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Innovative Development of Supply Chain for High-Tech Global Design and Manufacturing Enterprises in 2040

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Abstract

High-tech global design and manufacturing enterprises are crucial entities in the high-tech industry, serving as carriers of its progress. The management capabilities of these enterprises have a direct impact on the future trajectory of the high-tech industry, as well as the overall economic development and level of technological advancement within a nation. This essay focus on the innovative development of the supply chain for high-tech global design and manufacturing enterprises in 2040. It explores key characteristics, innovative mode supported by necessary technologies, research challenges, and potential interesting research issues. By doing so, this essay not only enhances the core competitiveness of enterprises and establishes unique advantages but also plays a constructive role in promoting market economy reforms.

Keywords: High-tech Industry; Globalization; Industry 5.0; Design and Manufacturing; Research and Development; Supply Chain

1 Introduction

Currently, countries worldwide are actively seizing the leading positions in science and technology, with a strong focus on the development of cutting-edge technologies. Each country has prioritized the advancement of high technology as a key national strategy, exemplified by initiatives such as Industry 4.0 (Germany), the Industrial Internet Consortium (USA), Made in China 2025 (China), and Society 5.0 (Japan) [1]. More recently, the concept of Industry 5.0 has emerged, aiming to enhance Industry 4.0 by incorporating essential principles such as sustainability, resiliency, and human-centricity [2].

The progress of the high-tech industry is closely tied to advancements in production technology and evolving production modes spurred by industrial revolutions. Within this context, high-tech global design and manufacturing enterprises play a vital role as carriers of the high-tech industries. These enterprises are characterized by their global operations, focus on high-tech domains, strong design and manufacturing capabilities, and remarkable performance and reputation. The management capabilities of these enterprises directly impact the future direction of the high-tech industry, as well as the overall economic development and degree of high-tech advancement within a nation.

With the emergence of Industry 5.0, the integration of transformative technologies such as big data, cloud computing, artificial intelligence, and mobile internet has propelled the global design and manufacturing enterprise onto a digitalized, sustainable, resilient, and personalized trajectory. This paradigm shift has transformed the mindset and approach of enterprises, extending their focus beyond the organizational boundaries and embracing the interconnected society of the supply chain. Therefore, achieving optimal efficiency in all significant activities and business

flows within the supply chain becomes crucial [3].

By 2040, enterprises are expected to complete the transition from Industry 4.0 to Industry 5.0. Thus, the objective of this essay is to explore the innovative development strategy of supply chain for high-tech global design and manufacturing enterprises in 2040. The aim of this essay is to examine the development trends of such enterprises during transition period and provide reasonable insights into future design and planning strategies. The innovation strategy of supply chain is widely recognized as an effective competitive strategy for firms to achieve superior performance [4]. Particularly, the integration between Industry 5.0 and supply chain management has the potential to fundamentally transform current business practices and managerial tasks. It not only enhances the core competitiveness of enterprises and establishes unique advantages but also plays a positive role in promoting market economy reforms.

This essay is organized as follows: The characteristics of the high-tech global design and manufacturing enterprises are identified in Section 2. In Section 3, the proposed innovative mode of supply chain and its necessary technologies are described. The research challenges that these enterprises will encounter when developing supply chain are discussed in Section 4. Relevant research directions are investigated in Section 5. Finally, closing remarks are provided in Section 6.

2 Characteristics of High-tech Global Design and Manufacturing Enterprises

Identifying the defining characteristics of enterprises in 2040 can greatly assist companies in clarifying their strategic development objectives. This not only facilitates long-term planning but also garners the attention and support of investors and partners. Particularly for high-tech global design and manufacturing enterprises, it is imperative to identify their distinctive features during the transition from Industry 4.0 to Industry 5.0.

Enterprises in Industry 4.0 have strived to utilize artificial intelligence and information technology to enhance their productivity. Serving as the foundation for the implementation of Industry 5.0, the predominant focus of Industry 4.0 on artificial intelligence-driven technologies has resulted in a digitalization-centric characterization. In contrast, Industry 5.0 will steer enterprises towards development based on three key dimensions: sustainability, resiliency, and human-centricity.

