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Industry 5.0 and Overall Supply Chain Performance: A Proposed Conceptual Framework †

Hamideh Nazarian * and Sharfuddin Ahmed Khan

Industrial Systems Engineering, University of Regina, Regina, SK S4S 0A2, Canada; sharfuddin.khan@uregina.ca

* Correspondence: hnu428@uregina.ca

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Abstract: This study investigates the impact of Industry 5.0 (I5.0) on the overall supply chain performance (SCP). Three dimensions of SCP, including efficiency, responsiveness, and visibility, have been defined based on the existing literature to evaluate the overall SCP. Moreover, seven enabling technologies of I5.0, which have the greatest impact on supply chain management (SCM), have been extracted from the existing literature. This study also demonstrates how I5.0 affects SCP dimensions and how each dimension contributes to overall SCP. The present work can provide managers and practitioners with a comprehensive perspective on the importance of I5.0 in improving their SCP by enhancing the efficiency and effectiveness of supply chain (SC) actions.

Keywords: Industry 5.0; digitalization; supply chain 5.0; supply chain performance (SCP); SCP dimensions

1. Introduction

A digital SC is a value-driven system incorporating recent technologies, modern methods, and digital analytics into SCM [1]. This transformation strengthens business models through new and diverse sources of income generated by the digital SC [2–4]. The role of disruptive technologies in this context is worth noting, as they are instrumental in transitioning SC processes to a digital form (downstream, upstream, and midstream) [5–7]. In this landscape, I5.0, the latest industrial revolution, empowers humans to work with cutting-edge technologies and collaborate with AI-powered robots to improve workplace processes, including those in the SC [8–11].

I5.0 has attracted increasing interest worldwide. I5.0 does not replace Industry 4.0 (I4.0) but rather expands and supplements it [11]. The transition from I4.0 to Industry 5.0 represents a significant manufacturing and SCM leap forward, introducing advancements that exceed its predecessor's capabilities. I5.0 introduces hyper-customization, going beyond I4.0's emphasis on intelligent SCs to enable mass customization with precision and cost-effectiveness. This allows the development of tailored products crucial for meeting diverse customer preferences and ensuring supply chain efficiency (SCE) in today's varied market. Additionally, I5.0 adopts a human-centered approach, integrating humans and machines to nurture innovation, creativity, and adaptability within the SC. Unlike I4.0, which tended to separate human labor from automation, I5.0 embraces collaboration, enhancing responsiveness to market needs. Furthermore, I5.0 expands its goals beyond mere efficiency and automation, integrating sustainability and environmental concerns into its framework. By managing the digital shifts initiated by I4.0, I5.0 aims to establish a sustainable and environmentally friendly industry, reducing waste and energy usage across the SC. Utilizing advanced technologies like Artificial Intelligence (AI), Internet of Everything (IoE), Blockchain (BC), 6G, Collaborative robots (Cobots), Big Data Analytics (BDA), and Digital Twin (DT), I5.0 optimizes SCP through data analysis, logistics optimization, and streamlined production processes. I5.0 emphasizes resilience and adaptability within

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the SC, stressing collaboration between humans and machines to address disruptions and shifts in demand swiftly. This transition towards a personalized, human-centered, sustainable, and resilient approach significantly elevates SCP in today's ever-changing business environment [8,9,12].

Human-centricity, sustainability, and resilience are the concepts on which I5.0 is focused. Environmental harmony, worker needs sustainability, and the demand to increase resilience throughout SCs and value are cherished by I5.0 [8,13,14]. Now, I5.0 has been conceived to influence the specific inventiveness of human experts for working jointly with intelligent, high-powered, and precise machinery. The idea of several technical aspects is that the human touch will be returned to the manufacturing industry with the help of I5.0. Building on the fundamentals of I4.0, I5.0 highlights the significance of human-centricity in industry and production. When processes, technologies, and systems are designed to improve the role of humans in the production environment, it is referred to as being human-centric. This means placing equal weight behind technological breakthroughs and human abilities, creativity, decision-making, and well-being. I5.0's human-centricity requires worker empowerment, customization and flexibility, safety and well-being, upskilling and training, as well as moral and social responsibility. In I5.0, the focus on human-centricity enhances SC operations and shapes solid corporate strategy by bolstering decision-making, flexibility, customization, ethical responsibility, skill development, teamwork, and innovation. Prioritizing human input ensures that employees are pivotal in driving SCE and crafting customer-centric, ethical, adaptable, and innovative business strategies [11,15].

