APPLICATIONS OF INDUSTRY 4.0 IN SUPPLY CHAIN OPTIMIZATION AND SUSTAINABILITY

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By

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Chapter 10

CONTRIBUTION, IMPLICATIONS, CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

10.1 Introduction

This chapter presents contributions, implications, conclusions, limitations, and future research directions of the study.

10.2 Contribution of the study

The contribution of the study is summarised in the below figure. It ranges from identifying enablers and barriers of adoption to providing a suitability model for I4.0 adoption. It also includes a detailed analysis of supply chain capabilities such as resilience, reliability, and flexibility in the context of sustainability and optimization. This study also provides technology identification, sustainable strategies, and adoption framework.

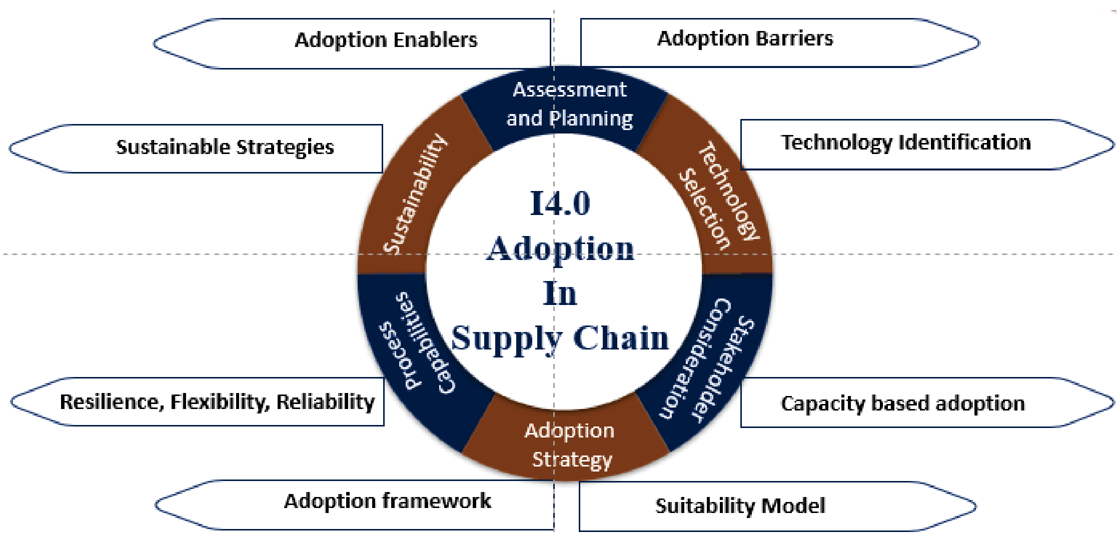

Figure 31: Contribution of the study

10.3 Research implications

This study provides a valuable contribution by delineating sixteen specific barriers to the integration of BT in global supply chain networks. It offers insights into the difficulties that hamper the successful implementation of BT in these operational contexts. The barriers have been classified into four primary domains, namely economic, legal, behavioral, and technical. Moreover, this research delves further into the examination of these barriers by differentiating between those that act as causal factors and those that arise from other influences. Moreover, it assesses the degrees of correlation among these barriers. Within the various categories under consideration, it is evident that technical barriers, predominantly falling within the causal group, play a pivotal role in influencing the adoption of BT. This highlights the necessity for conducting additional research in this particular domain in order to comprehend its consequential impact on other barriers. In the future, there exists the possibility of formulating a technology adoption model that seeks to acknowledge and alleviate the aforementioned barriers. This model could be subjected to testing in order to assess its efficacy in promoting the adoption of BT. The research highlights the significance of technical complexity as the primary barrier to the adoption of BT, emphasizing the need for focused endeavors to investigate approaches for streamlining this aspect. Additionally, the study posits that forthcoming research endeavors should explore the difficulties linked to trust, scalability, interoperability, integration, and financial limitations. These investigations possess the capacity to facilitate the adoption of BT on a broader scale within extensive, worldwide supply chain networks. In summary, this study holds significant implications for both the academic and industrial sectors, providing valuable insights into the effective integration of blockchain technology within intricate supply chain contexts.

