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IFAC PapersOnLine 58-8 (2024) 198–203

Transformation of the Product Lifecycle Value Chain Towards Industry 5.0

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Abstract: The transition from Industry 4.0 to Industry 5.0 has broadened the focus of enterprises, moving beyond their organisational boundaries limits to embrace the interconnected structure within the product lifecycle value chain. Despite this shift, there remains a significant gap in research on the framework for transforming the product lifecycle value chain from Industry 4.0 to Industry 5.0. Thus, building upon the achievements of Industry 4.0, the proposed value chain transformation frameworks are proposed, which can improve sustainability and resilience while considering human needs. The frameworks offer enterprises a comprehensive understanding of the structure and strategic approach required for the Industry 5.0 product lifecycle value chain transformation. Finally, the authors summarise six research challenges and opportunities and eleven research questions to advance the transformation of the Industry 5.0 product lifecycle value chain.

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Keywords: Industry 5.0; Value Chain, Digitalization, Sustainability, Resiliency, Human-centricity

1. INTRODUCTION

Countries are actively competing to become the leaders in science and technology, emphasising the development of cutting-edge technologies. This global trend is underscored by national strategies, such as Industry 4.0 (Germany), the Industrial Internet Consortium (USA), Made in China 2025 (China), and Society 5.0 (Japan), highlighting the commitment of each nation to technological innovation (Xu et al., 2021). More recently, the emergence of Industry 5.0 marks a significant evolution, aiming to enhance the principles of Industry 4.0 by incorporating essential principles, namely sustainability, resiliency, and human-centricity (Nayeri et al., 2023). The advent of Industry 5.0 has spurred a digital, sustainable, resilient, and personalised transformation in global design and manufacturing, leveraging technologies like big data, cloud computing, artificial intelligence, and mobile internet (Leng et al., 2022). This paradigm shift has transformed the mindset and approach of enterprises, extending their focus beyond the organisational boundaries, and embracing the interconnected society of the product lifecycle value chain. Therefore, achieving optimal efficiency in all significant activities and business flows within the value chain becomes crucial for managing the product lifecycle (Helo and Hao, 2022).

However, the value chain in the era of Industry 4.0 is often criticised for its profit-centric technological advancements, which tend to neglect environmental and social factors (Nara et al., 2021). Recognising these shortcomings, there is a growing interest in transitioning towards Industry 5.0, which seeks to address these issues. Although many articles have clarified the characteristics of Industry 5.0, more research is needed concerning the transformation structure of the product lifecycle value chain within this new context.

To fill the research gap, this paper proposes a framework for value chain transformation under the context of Industry 5.0 and identifies potential research challenges and opportunities within this evolving structure. To achieve these objectives, an analysis of the characteristics of Industry 5.0 is presented, followed by proposals for value chain transformation frameworks. The challenges and opportunities that could influence the realisation of this transformation are then explored. Building upon the achievements of Industry 4.0, the proposed value chain transformation framework can improve sustainability and resilience while considering human needs.

2. LITERATURE REVIEW

The product lifecycle value chain has evolved significantly, driven by industrial revolutions and advancements in production technology (Liu et al., 2009). Transitioning from the era of tools and integrated applications to a collaborative platform era (Terzi et al., 2010), the management of product lifecycle within the value chain is advancing through integrating emerging technologies. Such technologies facilitate the acquisition and processing of product information, management of customer preferences and behaviours, and optimisation of enterprise workflows and processes (Wang et al., 2021). Engineering assets, for instance, are considered products during their design and production stages and become assets when they generate value (Kiritsis, 2013). Value chain management allows enterprises to identify their core competencies and position themselves in the marketplace based on their competitive strengths (Al-Mudimigh et al., 2004).