Industries can satisfy the demand and provide tailored and personalized products faster with the help of disruptive technologies empowering I5.0, like AI, DT, 6G, IoE, cobots, etc., along with humans' innovation and cleverness [14,16]. Technological enablers play different roles in different contexts. Some enablers play a more critical role, which depends on each sector's unique features and circumstances. Based on the literature, the role that the seven enabling technologies of I5.0 play in the SC context is more important. IoE, BDA, AI, BC, 6G, Cobots, and DT are these enablers [9]. Consequently, the present research emphasizes these seven enablers. These enabling technologies empower I5.0 to enhance the overall performance of SCs, aiming to boost efficiency and productivity and strengthen the industry's role and impact on society [11].

Performance measurement is essential to successful SCM [17,18]. Researchers have taken different approaches and considered varied attributes for measuring SCP, like reliability, responsiveness, effectiveness, availability, flexibility, agility, costs, and asset management efficiency. However, the SCP measurements have primarily been focused on quantifying the efficiency and effectiveness of actions [18,19]. The existing literature on SCP suggests that some attributes overlap, and according to their nature and function, they can be broadly categorized into efficiency, responsiveness, and visibility. With this argument, the present research has called each category a dimension and deployed them to evaluate the performance of the SC.

The ability to utilize technology, expertise, and resources to cut down logistics costs and dramatically increase profits is referred to as SCE. The goal of an efficient SC is to save money and substantially increase profits through upgrading the stages and processes in the SC. In other words, SCE indicates rapid and economical satisfaction of demands.

The degree of actors' visual access to accurate and timely information on demand and supply within an SC, which is crucial or helpful for their SCs and operations, is called supply chain visibility (SCV). In general, the effects of visibility can be categorized into performance and capabilities. These are related to each other. Hence, if capabilities are improved, performance will automatically increase. Capability improvement is mainly considered to impact SCV directly. This is while the final effect is performance. Therefore, an indirect impact of SCV can be performance [20]. Dubey et al. [21] found that analytics capabilities and visibility support and complement each other.

The ability to rapidly adjust to changes in demand or other variables is called supply chain responsiveness (SCR). This implies that the SC can react quickly to changes in market

conditions, customer demand, or other factors that are probably effective on the SC [14,22]. A responsive SC is identified through agility, flexibility, and the ability to rapidly adapt to varying conditions. Flexibility indicates the ability to adjust operations to fulfill recent requirements. In addition, the capability to change strategies in return for changes in the business environment is adaptability [22,23].

I5.0 influences the dimensions of SCP in different ways. Technologies such as BC support complete visibility throughout the process, which is essential for making proactive and reactive decisions. AI and BDA are utilized to program and manage decision-making support. Sixth-generation wireless communication technology can significantly increase SC operations' efficiency, robustness, and agility, offering quicker, more dependable, and more intelligent communication and data processing capabilities. Cobots improve manufacturing and logistical operations by increasing their flexibility and efficiency. They optimize SCM procedures, including methodical inventory control, stock tracking, order completion, and product returns. Cobots help SC sectors diminish their overall cost of ownership. RFID and sensors enable visibility through an IoE-based infrastructure. DT offers substantial value within the context of the SC. They enhance the availability of customized products by providing real-time insights into product demand and production processes. By detecting and mitigating deficiencies early on, DT enables proactive problem-solving, leading to smoother operations and improved customer satisfaction. Moreover, DT facilitates the rapid exploration and implementation of innovative business ideas, ultimately driving profitability through agility and adaptability in the ever-evolving marketplace [9,11].