In addition, in this study, the authors have found that BT enabled CSFs for SCRS along with their mutual impact and causal relation among each other. Implementing blockchain-enabled technology is essential to building an SCRS, as it can enhance the system's ability to detect disruptions and respond appropriately. The research presented here identifies twenty-one critical success factors (CSFs) for SCRS that can be supported by BT. To prioritize these CSFs and obtain the cause/effect relation among them grey-DEMATEL method is employed. Among these factors, Internal Integration (IN), Efficient inter-organization communication (EIC), and Integration of Strategic Partners (ISP) are the most critical CSFs for the success of SCRS. Invoicing (INV), Efficient Logistics (EL), Efficient Financial Transactions (EFT), Quality data for Forecasting and Analytics (QDF), Inventory Management (IM), and Smart Contract (SC) are the CSFs of high importance among effect group. The findings and the approach of this work have major implications for academics and researchers looking for a deeper knowledge of BT deployment in the supply chain.

Further, this study is unique and has investigated and defined the benchmarking enablers of I4.0 for SC sustainability to build a reliable SC. This research work identified 15 benchmarking enablers of I4.0 to diffuse sustainability in SCs. As a methodological contribution, this study identified the causal relationships among benchmarking enablers of I4.0 in ambiguous and unclear environments. Additionally, the study produced an enabler interaction chart to help managers understand the impact of each enabler. This will further help create effective plans for achieving sustainability and building reliability in the context of SC. A clear understanding of these causal relationships between I4.0 enablers will help industry managers and practitioners understand their impact on the spread of sustainability and reliability in the SC. This work will focus on understanding the relevance of adopting benchmarking enablers of I4.0 for sustainable business development, including process innovation, technology applicability, infrastructure development, and economic, environmental, and social benefits.

The inter-relationships and ranking between enablers of I4.0 and benchmarking are very limited in previous studies, only the weights of these enablers are calculated in some studies. To assess the impact of I4.0 enablers on other enablers, enabler weights were generated for this study. Here this study not only generates the weight of each enabler but also shows the inter-relation and ranks them according to their impact. Researchers can create framework conditions for many industries or they may extend it by adding more enablers into their study and can come up with new benchmarking enablers which may impact more than the study here shows. It is expected that this research study will be helpful for policymakers in developing policies related to sustainability and reliability issues in SCs. Thus, this study has addressed all the questions that have been mentioned earlier and identified the benchmarking enablers behind I4.0's social, economic, and environmental issues for SCs.

Further, the findings of this research contribute vital theoretical improvements to the literature on supply chains in the areas of flexibility, resilience, and sustainability in the adoption of I4.0. This study focuses on I4.0 adoption enablers for flexibility in three dimensions of the supply chain and its impact on resilience and sustainability. It performs an extensive literature review, compiles and synthesizes the expert viewpoints, and then gives a full list of enablers that show how I4.0 could improve flexibility in supply chains. The research helps to fully identify the sixteen I4.0 adoption enablers for flexibility in the supply chain within three dimensions. To examine and prioritize the identified enablers, a thorough and integrated framework based on ISM, fuzzy, and ANFIS approaches is provided by the study. The study also provides the Key enablers for the adoption of I4.0 to enhance flexibility in the supply chain. It identifies 16 enablers of I4.0 for flexibility and by using the ISM model this study categorizes different I4.0 adoption enablers for flexibility. Further, by employing the Fuzzy and ANFIS approach this study answers the I4.0 adoption enablers effect on flexibility dimensions in the supply chain. According to the findings that have been presented, flexibility is crucial for the growth of both the economy and society. It offers significant advantages to a wide range of stakeholders, beginning with the organizations that are responsible for the creation of resilient and sustainable measures and extending down to individual members of society. In addition to resulting in cost savings and gains in areas such as competitiveness, profitability, and quality, providing a greater alignment between flexibility and strategic aims can result in a variety of other benefits as well.

