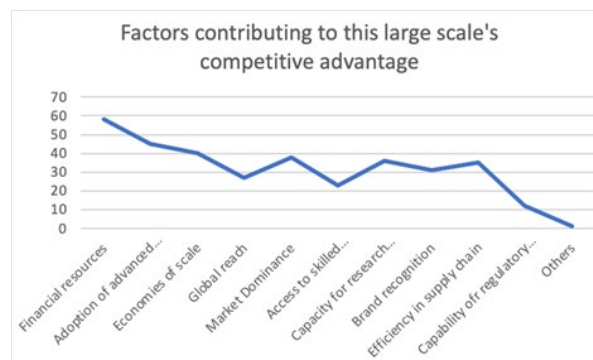


Figure 6. Respondents decide on the factors contributing to this large scale's competitive advantage

The bulk of respondents, 58, identified financial resources as the most significant factor contributing to the competitive advantage of large-scale enterprises. This underscores the consensus that financial backing plays a pivotal role in competitiveness.

The adoption of advanced technologies was chosen by 45 respondents. This suggests that staying technologically updated is a key element in the competitive edge of larger enterprises. Thereafter, economies of scale were acknowledged by 40 respondents, emphasizing the perception that operating on a larger scale brings efficiency and cost benefits. Market dominance was selected by 38 respondents, signifying the understanding that being a dominant force in the market is a source of competitive advantage.

Thirty-five respondents recognized the capacity for research and development as a factor. This indicates an appreciation of innovation's role in competitiveness. Supply chain efficiency was chosen by 36 respondents, highlighting the importance of streamlined operations. Followed by brand recognition, receiving 31 selections, indicating that a strong brand presence is considered a competitive advantage. Global reach was selected by 27 respondents, suggesting that a broad geographic presence contributes to competitiveness. Access to a skilled workforce was a factor recognized by 23 respondents, demonstrating the acknowledgment of the role of human resources in competitiveness. Regulatory compliance was chosen by 12 respondents, indicating that adhering to regulations can be a competitive advantage.

One respondent provided an insightful perspective by selecting the "other" option. They mentioned that these factors allow larger enterprises to invest in and leverage autonomous technologies more effectively, resulting in a competitive edge. This statement highlights that the advantage might vary depending on the specific industry and business strategy, suggesting that the competitive landscape can be complex.

In summary, the survey results clearly indicate that respondents believe large-scale enterprises have a competitive advantage over smaller counterparts. This advantage is attributed to various factors, including financial resources, technological adoption, economies of scale, market dominance, research and development capacity, supply chain efficiency, brand recognition, global reach, a skilled workforce, and regulatory compliance. The respondent's comment in the "other" option emphasizes the importance of nuanced industry and strategy-specific considerations in assessing the extent of the competitive advantage.

Within the section concerning warehouse operations, a question was posed using a linear scale to gauge perceptions. Respondents were asked to express their agreement with the statement: "Do you agree that small and middle-scale warehouses face challenges related to order fulfilment time?" The scale ranged from 1 to 5, with 1 indicating "strongly agree," 5 meaning "strongly disagree," 3 representing a neutral standpoint, and 2 and 4 signifying agreement and disagreement, respectively.

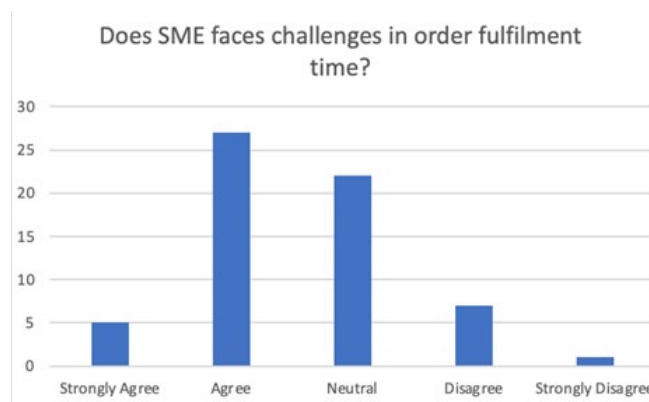


Figure 7. Respondents view on whether SME faces challenges in order fulfilment time

As in Figure 7, five respondents strongly agreed that small and middle-scale warehouses encounter challenges concerning order fulfilment time. This indicates a notable level of concern or consensus about this issue among a small group of respondents.