1.1. Problem Statement

Regardless of the extensive literature on the significant role of digitalization in making overall SCP, companies are still uncertain concerning the impact of I5.0 on SCP. This uncertainty is owing to the evolving nature of I5.0 [9]. Because enterprises need to allocate lots of resources and energy to present these technologies, managers must understand the benefits for the enterprise entirely. In this way, they are assured that a valuable investment will be carried out [3,24]. Thus, more research and detailed examination regarding the effect of I5.0 on the SCP is required since it is one of the latest trends in digital technology and simultaneously one of the most exhaustive ones. The motivation for the current study is to shed light on the impacts of I5.0 on SCP.

1.2. Research Objectives and Questions

This study aims to investigate the impact of I5.0, the newest industrial revolution, on SCP. In addition, how Industrial 5.0 technologies influence SCP will be recognized and presented in this study. To examine the impact of I5.0 on SCP, this research will investigate seven key technologies identified in the literature review. These technologies constitute IoE, BC, BDA, 6G, Cobots, and DT. Current research presents insights into how SCP can be enhanced via these technologies.

To fulfill the objectives mentioned above, this study explores the following three significant questions:

1. How does I5.0 contribute to SCP?
2. What are the dimensions of SCP?
3. How does I5.0 affect SCP?

1.3. Original Contributions

This study provides a better understanding of I5.0 from an SCM perspective by examining its effects on overall SCP. Therefore, it contributes to the literature on I5.0 and SCM. This study identifies three dimensions of SCP—SCE, SCR, and SCV—covering all significant key performance indicators (KPIs) defining SCP. Moreover, the study offers empirical evidence on the relationships between SCP dimensions. It includes relationships between SCV and SCE as well as SCV and SCR. How I5.0 affects the dimensions of SCP has been discussed in this research. These results hold implications for SC managers, highlighting

the benefits of adopting I5.0 for enhancing overall SCP. This study also identifies seven key enabling technologies of I5.0 within the SCM context and discusses their impacts on defined dimensions of SCP.

2. Literature Review

Owing to the significance of SCM in the effectiveness and efficiency of enterprises, comprehensive studies have explored the factors influencing SCP. According to Juan's [4] and Shi and Yu's [25] findings, SC performance encompasses accounting-based and market-based measures. In their study, Bhagwat and Sharma [26] stated that performance measurement explains the feedback on operations aimed at objectives, customer satisfaction, and strategic decisions. Beamon [27] presented an SCM system underscoring three performance measures: output, resource, and flexibility. Wu et al. [28] propose that financial and non-financial aspects should be considered in measuring the performance of an organization. Simão et al. [18] argue that balanced scorecard (BSC) [29] and SC operations reference (SCOR) [30] are among the most popular performance measurement systems, but they have deficiencies. Their study determined three dimensions of SCP: efficacy, efficiency, and environmental impact.

Integrating disruptive technologies and empowering I5.0, along with human intelligence and innovation, is crucial in helping industries meet the demand for personalized and customized products faster. With the help of these technologies, industries can improve their efficiency and speed while maintaining high-quality standards [10]. Maddikunta et al. [9] conducted research to deliver a tutorial based on surveys regarding the potential applications and underlying technologies of I5.0. Lv [31] investigated the influence of DT Technology on industrial manufacturing within the framework of I5.0. Zeb et al. [32] surveyed intelligent NextG Wireless Networks as technological facilitators. Nahavandi's [33] research underscores I5.0's tangible impact on productivity and the economy, highlighting its current implementation stage. They realized that enabling technologies are crucial for I5.0's success. The study advocates for cobots in I5.0 to prioritize understanding human intent, enabling seamless collaboration, and recognizing when human assistance is necessary. Defraeye et al. [34] introduced a DT approach to managing mango fruit's thermal characteristics during refrigerated transportation. They concluded that leveraging DT insights can optimize logistics processes, fostering a sustainable SC. Marinelli [35] explores the transition from I4.0 to I5.0, highlighting a shift towards human-centric collaboration in industrial settings, particularly in construction. The study emphasizes the necessity of carefully integrating robotics before advancing toward I5.0's collaborative environments, underscoring the potential of machine learning and vision research for enhancing safety and efficiency in Construction 5.0. Kumar et al. [36] reviewed I5.0's alignment with Kaizen for industrial sustainability, examining adoption, technologies, and barriers in manufacturing and medical fields. They highlight hurdles like resistance and financial limitations, emphasizing the importance of human–robot cooperation. The study advocates for collaborative frameworks, standards, and sector-specific models to drive sustainability in I5.0.