In the context of Industry 4.0, the value chain is defined by technological advancements primarily focusing on profit maximisation, frequently at the expense of environmental and social considerations (Nara et al., 2021). More specifically, coined by the German government's economic development

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2024.08.120

agency in 2011 (Dev et al., 2020), Industry 4.0 capitalises on emerging technologies like additive manufacturing, the Internet of Things (IoT), blockchain, artificial intelligence (AI), drones, autonomous vehicles, human-machine interaction, cloud computing, and cyber-physical system (Queiroz et al., 2021). Industries aim to achieve greater operational excellence in their value chains by implementing Industry 4.0 technologies. (Mangla et al., 2020). The value chain focuses on customer benefits, value-generating processes, and the flow of demand and funds (Feller et al., 2006). These innovations, coupled with extensive real-time data, are set to transform manufacturing and service operations across global value chains, altering the dynamics between humans (consumers and value chain stakeholders) and machines (Tang and Veelenturf, 2019). For example, enterprises are creating value by providing both products and services and involving more customers in value creation by offering crucial feedback information (Bogers et al., 2016) (Strange et al., 2017).

To address the issue of Industry 4.0 focusing primary on profit rather than environmental and social factors (Nara et al., 2021), innovating the transformation of the value chain is essential. The value chain transformation strategy is widely recognised as an effective competitive strategy for enterprises to achieve superior performance (Mansour and Barandas, 2017). The Industry 5.0 initiatives pave the way for a transformative shift in the value chain. Integrating Industry 5.0 and the product lifecycle value chain can transform current business practices and managerial tasks. The EU's White Paper on Industry 5.0 identifies sustainability, human-centricity, and resilience as key features (EU Commission, 2021). More specifically, the implementation of sustainability involves adjusting the position of one factor within the three pillars (i.e., economy, environment, and society) at the right time during various stages, aiming to achieve the global establishment of Industry 5.0 more effectively with increased quantity, accelerated speed, enhanced quality, and cost savings (Leng et al., 2022). Human-centricity refers to incorporating human needs and interests into manufacturing processes and industrial work systems, enabling individuals to work harmoniously while autonomously safeguarding the security and stability of social communication networks (Kravets et al., 2022). Resilience not only concentrates on enterprises' ability to manage unknown risks and navigate external uncertainties, such as market, supply chain, and customer uncertainties, but also underscores the resilience of a broader spectrum of industrial systems (Schaltegger, 2020).

In summary, while the characteristics of Industry 5.0 have been explored, more research is still needed on the transformation framework of the product lifecycle value chain towards Industry 5.0 from Industry 4.0. Even though the predominant focus of Industry 4.0 emphasises the application of disruptive technologies, resulting in a digitalization-centric characterisation, these technologies can be viewed as foundational for implementing the Industry 5.0 initiatives (Aquilani et al., 2020). Therefore, the aim of this paper is to propose a valid transformation framework.

3 INNOVATIVE FRAMEWORK OF VALUE CHAIN

Given the context of Industry 5.0, where enterprises are expanding their boundaries to the value chain within a broader societal context and recognising the significance of value co-creation and exploration in every organisation, the focus is on the innovative transformation framework of value chain management for enterprises. As value chains become increasingly global, the complexity and uncertainty levels rise. Therefore, it is essential for enterprises worldwide further to investigate the integration between Industry 5.0 and value creation and deliver processes through the application of Industry 4.0 technologies. In particular, the growing number of product returns from customers to retailers, driven by adopting environmentally friendly policies, has created a heightened necessity to manage backward materials effectively and information flows in the value chain domain.