A significant portion, 27 respondents, agreed with the statement. This implies that a substantial number of participants perceive challenges in order fulfilment time for small and middle-scale warehouses. A sizeable group of 22 respondents adopted a neutral stance on the issue. This suggests that while they didn't strongly agree or disagree, they might require further information or context to form a firm opinion. Seven respondents expressed their disagreement. This indicates that a minority within the survey does not perceive significant challenges related to order fulfilment time in small and middle-scale warehouses. Only one respondent strongly disagreed, signifying an exceptional viewpoint that order fulfilment time isn't a significant concern for these types of warehouses.

In summary, the survey responses reveal diverse perceptions regarding the challenges faced by small and middle-scale warehouses in terms of order fulfilment time. While a notable portion agrees or strongly agrees with this statement, a significant number remains neutral, and a smaller segment disagrees with the notion. The single strong disagreement response highlights that there are variations in how participants view this issue.

The next question delved into perceptions about work within small and middle-scale logistics companies. Respondents were asked to express their agreement with the statement: "Do you agree that work in small and middle-scale logistics companies is mostly manual, and this may impact inventory accuracy?" The responses were categorized into agree, disagree, and strongly agree as per the pie chart in Figure 8.

A significant majority of respondents, 38, agreed that work in small and middle-scale logistics companies is predominantly manual and that this manual work could potentially affect inventory accuracy. This indicates that many participants share the view that manual processes are prevalent in such companies and could have consequences for inventory precision. Fourteen respondents expressed their disagreement with the statement. This suggests that there is a substantial number of participants who don't believe that work in these companies is predominantly manual or that it has a significant impact on inventory accuracy. Ten respondents strongly agreed with the statement, signifying a noteworthy level of concern about the predominance of manual work in small and middle-scale logistics companies and its potential effects on inventory accuracy.

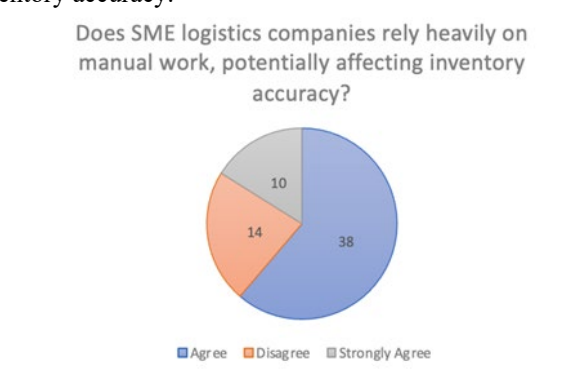


Figure. 8. Pie chart on respondents view of SME logistics companies relying heavily on manual work, which could potentially affect inventory accuracy

In summary, the survey results reveal that most respondents share the perception that work in small and middle-scale logistics companies relies heavily on manual processes and that this manual work may indeed influence inventory accuracy. However, there is also a significant portion of respondents who hold different views, disagreeing with this assertion. This diversity in perspectives highlights the varying opinions and experiences within the survey participant group.

Moving on to the "Impact and Strategies" section, participants were asked to identify the areas where they believed collaborative robots and automation could have the most significant impact if implemented in small and middle-scale warehouses. Respondents could select multiple options from the provided list as shown in the horizontal bar graph, Figure 9.