Furthermore, this study expands the theoretical scope of supply chain management by integrating sustainability and cost aspects of the supply chain network. It contributes to the literature by exploring and accounting for scope 1, 2, and 3 emissions of supply chain networks into a model. This study also discussed how I4.0 adoption can simultaneously reduce both carbon emissions and operational costs. Additionally, it addresses the challenges faced by stakeholders regarding the significant costs of adopting these technologies and fills a research gap by linking technology adoption with stakeholder capacity. Furthermore, the study introduces a novel approach to I4.0 adoption by categorizing it into three levels, demonstrating how these levels can be aligned with stakeholder capacity to minimize the financial burden and enhance firm performance.

While the potential benefits of I4.0 technologies in cost reduction and emissions control are evident, the existing literature is still scarce in terms of comprehensive research. This study underscores the necessity for more in-depth investigations to fully comprehend the role of I4.0 technologies in driving down supply chain costs and carbon footprints. To unlock the complete potential of these technologies, further research and exploration are essential, ensuring a holistic understanding of their contribution to sustainable and efficient supply chain management. Researchers can extend the concept and include other important aspect of the supply chain such as inventory, warehousing, cross-docking, recycling, etc., to create a more comprehensive model. In addition, the concepts discussed can be tested with other metaheuristic techniques and performance can be analyzed.

10.4 Policy implications

Effectively managing extensive global supply chains, which involve suppliers from various geographical locations, poses a significant challenge in terms of attaining uninterrupted end-to-end visibility. This challenge can lead to disruptions and increased costs. This study can contribute to shaping the regulations regarding the tracking of scope 1, 2, and 3 emissions and create a guideline for I4.0 adoption to facilitate these processes. It also suggests making policy regarding the use of renewable energy as encouraging the use of renewable energy sources can significantly reduce emissions and decrease manufacturing facilities' reliance on conventional energy sources. In addition, it recommends that policymakers develop strategies for the necessary implementation of fundamental tracking technologies to monitor all types of emissions and waste, enabling the creation of policies aimed at reducing them. Furthermore, it suggests policymakers develop a detailed framework by strategically grouping various technologies so that they can be easily adapted and cost-effective.

10.5 Managerial implications

The study's findings also have important managerial implications and observations that could help supply chains manage more effectively and plan for the successful implementation of BT to improve SCRS. First, the study contributes to the identification of BT-enabled CSFs to enhance the resilience of the supply chain. Second, it provides the prioritization of BT-enabled CSFs that will help in the systematic adoption of BT in supply chains. In addition to that, the causal relation and impact of these CSFs for SCRS will offer more insights to managers and help in decision-making. The CSFs of the cause group will aid in building a plan and providing a foundation for newly emerging enterprises to implement a resilient and sustainable supply chain equipped with the best features of BT. The causal relation will also help the managers to plan which CSFs will be given more priority and which ones receive the least. BT-enabled Standardized Data Management (SD) has the highest correlation among all CSFs and Internal integration (IN) has the highest driving power thus; the study suggests that these two CSFs shall be given top priority while laying down the plan for BT implementation. Managers can use sensitivity analysis to ensure that there is no expert bias, the results are stable, and they can be applied to further refine the company's strategy. This enables managers to accurately focus on the significant CSFs identified through the study and to develop frameworks and policies for adoption. Thus, enabling the organization to achieve a successful SCRS.