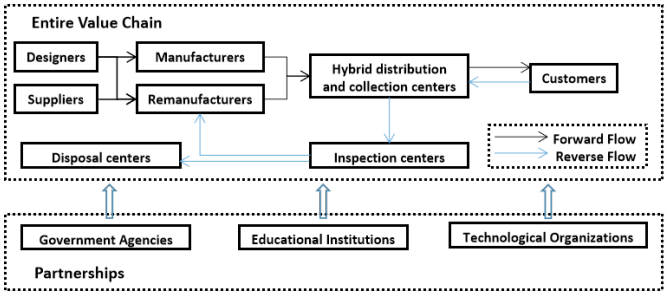


Figure 1. The Value Chain Structure

The product lifecycle value chain is interconnected and complex, comprising both the forward and reverse value chains to meet Industry 5.0 sustainable requirements, as depicted in Figure 1. The forward value chain encompasses the design, production, and distribution channels, commencing value identification, creation, and delivery from designers, suppliers, and manufacturers, extending through distributors, and ultimately reaching the end customers. On the other hand, the reverse value chain involves the recycling process of end-of-life products, including customer returns, collection centres, inspection and disassembly centres, and remanufacturing factories. Value is created through product manufacturing and disassembly, component/material reuse, repair, and remanufacturing. In addition, sustainable manufacturing practices and incorporate environmental design concepts are included throughout the entire value chain. Thus, such a forward and reverse structure will help reduce and optimise resource utilisation, create new customer demand, and establish a social recycling culture to align with the economic, environmental, and societal pillars of Industry 5.0's sustainable characteristics. Identifying the suitable structure facilitates meeting customer demands, digitalising business processes, enhancing responsiveness and resilience, and effectively integrating diverse stakeholders and partnerships.

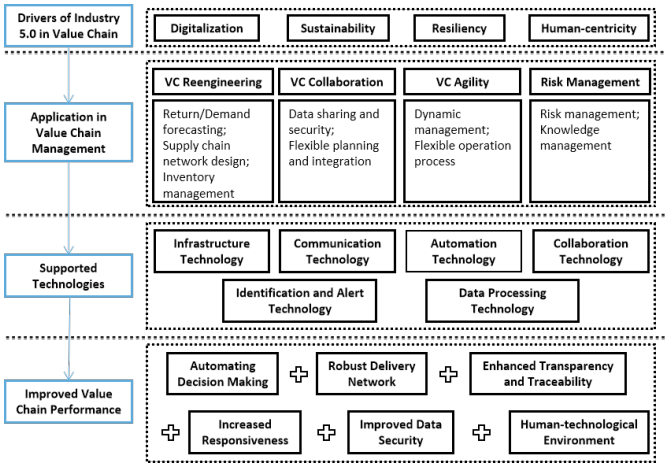


Figure 2. The Outlook of Industry 5.0 to Value Chain Management

In addition, establishing strategic partnerships throughout the entire value 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 value creation from Industry 4.0 to Industry 5.0. Engaging with other high-tech organisations specialising 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 the National Science Foundation, the Department of Commerce, and federal workforce agencies, will significantly benefit both enterprises' bottom line and their communities.