2.1 Digitalization

These enterprises possess agile and data-driven digital technology capabilities. They integrate emerging technologies such as the Internet of Things, cloud computing, big data, Blockchain, and simulation technology to establish networked, intelligent systems for industrial activities. This enables them to create value and explore new industrial application scenarios.

Firstly, these enterprises leverage various digital tools and technologies in design and manufacturing, including human-machine collaboration. Secondly, they prioritize flexible business models to gain a competitive edge in the digital age. Additionally, they employ digital technology to establish intelligent supply chains, enabling visualization and transparent management. Lastly, they leverage their digital

capabilities, digital platforms, and value networks to share information and complementary assets with other businesses and users.

2.2 Sustainability

These enterprises prioritize the application of innovative technologies for environmental protection and sustainability. They embrace sustainable manufacturing practices and incorporate environmental design concepts. They promote green production throughout the supply chain and leverage digital and intelligent technologies to optimize resource utilization. Moreover, they actively assume greater social responsibilities in this regard.

2.3 Resiliency

These enterprises demonstrate strong resiliency, enabling them to reduce the impacts or likelihood of possible disruptions. They can quickly adjust their business strategies, product designs, and production processes to meet evolving market demands and provide personalized customized services.

First, they maintain diversified product lines, utilizing 3D printing technology for the manufacturing of highly complex, small batch products. Secondly, they have agile and flat organizational structures and adopt fast iterative development processes. Third, they excel in monitoring uncertain events and identifying risks. Additionally, they have design and manufacturing centers worldwide, and a robust and agile global supply chain network that efficiently allocates resources.

2.4 Human-centricity

These enterprises place significant emphasis on user experience, personalized customization, and data-driven decision-making in their human-centric design approach.

Firstly, they prioritize user-centricity by delivering captivating and distinct products and services that cater to users' needs and expectations. Secondly, they utilize advanced data analysis and user behavior insights to guide design processes, such as user experience research and human-computer interaction design. Finally, they employ agile development methodologies and iterative approaches to promptly adapt to market changes and incorporate user feedback.

3 Innovative Mode of Supply Chain of The Enterprise

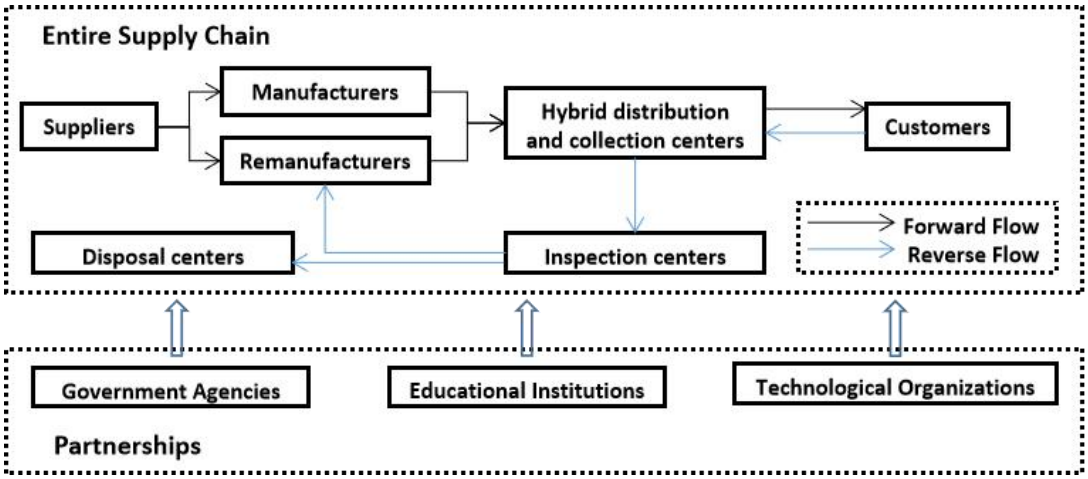

Figure 1. The Framework of The Entire Supply Chain

Given the context of Industry 5.0, where enterprises are expanding their boundaries to the supply chain within a broader societal context and recognizing the significance of supply chain management in every organization, we will specifically focus on the innovative model of supply chain management for enterprise in this essay. As supply chains become increasingly global, the complexity and uncertainty levels rise. Therefore, it is essential for enterprises worldwide to further investigate the integration between Industry 5.0 and supply chain processes. In particular, the growing number of product returns from customers to retailers, driven by the adoption of environmentally friendly policies, has created a heightened necessity to effectively manage backward materials and information flows in the supply chain domain.