Technical complexity emerges as the most crucial BT adoption barrier it causes effects on other barriers such as trust issues and deficiency of approach. It has a moderate correlation with other barriers. Managers need to prioritize it and create a simple and systematic framework to reduce the complexity. Workshops and training sessions can be organized to increase awareness about the technology and clear misconceptions. Data privacy issues can be fueled by a lack of transparency and traceability among stakeholders which increases the counterfeit and fraud risk in the supply chain. It can be resolved with increased trust and enhanced security to protect sensitive information throughout the network. Limited financial capability funds can be allocated in systematic manners to tackle the financial limitations additionally elevating knowledge of technology and its benefits can help in generating more funds with increased collaborations. Trust issues, deficiency of approach, lack of expertise, scalability issues, and Interoperability issues can be controlled and mitigated by mitigating the barriers of cause group.

In addition, the inefficiency in the supply chain can affect processes such as procurement, inventory management, ordering and logistics, etc., thus, requiring attention from the managers. In today's highly competitive market, where uncertainty is constant, blockchain technology in the supply chain has enormous managerial consequences. Blockchain can boost supply chain transparency, trust, and competitiveness. It streamlines operations and attracts customers. Blockchain provides a secure, decentralized platform for tracking and validating transactions, improving risk management. Managers may overcome market constraints and position their supply chains for success by analyzing the competitive landscape and strategically using blockchain or other technology. Blockchain deployment has expenses however, it improves openness, traceability, and confidence. These expenditures include technical infrastructure investment, system integration, staff training, and continuous maintenance. Blockchain technology's intricacy and novelty may demand specialized skills, and increasing consultancy or recruiting expenses. Additionally, switching to blockchain-based systems may interrupt workflows and lower productivity. Managers must consider the long-term benefits of blockchain adoption against the initial investment and operational costs. Phased implementation or partnerships with blockchain technology providers might reduce adoption cost increases.

The study gives managers and experts the information they need to make cost-effective and sustainable decisions throughout the supply chain. The identification will help managers prepare the I4.0 adoption policy for flexibility in the supply chain. The proposed ISM model provides the contextual relation among enablers. Also, the driving and dependence power of enablers has been calculated to provide a better understanding to the managers for policy making. Planning and scheduling tools (PS) have the highest driving power thus, managers need to consider these enablers on a priority basis. Effective planning and scheduling provide better control over involved operations. Traceability tools, real time analysis of tools, and logistics decision-making tools have higher driving power and need to be given priority in adoption policy. Understanding the location of resources is essential for identifying ineffective processes and enhancing flexibility. If TT is already considered, it will open the door for the adoption of I4.0 as well and improve flexibility. The RTA is required for immediate action since it enables us to rapidly identify issues through automated warnings to the responsible firm employee. To improve flexibility, inefficient circumstances can be further examined, and automatic protocols can be set up to prevent decision-making delays. The fuzzy and ANFIS model suggests that to is a noticeable improvement in flexibility in the supply chain.

In summary, the implications of this study span across various managerial domains. From the optimization of inventory and transportation to enhancing production efficiency and quality control, our research provides actionable insights for Chief Supply Chain Officers, Logistics Managers, Production Managers, Quality Assurance Managers, Demand Planning Managers, and Technology Officers alike. These findings offer a roadmap for achieving competitive advantage and adaptability in today's rapidly evolving business landscape. In addition, this study presents a suitability model to analyze the adoption strategies.

This study suggests decision makers adopt I4.0 technologies by identifying the optimum capacity ranges that would yield the highest value in terms of cost optimization and sustainability. The integration of advanced technologies can undoubtedly lead to improved efficiency, reduced lead times, enhanced visibility, and better decision-making capabilities in the supply chain. Nonetheless, to avoid excessive costs and ensure sustainable adoption, companies must tailor their technology implementations according to their specific capacities and operational requirements. For small stakeholders IoT and basic tracking and tracing technologies are recommended. For sustainability and optimal cost optimization, medium-sized firms are encouraged to adopt level II technologies, while large-sized firms are suggested to explore level III technologies. However, determining the appropriate capacity of stakeholders for each level of technology adoption poses a challenge that warrants careful modeling and analysis.