Ivanov's [11] findings demonstrated that efficiency and productivity in I5.0 profit from increased responsiveness, capacity utilization, lead time, and flexibility. The significance of I5.0 in achieving sustainable development goals was investigated by Kasinathan et al. [37]. This research offered an integrated framework incorporating recent technologies to introduce the concepts of I5.0 and society 5.0 in intelligent cities. The work of Wamba et al. [38] demonstrated that BDA could undoubtedly help improve SC function and performance. Jum'a [39] conducted a study demonstrating BC adoption's direct and indirect impact on achieving a competitive SC advantage and improving innovation capabilities to achieve higher SCP. Greif et al. [40] presented a concept of lightweight DT for the construction industry. In this work, they investigated the advantages of DT in minimizing SCM costs. Narkhede et al. [41] examined how I5.0 can promote sustainable manufacturing by incorporating eco-friendly practices. Their proposed framework emphasizes unbiased assessment

and integration of sustainability principles, targeting resource efficiency, waste reduction, and ethical considerations. They realized I5.0 could enable optimized resource usage and environmental impact mitigation by blending advanced technologies like AI and BDA with sustainability objectives. Researchers like Li et al. [42] also investigated the impact of emerging technologies throughout the SC. Their findings showed that disruptive technologies like BC could improve SCV, and SCV, in turn, enhanced SC resilience. Improved resilience will lead to improved SCP. Ghobakhloo et al. [43] explored the shift from I4.0 to I5.0, focusing on sustainability. They identified challenges in understanding I5.0's growth drivers and meeting sustainability goals. Their findings showed that I5.0 can effectively leverage I4.0 tools to achieve environmental and economic sustainability objectives. Nayeri et al. [14] developed a novel decision-making method for the healthcare industry and introduced a responsive SC based on the I5.0 pillars: sustainability, resiliency, and human-centricity. Marmolejo [44] introduced a DT-based approach in the pharmaceutical SCM, leveraging analytical tools and simulators. They concluded that DT facilitates a more agile and responsive SCM, vital for adapting to shifts and maintaining efficient pharmaceutical operations.

Literature Gap

Although a significant amount of research has been conducted on I5.0 and its enabling technologies, there has not been much research specifically focusing on the impacts of I5.0 on SCM, particularly SCP. Therefore, there is a need for more research in this area to gain a better understanding of the impact of I5.0 on SCP. This research can provide valuable insights for SC managers and decision-makers looking to adopt I5.0 technologies. Moreover, previous research has primarily focused on SCP's financial and operational aspects, which do not cover all performance aspects. This study aims to bridge this gap by presenting three dimensions of SCP (efficiency, responsiveness, and visibility) that cover all the key indicators of SCP, including sustainability.

3. Conceptual Framework Development

The concept of I5.0 involves combining the decision-making and intelligence abilities of human beings with the co-working capabilities of robots. This innovative approach is made possible through key-enabling technologies and has the potential to enable mass personalization in various sectors like never before.