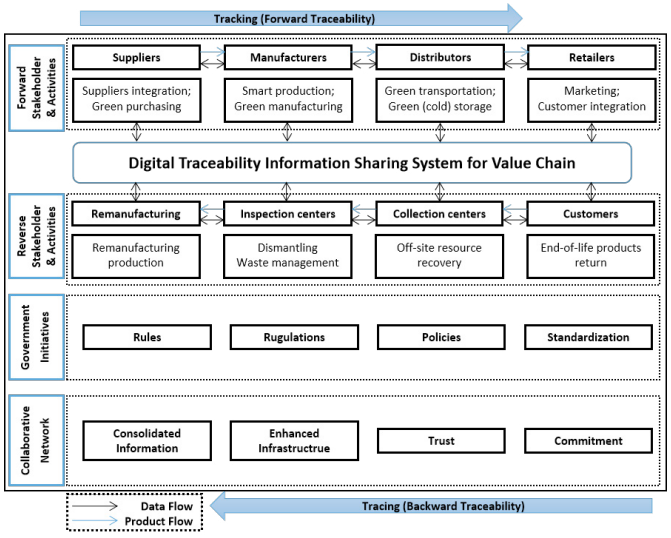


Figure 3. The Overview of Digital Information System for Value Chain

The features of Industry 5.0, supported by the technologies of Industry 4.0, present opportunities for developing new functionalities among enterprise systems within the product lifecycle value chain that handle operations, communication, and logistics. The future potential of Industry 5.0 in value chain management is illustrated in Figure 2. The proposed synthesis framework aims to consolidate the characteristics of enterprises in value chain management, focusing on its application in value chain reengineering, collaboration, agility, and risk management. This framework emphasises the increasing demand to leverage advanced technologies, such as automation, collaboration, and communication, to enhance capabilities and fully realise the potential of Industry 5.0 in improving value chain performance and better exploring potential customer value.

To enhance value chain management's digitalisation, transparency, trust, and sustainability, enterprises can establish a digital traceability information-sharing system for a product lifecycle value chain, as illustrated in Figure 3. This system would receive support from government initiatives and collaboration networks. By implementing this system, enterprises can establish an information network for sustainable value creation, fostering robust collaboration with customers, suppliers, and partners to drive innovative collaboration.

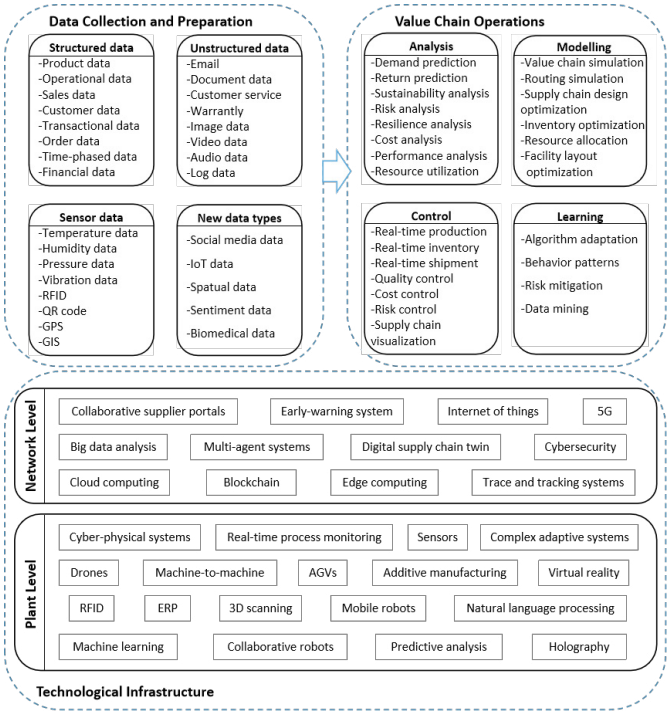


Figure 4. The Data Framework for Digital Information System

Additionally, an overview of the process involved in developing a data framework for the proposed digital information system is depicted in Figure 4. This framework collects real-time and historical data from industrial sensors supported by network-level and plant-level fundamental technologies. The proposed digital information system based on a data framework can be implemented to facilitate effective data analysis and enhance value chain operations. For example, enterprises can leverage various digital tools and technologies in design and manufacturing to boost user experience, personalised customisation, and data-driven decision-making. They can leverage their digital capabilities, platforms, and value networks to share information and complementary assets with other businesses and users. More importantly, with the support of technologies like blockchain, cloud computing, big data, IoT, etc., the value chain's transparency, trust, efficiency, and automation level can be significantly improved to align with the digitalisation goals.

Moreover, enterprises can establish a framework for a resilient value chain to enhance the resilience and customer-centricity of value chain management, as shown in Figure 5. This framework addresses unexpected risk and disruption, enabling organisations to meet customer demands for adaptability and flexibility. By integrating resilience with innovative value delivery strategies, enterprises can achieve rapid responsiveness and make flexible adjustments in business strategies, product designs, and production processes to adapt to changes in market demand and provide personalised, customised services. For instance, enterprises can maintain diversified product lines, develop agile and flat organisational structures, adopt fast iterative development processes, monitor uncertain events to identify potential risks and develop a robust global supply chain network worldwide.