10.6 Conclusion

Global supply chains are continuously growing in complexity with interconnected operations and intricate networks, making it increasingly challenging to operate efficiently and sustainably. The rapid growth of emissions associated with these supply chains poses significant threats to the environment and society at large. Traditional approaches to managing these issues are proving ineffective, necessitating the adoption of capabilities and practices that are both effective and sustainable. I4.0 offers the essential tools and technologies to implement such sustainable practices effectively. This study examined a supply chain network and modeled it by considering the adoption of I4.0. The associated cost of technology adoption is analyzed in detail and its impact on cost and emission is observed through the development of a cost-effective and sustainable supply chain network model.

The observations of this study imply that the integration of technology into the supply chain has the potential to yield cost reductions and enhance operational effectiveness. This observation shows that the integration of technology into supply chain management can improve operational efficiency, increase transparency, and optimize resource utilization. Through the automation of activities, enhancement of data analytics, and facilitation of real-time monitoring, technology has the potential to eliminate bottlenecks, decrease lead times, and mitigate operational expenses Thus, organizations should promote the adoption of I4.0 into their supply chain networks. Advanced technologies and renewable energy sources can cut industrial facility emissions and energy use. It was recommended that small stakeholders adopt level I technologies, while medium and large-sized firms should consider level II and III technologies, respectively. Careful modeling and analysis are necessary to determine the appropriate capacity of stakeholders for each level of technology adoption to achieve optimal cost optimization and sustainability. The policymakers should also consider the technology adoption and frame better policies to provide the desired environment in the organization.

Overall, the integration of I4.0 and sustainable solutions can lead to improved operational efficiency, cost savings, and reduced environmental impacts in the supply chain. Policymakers should consider the impact of technology adoption and frame policies that foster a conducive environment for its implementation. By embracing advanced technologies and sustainable practices, supply chain stakeholders can achieve better cost management, and increased efficiency, and contribute to overall environmental responsibility. In addition, this study aids practitioners and researchers in selecting the optimal strategy for I4.0 adoption in their supply chains. Future research could investigate more variables and the efficacy of other approaches under various parameter settings and problem types to obtain a deeper understanding**.**

10.7 Limitations of the study

This study provides a comprehensive view of I4.0 adoption however, there are a few limitations. The first limitation of this study is that there may be a possibility that a few I4.0 adoption factors have not been considered. Secondly, the qualitative part of this study is entirely dependent on the decision-maker's inputs, and the I4.0 adoption factor's priority may change for a different set of decision-makers. This study can be extended to use other hybrid MCDM methods and results can be compared. Thirdly, the suitability model is tested and validated on a specific industry dataset, which creates a scope for the addition of constraints and variables to the model. In addition, it can be tested and validated on more diverse datasets. Also, this study has not considered the aspects of I5.0.

10.8 Future Scope of the study

Future research directions could incorporate additional supply chain capabilities that are specific to a given area. Furthermore, an examination can be conducted on the enduring effects of I4.0 on the aspects of flexibility, resilience, and sustainability. In contemporary times, global supply chains have encountered uncertainties about cross-border trade, regulatory frameworks, and geopolitical influences. Consequently, future studies can encompass these factors and undertake comprehensive analyses. The analysis of the role of I4.0 can be further explored related to I5.0 particularly concerning its influence on carbon emissions, by examining various technologies. The examination of the human element, specifically focusing on the adoption of I4.0 and investigating the interconnections between workforce training, organizational culture, and management change concerning enhancing flexibility can be performed. The analysis of cybersecurity threats and risk management can also be applied to the emerging technologies of I4.0. Furthermore, an analysis can be conducted on the concept of circular economy, waste reduction, and recycling, in conjunction with the adoption of I4.0 and its effects on flexibility, resilience, and sustainability of the supply chain. The suitability model can also be expanded to incorporate more diverse supply chains and solutions strategies. Additional social and environmental matrices, cross industry applications, and impact on policy and regulations can also be examined.