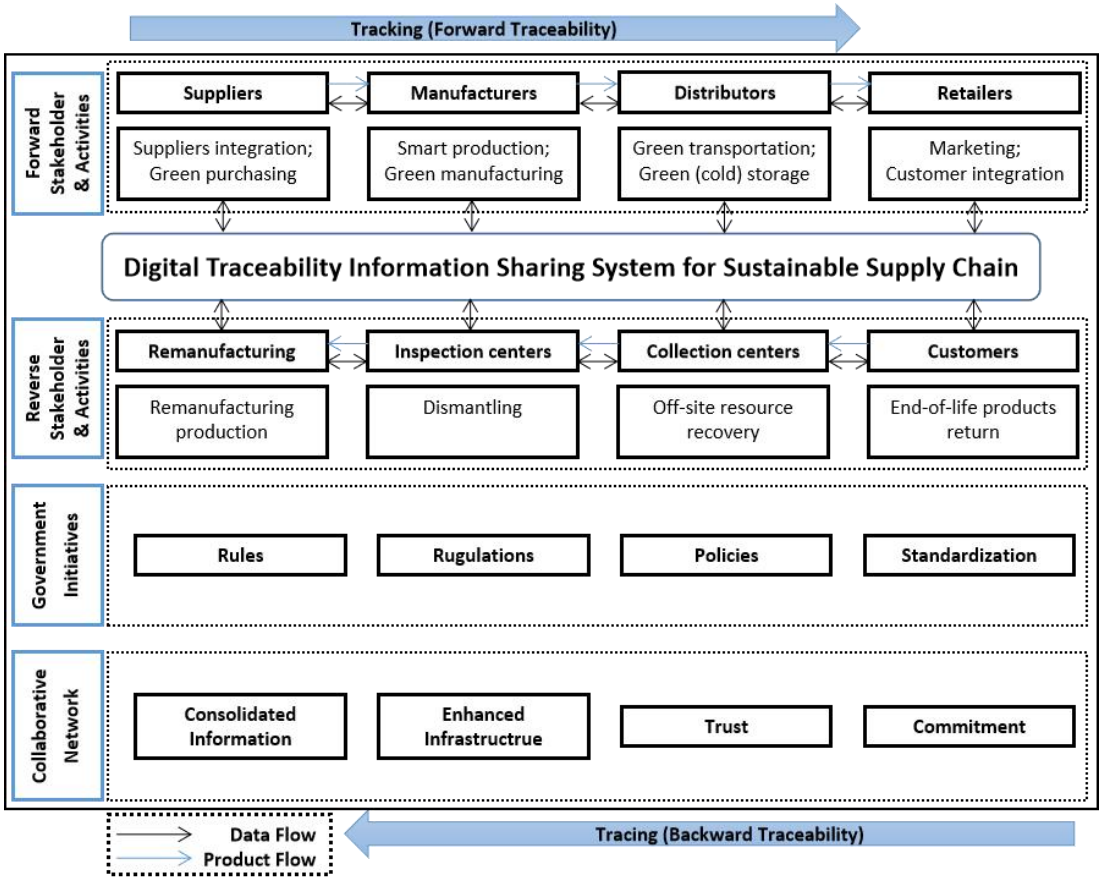

Figure 2. The Outlook of Industry 5.0 to Supply Chain Management

The concept of supply chain is interconnected and complex, comprising both the forward supply chain and the reverse supply chain, as depicted in Figure 1. The forward supply chain encompasses the entire production and distribution channels, commencing from suppliers and manufacturers, extending through distributors, and ultimately reaching the end customers. On the other hand, the reverse supply chain involves the recycling process of end-of-life products, including customer returns, collection centers, inspection and disassembly centers, and remanufacturing factories. Identifying the suitable supply chain model for an enterprise facilitates meeting customer demands, digitalizing business processes, enhancing responsiveness and resilience, and effective integrating diverse stakeholders and partnerships.