I5.0 enhances the intelligence, efficiency, and competency of SCs [45]. Reducing overall expenses is a significant advantage of I5.0, as Rada [46] highlights. I5.0 can also improve SCE by promoting decentralized manufacturing where smaller production facilities are nearer to end markets. This shift could result in shorter SCs, decreased transportation expenses, and potentially more eco-friendly practices. By enabling decentralized manufacturing capacity to be openly accessed, manufacturing tasks can autonomously align with social manufacturing resources [10]. Industrial 5.0 technologies like cloud computing help develop supply networks as well as the efficiency and responsiveness of SC processes [9,37]. The information obtained through BDA can dramatically increase productivity, speed, and collaboration while making better interactions with actors of SC [9,38]. AI aims to automate tasks that were once performed by humans, leading to decreased reliance on labor resources and allowing for more efficient execution of projects. This reduces the time and effort required to complete routine tasks, significantly boosting productivity [9,47].

I5.0 has the potential to improve transparency and visibility by encouraging immediate data exchange throughout the SC, which could boost cooperation, decrease wait times, and enhance overall SCP [11]. Additionally, it could facilitate the adoption of eco-friendly approaches across the SC, promoting sustainability and environmentally conscious practices. By integrating disruptive technologies, I5.0 can optimize energy usage, reduce waste, and mitigate environmental effects [9,32].

I5.0 could improve SCR, addressing both customer needs and environmental shifts. It may prioritize mass customization, necessitating more adaptable production methods and flexible supply networks [22]. For example, by merging BDA into operations and

SCs, enterprises can recognize their customers better, efficiently manage risks, cut down on service costs, and create unpredictable and new and different sources of income [48]. AI processes human images similarly to cookies, enabling personalized services tailored to customer preferences. Certain businesses are exploring facial recognition technology to assess customer moods and offer suitable product suggestions [47]. Furthermore, I5.0 emphasizes resilience-building strategies such as dual sourcing and scenario planning. Human–robot collaboration is a key focus of I5.0, potentially leading to improved forecasting, risk mitigation, and more agile responses to disruptions [14]. According to these arguments, the following hypotheses are proposed:

H1a. *I5.0 has a positive impact on SCE.*

H1b. *I5.0 has a positive impact on SCV.*

H1c. *I5.0 has a positive impact on SCR.*

An indirect effect of SCV can be performance [20,49]. Through the use of SCV, it is possible to determine and decrease costs; as a result, SCP will be improved [49,50]. It has been recognized in several studies that more excellent competitive positions and higher profitability levels can be shown to organizations through SCV [20,51]. Many studies have demonstrated that SCV positively influences customer service [20,52]. Caridi et al. [53] declared that reducing delays in internal logistics can be achieved by enhancing visibility. Other studies have also shown that SCV can lead to various advantages, such as more effective responses, improved sales data, and the ability to fulfill customer expectations, leading to higher customer satisfaction [20]. These are all critical outcomes of SCV. Likewise, Wamba et al. [38] stated that SCV can enhance market value for organizations. Barratt and Barratt [54] maintained that SCV is crucial for implementing quality management programs for safety performance and quality improvements. The current literature has established that visibility has a vital role in ascertaining the general performance of a SC. Nevertheless, this is not a direct impact; instead, it arises from SCE enhancement and responsiveness resulting from enhanced visibility. Regardless of such initial dimensions, greater visibility can also result in SCP improvements in areas like sustainability. Besides economic sustainability, SCV can result in social and environmental sustainability [55]. Wang et al. [56] and Brun et al. [57] stated that what is crucial to improved sustainability is SC visibility. According to these arguments, the following hypotheses are proposed:

H2a. *SCV has a positive impact on SCE.*

H2b. *SCV has a positive impact on SCR.*

H3b. *SCV has a positive impact on overall SCP.*

Time and resource wastage is reduced via efficient SCM, which allows businesses to decrease SC costs and dramatically increase profits. Increased efficiency of SC operations of the enterprise through making warehouse management and inventory more efficient can reduce redundancy and cut down liabilities; consequently, SCP is improved. In addition to efficiency, a responsive SC is crucial for expanding a business rapidly when needed. A business will frequently undergo fast periods of growth. With the help of a responsive SC, an enterprise can quickly satisfy that rising demand and learn about its customers' demands; as a result, performance is improved. From a resilience viewpoint, the capability of enterprises to rapidly create the proper risk management strategies and react to market changes while disruption events happen is underlined by the ability of SC to respond [58–60]. According to these arguments, the following hypotheses are proposed:

H3a. *SCE has a positive impact on overall SCP.*

H3c. *SCR has a positive impact on overall SCP.*

Innovative technology has recently become necessary. Consumers use intelligent technologies to simplify various purposes that directly affect the performance of firms or organizations [61]. Hence, I5.0 has a direct impact on the all-inclusive SCP. Moreover, sustainability stands out as a fundamental principle of I5.0. Implementing I5.0 within an organization can benefit the choices and engagements of sustainability-conscious customers throughout SC 5.0, thereby enhancing the overall performance of the SC [15]. According to these arguments, the following hypothesis is proposed:

H4. *I5.0 has a positive impact on overall SCP.*

To better understand the effect of I5.0 on overall SCP, a framework is constructed to describe the cause-and-effect relationships between I5.0, the dimensions of SCP, and overall SCP. Figure 1 shows the theoretical model depicting the five constructs discussed earlier. The numbers next to each arrow correspond to the nine hypotheses developed in this section. This model (Figure 1) establishes positive and direct relationships between I5.0 and the dimensions of SCP and also positive relationships between the dimensions of SCP and overall SCP. The rationale supporting this research framework is stated in this way: I5.0 affects the SC dimensions; then, dimensions of SCP affect overall SCP.

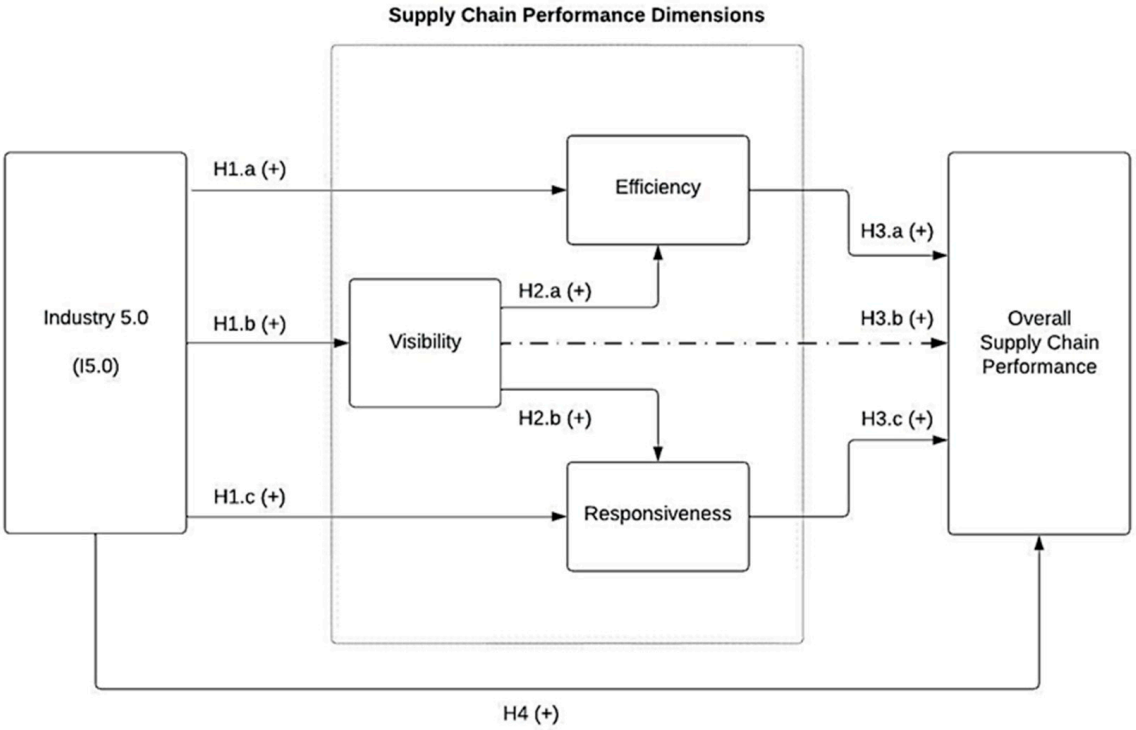


Figure 1. Research Model.