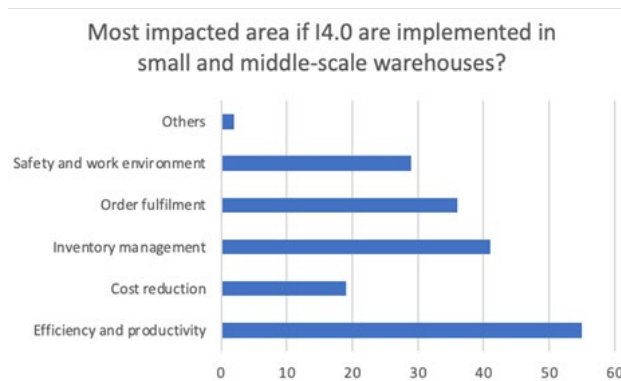


Figure. 9. Areas with the Greatest Potential Impact from Implementing Collaborative Robots and Automation in Small and Middle-Scale Warehouses

A substantial majority of respondents, 55, identified efficiency and productivity as the primary area for potential impact. This indicates that many participants perceive collaborative robots and automation as valuable tools for enhancing operational efficiency and productivity in these warehouse settings. Forty-one respondents recognized the potential for collaborative robots and automation to impact inventory management. This suggests that a considerable number of participants believe these technologies can contribute to more effective inventory control within small and middle-scale warehouses. Thirty-six participants saw order fulfilment as an area with substantial potential impact. This highlights the perception that automation technologies can play a crucial role in expediting and improving the accuracy of order fulfilment processes. Safety and creating a favorable work environment were identified by 29 respondents as areas that could benefit from the implementation of collaborative robots and automation. This demonstrates a recognition of the potential for these technologies to enhance workplace safety and overall work conditions. Nineteen respondents indicated that cost reduction was a key area for potential impact. This suggests that some participants see the introduction of automation to achieve cost savings in warehouse operations. Additionally, two respondents provided open-ended "other" responses. They mentioned several aspects, including concerns about reduced jobs and employment issues, as well as the potential for improved scalability and more efficient handling of increased demand.

The final question in the survey aimed to gather insights regarding the strategies perceived as effective in tackling the challenges related to the implementation of autonomous technologies in small and middle-scale logistics. Out of the 62 respondents, only 9 chose not to respond, indicating a notable level of engagement and interest. The majority of the participants provided valuable opinions and suggestions.

Among the recurring themes in the responses was the support for government intervention to address funding gaps, a critical factor that often hinders the adoption of new technologies in smaller logistics companies. Additionally, several participants emphasized the importance of facilitating a smooth transition for employees who might find it challenging to embrace new paradigms and ways of working. To do so, they proposed initiating the adoption of autonomous technologies through pilot testing, allowing employees to gradually adapt to the changes. These recommendations align with the need for a holistic approach to address the multifaceted challenges associated with technological advancements in the logistics sector.

In summary, the survey results reflect diverse perceptions about the areas where collaborative robots and automation can make the most significant impact in small and middle-scale warehouses. Efficiency and productivity stand out as the top priority, followed by inventory management, order fulfilment, safety, and cost reduction. The "other" responses point to broader considerations related to workforce implications and scalability.

5.2 Strengths, Weaknesses and Limitations

From the survey conducted, this study's practical relevance to the obstacles and challenges that small- and medium-sized logistics and warehousing businesses encounter in the real world is one of its key strengths. Ensuring that the study stays highly relevant to the demands of the industry today, the research questions have been carefully constructed

to directly address the current needs. Furthermore, the study takes a comprehensive approach by examining various aspects of automation adoption, including challenges, benefits, and strategies for successful implementation. This ensures that the study offers a comprehensive grasp of the issue at hand.

Additionally, given that the survey questions are aligned with current industry advancements, specifically the adoption of concepts from Industry 4.0 and the integration of automation technologies. Along with practicality and realism, the proposed solutions too, address the challenges identified in the survey questions in a manner that can be readily implemented by enterprises. Lastly, the study's findings and recommendations have broad applicability, extending their relevance to a wide range of small and middle-scale logistics and warehousing enterprises.