In addition, establishing strategic partnerships throughout the entire supply chain is imperative. Collaborating with educational institutions, such as K-12 schools, that share research interests in the advanced technologies of Industry 5.0 will facilitate the evolution of the supply chain from Industry 4.0 to Industry 5.0. Engaging with other high-tech organizations specializing in relevant areas will enable the development of optimal and efficient processes while staying within their respective areas of expertise. Cooperation with government agencies, such as National Science Foundation, the Department of Commerce, and federal workforce agencies, will significantly benefit both enterprises' bottom line and the communities they operate in.

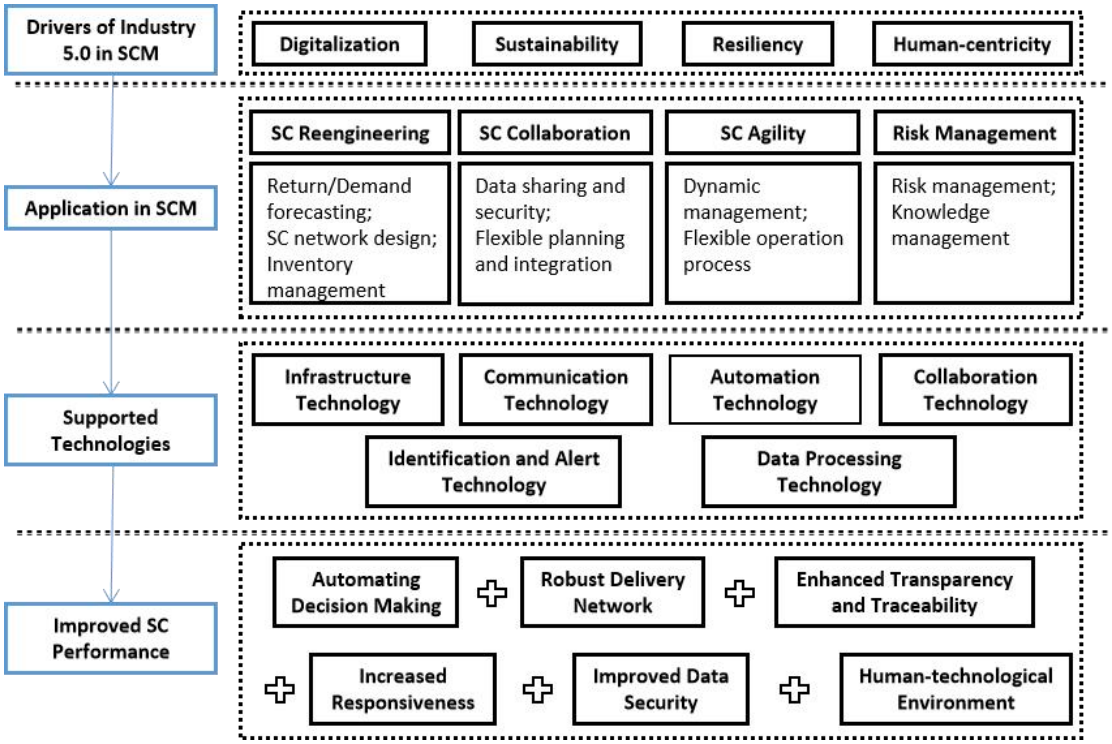

Figure 3. The Overview of Digital Information System for Sustainable Supply chain

The features of Industry 5.0, supported by the technologies of Industry 4.0, present opportunities for the development of new functionalities within enterprise systems that handle operations and logistics. The future potential of Industry 5.0 in supply chain management are illustrated in Figure 2. The aim of the proposed synthesis framework is to consolidates the characteristics of enterprises in supply chain management, with a particular focus on its application in supply chain reengineering, collaboration, agility, and risk management. This framework emphasizes the increasing demand to leverage advanced technologies, such as automation, collaboration, communication, in order to enhance capabilities and fully realize the potential of Industry 5.0 in improving supply chain performance.