Figure 5. The Framework for Value Chain Resiliency

In summary, when transitioning from Industry 4.0 to Industry 5.0, the focus of the value chain will undergo significant change. Firstly, the value chain will gradually adopt a balanced human-technological environment, primarily facilitated by integrating collaborative robots. Secondly, the value chain strives for enhanced performance in transparency, responsiveness, flexibility, and efficiency and seeks to achieve mass personalisation of products and services. Building upon the foundation of Industry 4.0 technologies, the value chain will also prioritise 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 a smart society will be key objectives. Finally, the value 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.

4 RESEARCH CHALLENGES AND POTENTIAL RESEARCH QUESTIONS

At the beginning stage of exploring Industry 5.0, enterprises and researchers will encounter various research challenges before implementing an innovative product lifecycle value chain strategy. The specific research challenges are illustrated below.

Research Challenge 1: The transparency of the entire value chain and the availability of information within the stakeholders are suboptimal.

Research Direction 1: Future studies should establish an end-to-end visibility system by integrating the forward and reverse value chains to address this challenge. Enhancing the transparency of the entire value chain allows for real-time information tracking across all aspects of business through traceability. This enables flexible adjustments and rapid responses within the value chain, ensuring timely product delivery and high quality and enhancing stakeholder trustiness and traceability towards a more human-centric value chain.

Research Challenge 2: The recovery processes within the reverse value chain increase companies' uncertainties. Each stage where products should be handled and distributed to remanufacturers must be managed.

Research Direction 2: To address this challenge, future studies should prioritise product lifecycle management in the mid-life and end-of-life stages (Ren et al., 2019). This involves designing products that are easy to disassemble and recycle and providing parts and maintenance services to extend product lifespan (Leng et al., 2021). Additionally, enterprises can collaborate with suppliers, customers, and partners to establish blockchain-based recycling networks. This enables waste product recovery, reuse, and remanufacturing, fostering sustainable value 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 organisations through smooth interoperability standardising processes remains a major obstacle.

Research Direction 3: Although the challenge has been partially addressed, with certain areas of data sharing explored, including asset optimisation, product tracking, process conditions tracing, digital product characteristics exchange, and provenance verification (WEF, 2020), there remains a need for future research. Future studies should focus more on implementing system integration and developing encrypted cloud-based security tools in the value chain based on data transfer standards (Zareian et al., 2016). Furthermore, attention should be given to privacy protection, information system management, and security, while enhancing data storage and transparency from a dual blockchain architecture with IoT and radio frequency identification (RFID) devices. This can help overcome regulatory barriers, scale globally, and ensure data confidentiality and privacy.

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

Research Direction 4: To address the challenge, future studies can prioritise 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 value chain due to natural disasters, strikes, virus outbreaks, and operational risks (e.g., regulatory uncertainty and potential system failures) are common. Managing such events' severe

impact and consequences on value creation and supply chain networks is always challenging.

Research Direction 5: Future studies should explore a dynamic and robust cyber risk analysis and early warning system to address the challenge. This system can identify and assess potential risks by analysing operational and supply chain data for patterns associated with specific risks (Lee, 2021).

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

Research Direction 6: Future studies can develop a self-adaptive and self-learning decision support model among various value chain stakeholders to address the challenge. This model can address compromise decision support problems and enable a flexible value chain (Zhu et al., 2018). 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 collaborate strategically with other organisations, fostering resource sharing, technological innovation, and joint market development, ultimately leading to mutual success.

Building on the preceding discussion, several worthwhile research questions (RQ) have been proposed 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 value chain management?

RQ 2: What are the primary obstacles encountered during the transition from Industry 4.0 to Industry 5.0 regarding the product lifecycle value chain?

RQ 3: Which capabilities need to be developed to prepare for advancing the value chain in Industry 5.0?