4. Conclusions

The fifth industrial revolution goes beyond just improving efficiency and productivity and emphasizes the importance of the industry's role in society. This study investigates the impact of I5.0 on the SC's overall performance. The direct effect of I5.0 on SCP and its indirect effects through SCP dimensions will be demonstrated. Three dimensions of SC have been defined based on the existing literature. To evaluate the indirect impact of I5.0 on overall SCP, the effects of I5.0 on SCP's dimensions, including SCE, SCV, and SCR, and subsequently, the effect of each dimension on the overall performance of the SC were considered. This study also identifies how I5.0 affects the dimensions of the SC and, thus,

the overall performance of the SC. Professionals and strategic leaders, especially those developing plans for digitization, may find this study interesting. Decision-makers will be better equipped to make informed adoption decisions thanks to managerial insights, including a greater comprehension of I5.0's possible impact on SCP. Furthermore, the study supports managers who are interested in sustainable SCM and who are thinking about making the switch from I4.0 to I5.0. The results also provide providers of I5.0 technology with useful information to improve their offerings and approaches, bringing them closer to consumer needs and encouraging uptake.

4.1. Future Steps to Complete the Research

The research process to complete this study involves further essential steps. The first step would be to develop a questionnaire appropriate for the research topic and objectives. To do this, the measurement indicators should be derived according to the relevant theories and previous studies. SCE will be assessed in this study using potential metrics such as cash-to-cash cycle time, order-to-delivery lead time, return rate, inventory turnover ratio, transportation cost per unit, warehousing cost per unit, perfect order fulfillment rate, supplier on-time delivery performance, and carbon footprint. Assessing SCV entails tracking and monitoring shipments, orders, and inventory through the SC [9,33]. SCV will be measured in this study using metrics such as data timeliness and accuracy, compliance, lead time, inventory turnover, supplier performance, and track and trace effectiveness. Evaluating an SC's responsiveness entails determining how rapidly it can adjust to shifts in consumer demand, market dynamics, and disturbances [9,62]. The following are some possible metrics that could be used to evaluate SCR in this study: lead time variability, time to market, order fulfillment cycle time, forecast accuracy, inventory velocity, capacity utilization, SC flexibility index, percentage of expedited orders, supplier lead time, backorder rate, and customer satisfaction index [14,60].

Once the questionnaire is formed and approved, the data collection process can begin, which can involve distributing the questionnaire to a sample of participants. Next, the Partial Least Squares-Structural Equation Modeling (PLS-SEM) model should be implemented to analyze the collected data. This is a crucial step in understanding the relationships between the different variables in the research study. After the data analysis, research findings will be introduced and discussed. It involves presenting the results clearly and concisely and explaining the implications and significance of the findings. Finally, a conclusion can be drawn based on the research outcomes.

4.2. Future Research Directions

This section provides some recommendations for the researchers interested in this topic and research area. The current study focuses on I5.0's impact on SCP. It suggests researchers explore adoption determinants within specific industries, expanding the investigation. Including drivers, barriers, mediators, and moderators could enhance understanding within specific industry contexts. Therefore, future studies could focus on strategies to overcome acceptance barriers and enhance the successful implementation of I5.0 in the SC. This would provide managers with insights to identify and address adoption challenges, empowering decision-makers to make informed choices about integrating I5.0 within their organizations. Also, this study solely assesses I5.0's impact on SCP using the PLS-SEM method without prioritizing enabling technologies. Future research is recommended to prioritize these technologies' effects on SCP dimensions. Additionally, employing AI and data mining methods on big data could enhance understanding of I5.0's impact. Moreover, research on I5.0 requires interdisciplinary collaboration, drawing from fields like industrial engineering, SCM, computer science, automation, and robotics. This collaboration enables the development of cost-effective, agile, transparent, and human-centric SCs, advancing I5.0's unique features.

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