To enhance the digitalization and sustainability of supply chain management, enterprises can establish a digital traceability information sharing system for a sustainable supply chain, as illustrated in Figure 3. This system would receive support

from government initiatives and collaboration networks. Through the implementing of this system, enterprises can establish an information network for sustainable value creation, fostering strong collaboration with customers, suppliers, and partners to drive innovative collaboration.

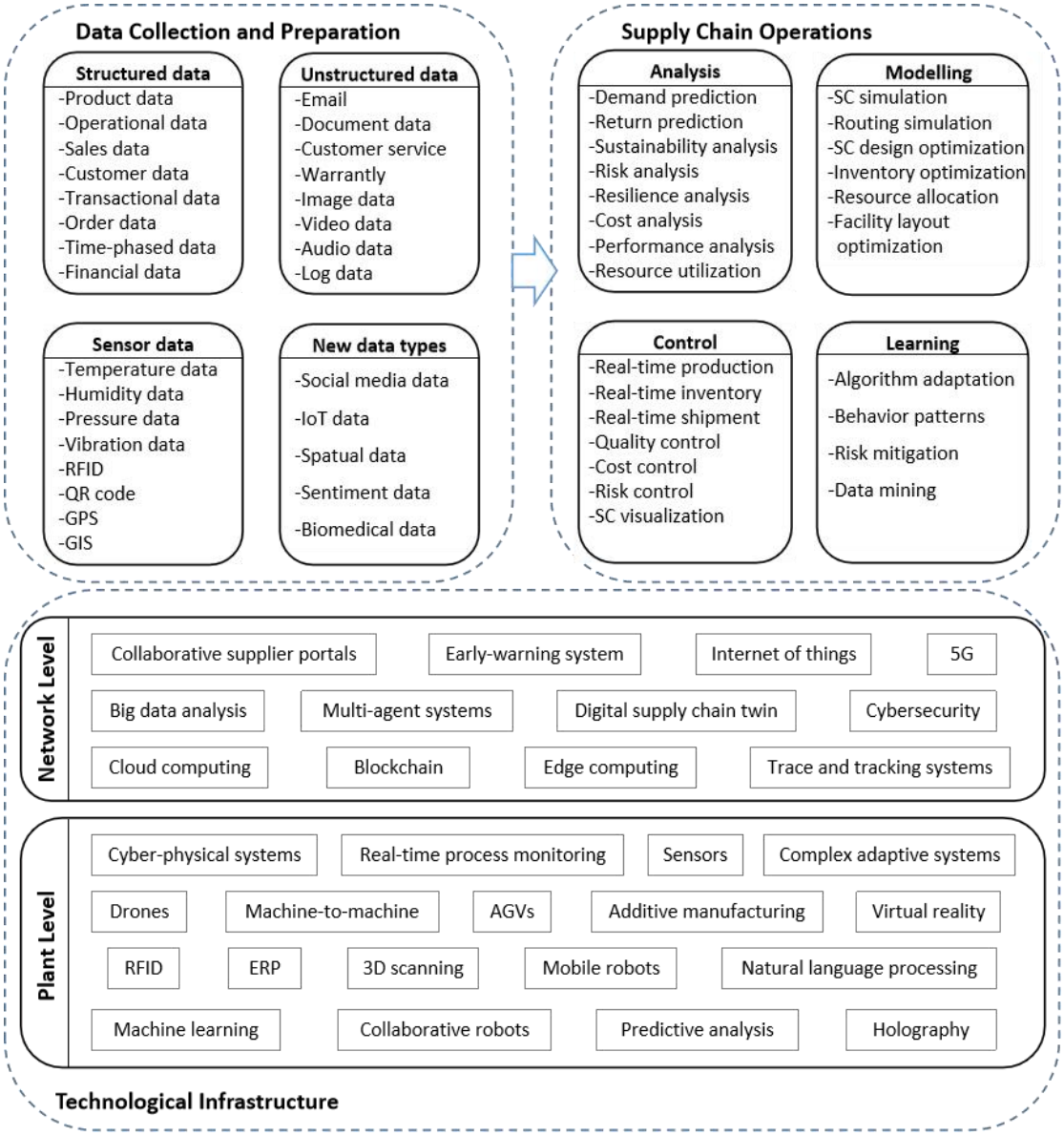

Figure 4 The Data Framework for Digital Information System

Additionally, an overview of the process involved in developing a data framework for the digital information system is depicted in Figure 4. This framework involves the collection of real-time and historical data from industrial sensors, supported by network-level and plant-level fundamental technologies. These measures are implemented to facilitate effective data analysis and enhance supply chain operations.