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

RQ 5: How can Industry 5.0 technologies interoperate across the value chain and effectively interplay with society?

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

RQ 7: How can alignment with the stakeholders engaged in the value chain be achieved to facilitate its development in Industry 5.0?

RQ 8: How can the stakeholders in the value 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 the value chain in Industry 5.0 to foster a more sustainable value chain?

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

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

5 CONCLUSIONS

In the context of Industry 5.0, where enterprises are broadening their scope to incorporate the value chain into a wider societal framework, this paper focuses on managing the product lifecycle value chain. Through an analysis of cutting-edge technologies of Industry 4.0 and current trends within the framework of Industry 5.0, the authors identify four key characteristics expected of the product lifecycle value chain: digitalisation, sustainability, resiliency, and human-centricity. Subsequently, the authors outline a blueprint for transforming the entire value chain, emphasising the essential partnerships required in Industry 5.0 and supported by the necessary technology. To enhance the sustainability of the product lifecycle value chain, the authors propose a value chain framework incorporating a reverse value creation chain through product recovery, reuse, and remanufacturing. To improve the digitalisation of value chain management, the authors propose establishing a digital traceability information-sharing system to create a transparent value chain.

Additionally, enterprises can adopt a resilient value chain framework to boost the resilience and customer-centricity of value chain management. Then, the research challenges are addressed, and their future directions are discussed, providing insights into their future directions. Furthermore, recognising the shifting focus of the value chain during the transition from Industry 4.0 to Industry 5.0, the authors formulate 11 valuable research questions for future investigation. These questions highlight the changes and emerging areas of inquiry within product lifecycle value chain management.

The proposed innovative transformation framework, supported by advanced technologies, enables enterprises to create value and explore new industrial application scenarios. These enterprises will be well-prepared to drive the implementation of Industry 5.0 programs within their product lifecycle value chains.

REFERENCE

Al-Mudimigh, A. S., Zairi, M., & Ahmed, A. M. M. (2004). Extending the concept of supply chain: The effective management of value chains. *International Journal of Production Economics, 87*(3), 309-320.

Aquilani, B., Piccarozzi, M., Abbate, T., & Codini, A. (2020). The role of open innovation and value co-creation in the challenging transition from industry 4.0 to society 5.0: Toward a theoretical framework. *Sustainability, 12*(21), 8943.

Bogers, M., Hadar, R., & Bilberg, A. (2016). Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing. *Technological Forecasting and Social Change, 102*, 225-239.

Dev, N. K., Shankar, R., & Qaiser, F. H. (2020). Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance. *Resources, Conservation and Recycling, 153*, 104583.

EU Commission. (2021). Industry 5.0 - Towards a sustainable, human-centric and resilient European industry. Retrieved from https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en

Feller, A., Shunk, D., & Callarman, T. (2006). Value chains versus supply chains. *BP trends, 1*, 1-7.

Helo, P., & Hao, Y. (2022). Artificial intelligence in operations management and supply chain management: An exploratory case study. *Production Planning & Control, 33*(16), 1573-1590.

Kiritsis, D., Bufardi, A., & Xirouchakis, P. (2003). Research issues on product lifecycle management and information tracking using smart embedded systems. *Advanced engineering informatics, 17*(3-4), 189-202.

Kravets, A. G., Bolshakov, A. A., & Shcherbakov, M. (2022). *Society 5.0: Human-centered society challenges and solutions*: Springer.

Lee, I. (2021). Cybersecurity: Risk management framework and investment cost analysis. *Business Horizons, 64*(5), 659-671.

Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., . . . Wang, L. (2022). Industry 5.0: Prospect and retrospect. *Journal of Manufacturing Systems, 65*, 279-295.

Leng, J., Wang, D., Shen, W., Li, X., Liu, Q., & Chen, X. (2021). Digital twins-based smart manufacturing system design in Industry 4.0: A review. *Journal of Manufacturing Systems, 60*, 119-137.