Nonetheless, there are too, flaws worth considering. First, the possibility of sampling bias. Sample of respondents has a major influence on the study's conclusions. If this sample is not representative of the entire population of small and middle-scale logistics and warehousing enterprises, the study's generalizability may be limited. Furthermore, many survey questions rely on the views and judgements subjected to respondents. Although these insights are useful, there's a likelihood that they might insinuate elements of subjectivity and even bias into the answers.

The study's primary reliance on survey data, a single form of data gathering. The exclusive use of this method may constrain the depth of insights that can be gained. Finally, the study did not deeply explore the specifics of implementation and the potential hurdles that may be encountered during the execution of the proposed solutions.

Moreover, it is imperative to acknowledge specific limitations. Firstly, the study's findings and recommendations are subject to the fast-paced evolution of technology and industry trends. This inherent time sensitivity implies that the applicability of the suggested solutions may wane over time if they are not continually revised and tailored to adapt to evolving circumstances. Secondly, the generalizability of the study's findings may have constraints rooted in the context and the sample used for the survey. It is plausible that the results may not universally apply to all small and middle-scale logistics and warehousing enterprises. Additionally, the implementation of the proposed solutions might face limitations due to the availability of resources, including financial, technological, and a skilled workforce. The market dynamics, governmental regulations, and economic conditions are examples of external elements that can affect the effectiveness of automation technology implementation. These outside variables may affect how successfully the suggested remedies work and are outside of the enterprises' control.

6. Conclusion

In conclusion, this project has effectively addressed the research questions and has successfully achieved the research objectives. The analysis of survey data have yielded valuable insights into the formidable challenges encountered by small-scale warehouses as they strive to implement automation for optimizing their processes.

Chief among these challenges is the substantial financial burden that often obstructs the adoption of automation solutions in small-scale warehouses. These establishments frequently grapple with limited capital and investment capacity, serving as a significant impediment. Our findings have shed light on potential solutions, including government intervention and the imperative need for pilot runs. Pilot tests have proven to be instrumental in shifting prevailing mindsets and facilitating the transition towards automation.

Furthermore, our research has delved deeply into the contribution of various automation technologies towards enhancing efficiency and productivity within small-scale warehouses. Despite the prominent barriers, especially the challenge of securing adequate funding, our study underscores the critical need to extend opportunities and trust to Small and Medium Enterprises (SMEs). This empowerment is crucial for SMEs to make meaningful contributions to economic growth and transformation. A compelling aspect that has emerged is the remarkable synergy among barcode scanners, Automated Guided Vehicles (AGVs), and OCR scanners. These technologies effectively complement each other, streamlining processes within small-scale warehouses and delivering tangible benefits. The collaborative approach optimizes inventory management, enhances order fulfillment accuracy, and reduces operational costs.

Our exploration of effective strategies and best practices for implementing automation in small-scale warehouses has also provided essential insights. The survey results underscore the significance of conducting pilot tests to assess the feasibility and benefits of automation. Furthermore, reskilling and educating employees are vital components of successful automation adoption. Providing the workforce with technological knowledge ensures they can leverage

automation tools for maximum efficiency. To maintain competitiveness, it is imperative to provide continuous education and regular training to keep employees updated with current technology trends.

The primary findings of this project underscore the persistent challenges of funding and the essential need for technological knowledge, even within Singapore's high-tech and advanced landscape. While it presented some difficulty in finding survey respondents favorably inclined towards our findings, their responses have been invaluable in shaping our conclusions.