Moreover, to enhance the resilience and customer-centricity of supply chain management, enterprises have the option to establish a framework for a resilient supply chain, as shown in Figure 5. This framework addresses unexpected risk and disruption, enabling organizations to meet customer demands for adaptability and

flexibility. By integrating resilience with innovative supply chain strategies, enterprises can achieve rapid responsiveness and make flexible adjustments in production to adapt to changes in market demand and the external environment.

Figure 5 The Framework for Supply Chain Resiliency

4 Research Challenges

Driven by the characteristics of the high-tech global design and manufacturing enterprises in 2040, these enterprises often operate at the forefront of technology and encounter various research challenges before implementing innovative supply chain strategy in Industry 5.0 [5]. To maintain their competitiveness and innovation ability, enterprises need to proactively address the challenges and conduct relevant research.

Research Challenge 1: The visibility of the entire supply chain and the availability of information within the enterprise are suboptimal.

Research Direction 1: To address this challenge, future study should establish an end-to-end visibility system by integrating the forward and reverse supply chains. Enhancing the visibility of the entire supply chain allows for real-time information tracking across all aspects of business through traceability. This enables flexible adjustments and rapid responses within the supply chain, ensuring timely product delivery and high quality.

Research Challenge 2: The recovery processes within reverse supply chain increase the uncertainties faced by companies. It is necessity to manage each stage where products should be handled and distributed to remanufacturers.

Research Direction 2: To address this challenge, future study should prioritize product lifecycle management in the mid-life and end-of-life stages [6]. This involves designing products that are easy to disassemble and recycle, as well as providing parts and maintenance services to extend product lifespan [7]. Additionally, enterprises can collaborate with suppliers, customers, and partners to establish blockchain-based recycling networks. This enables the recovery, reuse, and remanufacturing of waste products, fostering sustainable supply chains and circular economy models.

Research Challenge 3: With the expansion of global business and digital transformation, ensuring security and privacy for data and models has become increasingly challenging. Sharing information among different organizations through smooth interoperability standardizing processes remains a major obstacle.

Research Direction 3: To address the challenge, future study should emphasize

the implementation of system integration and the development of encrypted cloud-based security tools in the supply chain, based on data transfer standards [8]. Furthermore, attention should be given to privacy protection, information system management, and security, while enhancing data storage and transparency from the perspective of a dual blockchain architecture with Internet of Things and radio frequency identification devices (RFID) devices. This can help overcome regulatory barriers, scale to a global level, and ensure data confidentiality and privacy.

Research Challenge 4: Additionally, adaptability, standardization, expandability, and incorporation between disruptive technologies from Industry 4.0 present further challenges that require thorough research.

Research Direction 4: To address the challenge, future study can prioritize exploring the synergy and complementarity between different technologies, aiming to design flexible and adaptable technical solutions aligned with general technical standards to cope with changing needs and environments.

Research Challenge 5: Disruptions and vulnerabilities in the supply chain due to events such as natural disasters, strikes, virus outbreaks, and operational risks (e.g., regulatory uncertainty and potential system failures) are common. Managing the severe impact and consequences of such events on supply chain networks is always a challenge.

Research Direction 5: To address the challenge, future study should explore a dynamic and robust cyber risk analysis and early warning system. This system can identify and assess potential risks by analyzing operational and supply chain data for patterns associated with specific risks [9].

Research Challenge 6: Resolving conflicts in objectives among different stakeholders, stemming from cultural and work methodological differences, is a significant issue.

Research Direction 6: To address the challenge, future study can develop a self-adaptive and self-learning decision support model among various supply chain stakeholders. This model can address compromise decision support problems and enable a flexible supply chain [10]. This system would automate the learning and analysis processes using real-time data, facilitating timely and continuous decision-making. It would also enable stakeholders to engage in strategic collaborations with other organizations, fostering resource sharing, technological innovation, and joint market development, ultimately leading to mutual success.

