Abstract

The goal of satisfying global demand across the world has led to profit-oriented practices that usually ignore sustainability concerns and frequently come at the expense of long-term effects on society and the environment. Traditional approaches to managing these issues have proven ineffective, necessitating the adoption of new capabilities and practices that are both cost-effective and sustainable. Increasing complexity and the involvement of additional stakeholders make it impossible to predict the impact of each decision, which puts supply chain managers in uncertain situations. In addition, supply chains all around the globe have experienced unprecedented disruptions. In response to these disruptions, supply chains have implemented various strategies. However, as the global supply chain industry encompasses a wide range of activities and forms complex networks these strategies need to be more flexible, reliable, and resilient for effective implementation to fulfill consumer demand under various global challenges. The global supply chains require the characteristics of sensing disturbances or threats and giving appropriate responses. This can be improved with the implementation of Industry 4.0 (I4.0) technologies which can prove critical in building a cost-effective and sustainable supply chain.

Most of the supply chains in the world use limited or no technology which may be attributed as a major reason behind higher supply chain costs and emissions. The digital technologies of I4.0 such as big data analytics, artificial intelligence, machine learning, blockchain, and IoT offer businesses numerous opportunities. In response to this concern, this study pioneers an investigation into the adoption of I4.0 technologies and their dual impact on both cost optimization and carbon footprint reduction. This study aims to provide a suitability model for I4.0 adoption. In addition, this study seeks to analyze the impact of I4.0 adoption on global supply chains in terms of resilience, sustainability, reliability, and flexibility. This study has used a qualitative approach to explore I4.0 adoption barriers, critical success factors, and impact on supply chain capabilities such as reliability, resilience, flexibility, and sustainability. Further, a quantitative approach is adopted based on the insights of the qualitative study. The following paragraphs summarise the different studies performed in this work.

Firstly, to enhance the understanding of the barriers hindering the effective integration of I4.0 (blockchain technology) into supply chain operations. By delineating sixteen discrete barriers across economic, legal, behavioral, and technical classifications, this study aims to provide insights into the complexities of modern supply chains and facilitate the development of cost-efficient and flexible solutions for diverse organizations. Further, to analyze the impact of I4.0

adoption on supply chain resilience and sustainability this study has identified twenty-one blockchain technology-enabled critical success factors, and grey theory is used to address the limitation of data availability. The findings indicate that internal integration is the most crucial causal factor as it initiates the effects of many other critical success factors. Whereas Standardized Data Management followed by Smart Ordering tops the effect group.

After that, to analyze the impact of I4.0 adoption on supply chain sustainability, and reliability this study identified and benchmarked the enablers of I4.0. The identified potential enablers are validated empirically. Digitalization of the supply chain, decentralization, smart factory technologies, and data security and handling are the most prominent enablers of I4.0 for SC sustainability to build an RSC. Further, this study investigated the seamless integration of flexible supply chain processes with I4.0 technologies to foster resilience and sustainability. The synergized capabilities of I4.0 technologies and flexibility can empower supply chains to navigate uncertainties and withstand disruptions. The results of this research offer significant theoretical advancements to the literature on supply chains in the areas of flexible practices, resilience, and sustainability in the supply chain through I4.0 technologies.

After the recommendations from the qualitative study, the quantitative study develops a robust model for supply chain networks and seeks to delve into the impact and strategic adoption of I4.0 for cost optimization and the reduction of scope 1, 2, and 3 carbon footprints. The proposed model is solved using genetic algorithm (GA), adaptive genetic algorithm (AGA), differential evolution (DE), and adaptive differential evolution (ADE) approaches. The finding of the study suggests decision makers adopt I4.0 technologies by identifying the optimum stakeholder capacity ranges that would yield the highest value in terms of cost optimization and sustainability. Furthermore, this study expands the theoretical scope of supply chain management by integrating sustainability and cost aspects of the supply chain network.

Keywords: Supply Chain, Industry 4.0 adoption, reliability, flexibility, resilience, sustainability, Digital Technologies, Blockchain, AI/ML, IoT, Bigdata, Optimization.