Further studies should consider a Comparative Analysis of Warehouse Management Systems, where a detailed evaluation of different systems, including SAP Business One, can provide insights into their efficiency and applicability within small and middle-scale warehouses. Understanding their performance in varying operational contexts is critical for informed decision-making. Expanding the scope to a global perspective on small and middle-scale warehouses is another promising avenue. By comparing warehouse operations across different countries and evaluating the adoption and influence of automation and Industry 4.0 technologies, researchers can unveil regional variations and best practices. This broader view contributes to a more comprehensive understanding of global logistics trends. Addressing these areas can contribute to the ongoing evolution and enhancement of warehouse operations in an increasingly technology-driven world.

While these suggestions can significantly enrich the field of study, it's crucial to acknowledge the limitations faced in the current research. Due to time constraints, the pool of respondents could not be expanded as desired, potentially impacting the comprehensiveness of the findings. Additionally, a digital twin model can be explored to incorporate real-life scenarios to enhance its real-world applicability. These avenues for future study can address these limitations and offer a more extensive understanding of the complex logistics landscape.

References

- Adams, N.D., Warehouse and Distribution Automation Handbook, 1996.
- Ali, S. S., & Kaur, R., Exploring the impact of technology 4.0 driven practice on warehousing performance: a hybrid approach. *Mathematics*, 10(8), 1252, 2022.
- Azadeh, K., Koster, R.M., & Roy, D., Robotized and Automated Warehouse Systems: Review and Recent Developments. *Transportation Science*, 53, 917-945, 2019.
- Baker, P., & Halim, Z.I., An exploration of warehouse automation implementations: cost, service and flexibility issues. *Supply Chain Management*, 12, 129-138, 2007.
- Bogue, R., Growth in e-commerce boosts innovation in the warehouse robot market. *Industrial Robot*, 43, 583-587, 2016.
- Bogue, R., Warehouse robot market boosted by Covid pandemic and technological innovations. *Industrial Robot*, 49, 181-186, 2021.
- Dhaliwal, A., *The Rise of Automation and Robotics in Warehouse Management*, 2020.
- Fager, P., Sgarbossa, F., & Calzavara, M., Cost modelling of onboard cobot-supported item sorting in a picking system. *International Journal of Production Research*, 59(11), 3269-3284, 2022.
- Glynn, F., & Cook, C., Collaborative mobile robots: Bringing greater productivity and flexibility to warehouse operations. *Journal of Supply Chain Management, Logistics and Procurement*, 2022.
- Horváth, D., & Szabó, R. Z., Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?. *Technological forecasting and social change*, 146, 119-132, 2019.
- Koster, D.M., & René, B.M., Automated and Robotic Warehouses: Developments and Research Opportunities. *Logistics and Transport*, 38, 33-40, 2018.
- Sun, X., Yu, H., Solvang, W. D., Wang, Y., & Wang, K., The application of Industry 4.0 technologies in sustainable logistics: a systematic literature review (2012–2020) to explore future research opportunities. *Environmental Science and Pollution Research*, 1-32, 2022.

Biographies

Wang Yuan Jessica is a Senior Lecturer at Singapore University of Social Science (SUSS). Before that she was a Research Assistant Professor at Department of Industrial and Systems Engineering in National University of Singapore. She received her PhD degree in Optimization and Simulation, with specialization in transportation and logistics system at National University of Singapore 2012. Her major research interests include Mathematical Modeling, Complex System simulation and optimization. She has published 30+ high quality journal papers, such as

Transportation Science, Transportation Research Part B/C/E, IEEE Transactions on Intelligent Transportation Systems, and 3 ESI highly cited papers. She serves as an associate editor in <Journal of Simulation>&<Asia-Pacific Journal of Operational Research>.

Zhao Qitong is a Lecturer in the Logistics and Supply Chain Management Programme at the School of Business, Singapore University of Social Sciences (SUSS). Her research interests encompass port operations, warehouse operations management, and logistics and supply chain management using simulation and optimization methods. Dr. Zhao has published several papers in reputable journals, including Flexible Services and Manufacturing Journal and the Asia-Pacific Journal of Operational Research. She earned her Ph.D. in Industrial Systems Engineering and Management from the National University of Singapore.