Liu, W., Zeng, Y., Maletz, M., & Brisson, D. (2009). *Product lifecycle management: a survey.* Paper presented at the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Mangla, S. K., Kusi-Sarpong, S., Luthra, S., Bai, C., Jakhar, S. K., & Khan, S. A. (2020). Operational excellence for improving sustainable supply chain performance. In (Vol. 162, pp. 105025): Elsevier.

Mansour, D., & Barandas, H. (2017). High-tech entrepreneurial content marketing for business model innovation: A conceptual framework. *Journal of Research in Interactive Marketing, 11*(3), 296-311.

Müller, J. (2021). Enabling Technologies for Industry 5.0-Results of a workshop with Europe's technology leaders (2020). *URL: https://op. europa. eu/en/publication-detail/-/publication/8e5de100-2a1c-11eb-9d7e-01aa75ed71a1/language-en*.

Nara, E. O. B., da Costa, M. B., Baierle, I. C., Schaefer, J. L., Benitez, G. B., do Santos, L. M. A. L., & Benitez, L. B. (2021). Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil's plastic industry. *Sustainable Production and Consumption, 25*, 102-122.

Nayeri, S., Sazvar, Z., & Heydari, J. (2023). Towards a responsive supply chain based on the industry 5.0 dimensions: A novel decision-making method. *Expert Systems with Applications, 213*, 119267.

Queiroz, M. M., Pereira, S. C. F., Telles, R., & Machado, M. C. (2019). Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities. *Benchmarking: an international journal, 28*(5), 1761-1782.

Ren, S., Zhang, Y., Liu, Y., Sakao, T., Huisingh, D., & Almeida, C. M. (2019). A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: A framework, challenges and future research directions. *Journal of Cleaner Production, 210*, 1343-1365.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston consulting group, 9*(1), 54-89.

Schaltegger, S. (2020). Sustainability learnings from the COVID-19 crisis. Opportunities for resilient industry and business development. *Sustainability Accounting, Management and Policy Journal, 12*(5), 889-897.

Strange, R., & Zucchella, A. (2017). Industry 4.0, global value chains and international business. *Multinational Business Review, 25*(3), 174-184.

Tang, C. S., & Veelenturf, L. P. (2019). The strategic role of logistics in the industry 4.0 era. *Transportation Research Part E: Logistics and Transportation Review, 129*, 1-11.

Terzi, S., Bouras, A., Dutta, D., Garetti, M., & Kiritsis, D. (2010). Product lifecycle management–from its history to its new role. *International Journal of Product Lifecycle Management, 4*(4), 360-389.

Wang, L., Liu, Z., Liu, A., & Tao, F. (2021). Artificial intelligence in product lifecycle management. *The International Journal of Advanced Manufacturing Technology, 114*, 771-796.

WEF. (2020). Share to Gain: Unlocking Data Value in Manufacturing. Retrieved from https://www.weforum.org/publications/share-to-gain-unlocking-data-value-in-manufacturing/.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems, 61*, 530-535.

Zareian, S., Fokaefs, M., Khazaei, H., Litoiu, M., & Zhang, X. (2016). *A big data framework for cloud monitoring.* Paper presented at the Proceedings of the 2nd International Workshop on BIG Data Software Engineering.

Zhu, Q., Wu, J., & Song, M. (2018). Efficiency evaluation based on data envelopment analysis in the big data context. *Computers & Operations Research, 98*, 291-300.



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2024-06
Elsevier
https://doi.org/10.1016/j.ifacol.2024.08.120
Xia H, Li J, Milisavljevic-Syed J, Salonitis K. (2024) Transformation of the product lifecycle value chain towards industry 5.0. IFAC-Papers OnLine, Volume 58, Issue 8, June 2024, pp. 198-203. 6th IFAC Workshop on Advanced Maintenance Engineering, Services and Technology, AMEST 2024: 12-14 June 2024, Cagliari, Italy

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