5 Worthwhile Research Questions

When transitioning from Industry 4.0 to Industry 5.0, the focus of supply chain will undergo significant change. Firstly, the supply chain will gradually adopt a balanced human-technological environment, primarily facilitated by the integration of collaborative robots. Secondly, the supply chain not only strive for enhanced performance in terms of transparency, responsiveness, flexibility, and efficiency, but also seek to achieve mass personalization of products and services. Thirdly, building upon the foundation of Industry 4.0 technologies, the supply chain will also prioritize other technological advancements, such as multi-agent systems, digital ecosystems,

complex adaptative systems, 5D printing, holography, intelligent autonomous systems, and machine cognition. Fourthly, sustainable development and the creation of smart society will be key objectives. Finally, the supply chain will not only address the challenges encountered in Industry 4.0, such as coordination support, digital infrastructure, strategic alignment, and skills training, but also address the issues related to psychology, worker safety, social and ethical considerations, as well as legal and regulatory issues.

Building on the preceding discussion, several worthwhile research questions (RQ) have been put forward for future investigation.

RQ 1: How can new innovative technological approaches be effectively integrated with the existing technologies employed in Industry 4.0 to enhance supply chain management?

RQ 2: What are the primary obstacles encountered during the transition from Industry 4.0 to Industry 5.0 in terms of supply chain management?

RQ 3: Which specific capabilities need to be developed to prepare for the advancement of supply chain in Industry 5.0?

RQ 4: How can innovative ecosystems be established to promote the implementation of Industry 5.0 programs within supply chains?

RQ 5: How can the technologies of Industry 5.0 be made interoperable across the supply chain and effectively interplay with society?

RQ 6: How can the stakeholders engaged in the supply chain influence the transition from Industry 4.0 to Industry 5.0?

RQ 7: How can alignment with the stakeholder engaged in the supply chain be achieved to facilitate the development of the supply chain in Industry 5.0?

RQ 8: How can the stakeholders in the supply chain gain a competitive edge by implementing collaborative initiatives within the context of Industry 5.0?

RQ 9: How can environment and society objectives be aligned with supply chain in Industry 5.0 to foster a more sustainable supply chain?

RQ 10: How can a synergistic environment be created between humans and smart systems to realize a balanced human-centric perspective and enable personalization to reach a higher level?

RQ 11: How can a resilience supply chain be established in Industry 5.0 to enhance responsiveness and mitigate risks?

6 Closing Remarks

Given the context of Industry 5.0, where enterprises are expanding their boundaries to the supply chain within a broader societal context, we primarily focus on supply chain management for enterprise in this essay. Through an analysis of current trends in manufacturing and supply chain within the framework of Industry 5.0 and bleeding-edge advanced technologies, we have identified four key characteristics that high-tech design and manufacturing enterprises in 2040 are expected to possess: digitalization, sustainability, resiliency, and human-centricity. Based on the characteristics of enterprises, we have outlined a blueprint for innovative mode of the entire supply chain, w emphasizing the essential partnerships required in

Industry 5.0 and supported by necessary technology. To enhance the digitalization and sustainability of supply chain management, we propose the establishment of a digital traceability information sharing system aimed at creating a sustainable supply chain. Additionally, to enhance the resilience and customer-centricity of supply chain management, enterprises have the option to adopt a framework for a resilient supply chain. Then, the research challenged to be faced and their future directions have been discussed. Subsequently, we address the research challenges that lie ahead and provide insights into their future directions. Furthermore, as we recognize the shifting focus of the supply chain during the transition from Industry 4.0 to Industry 5.0, we have formulated 11 valuable research questions for future investigation. These questions highlight the changes and emerging areas of inquiry within supply chain management.

It is crucial for successful design and manufacturing companies to plan for the long-term future of their facilities. We firmly believe that by leveraging the innovative framework supported by advanced technologies outlined in this essay, these enterprises will be well-prepared to drive the implementation of Industry 5.0 programs within their supply chains.

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