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An Empirical Study on the Importance of Digital Transformation (5.0) in Improving the Supply Chain

Suliyanto[1*], Weni Novandari[2]

[1] Economics and Business Faculty Universitas Jenderal Soedirman, Purwokerto, Indonesia; suli_yanto@yahoo.com
[2] Economics and Business Faculty Universitas Jenderal Soedirman, Purwokerto, Indonesia; weni_novandari@yahoo.com

* Correspondence: suli_yanto@yahoo.com

Abstract
Digital transformation in supply chain optimization has received significant attention in recent years because of its critical importance. This study aims to provide empirical evidence and insights regarding the benefits and challenges associated with digital transformation in supply chain management. This research examines the impact of digital transformation on supply chain optimization through a hybrid methodology. It incorporates a detailed literature review, the development of a theoretical framework, and empirical findings derived from multiple case studies based on established selection criteria. The case analyses underscore essential components that facilitate successful digital transformations, such as real-time data analytics, collaboration, blockchain technology, digital twin technology, augmented and virtual reality, and collaborative robots. The findings of this study provide insights that are valuable for professionals across various industrial sectors and businesses undertaking similar digital transformation initiatives. This empirical study regarding the implications of Digital Transformation 5.0 on supply chain management contributes novel insights to the existing literature. Further research is essential to validate the findings, extend their applicability to a broader spectrum of enterprises, and explore various dimensions of digital transformation in supply chain optimization.

Keywords: Digital transformation; Supply chain optimization; Industry 5.0.

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1. Introduction

In the current dynamic and competitive business environment, organizations are recognizing the significance of digital transformation in enhancing efficiency, agility, and competitiveness across diverse sectors. Supply chain management is a crucial domain in which digital transformation plays a significant role. Utilizing digital technologies and

data-driven strategies enables businesses to transform supply chain processes, acquire valuable insights, enhance operational capabilities, and effectively respond to evolving customer demands. Conventional supply chain management approaches struggle to meet the demands of today's fast-paced corporate environment. The emergence of Digital Transformation 5.0, which includes advanced tools such as blockchain, the Internet of Things, and artificial intelligence, offers significant opportunities to enhance and optimize supply chain processes. There is a notable deficiency of empirical studies investigating the actual impact.

The effectiveness of Digital Transformation 5.0 in real-world supply chain contexts. This study conducts an empirical analysis of the significance of Digital Transformation 5.0 in supply chain optimization, aiming to address the existing knowledge gap and provide valuable recommendations for companies seeking to enhance their resilience and competitiveness in a progressively digitalized landscape.

Supply chain management (SCM) involves the strategic coordination and oversight of all activities related to the flow of goods, services, information, and finances, starting from the initial sourcing of raw materials to the final delivery of products or services to end customers. The process encompasses planning, execution, control, and monitoring across various organizations and stakeholders within the supply chain (Zhang et al., 2023).

The lack of real-time information and transparency is a significant limitation of traditional supply chain management. Revolutionary technologies such as the Internet of Things (IoT), cloud computing, and big data analytics enable organizations to capture and analyze vast quantities of data throughout the supply chain. Organizations can swiftly make data-driven decisions by obtaining real-time insights into inventory levels, manufacturing plans, transportation, and demand patterns. Enhanced coordination, reduced delays, minimized disruptions, and improved supply chain performance are all advantages of increased visibility (Hamidu et al., 2023). Digital transformation refers to the integration of digital innovations across various aspects of a company's operations, processes, and strategies, fundamentally changing its functioning and the value it delivers to customers. The use of digital tools, technology, and data is essential for fostering innovation, enhancing productivity, improving customer experience, and sustaining competitiveness in a rapidly evolving digital landscape (Chin et al., 2023). Digital transformation encompasses a wide range of initiatives that may vary across different businesses and organizations. Digital transformation can significantly impact key areas such as customer experience, business processes, data analytics, supply chain and logistics, cutting-edge technologies for product development, business models, and workforce empowerment (Kraus et al., 2021; Feliciano-Cestero et al., 2023). The adoption of disruptive technologies is essential to the digital transformation process, as it enhances societal welfare, productivity, and profitability (Ebert and Duarte, 2018).

This study aims to provide empirical evidence and insights regarding the benefits and challenges associated with the digital transformation of supply chain management. This study employs several case studies in an empirical analysis to examine the role and impact of digital transformation on supply chain optimization initiatives. In the context of Industry 5.0, "digital transformation" refers to the integration of contemporary digital technologies with human-centered approaches to foster innovation and value creation across all industrial sectors (Skobelev and Borovik, 2017). The fourth industrial revolution, termed Industry 4.0, established the groundwork for Industry 5.0, which emphasizes the collaboration between humans and machines to enhance profitability, efficiency, and personalization (Danuso and da Silva, 2022).

2. Materials and Methods

The research methodology utilized in this work is a combi- nation of literature review, theoretical framework develop- ment, and empirical studies based on case analyses. Figure 1 shows the research design diagram and the process involved.

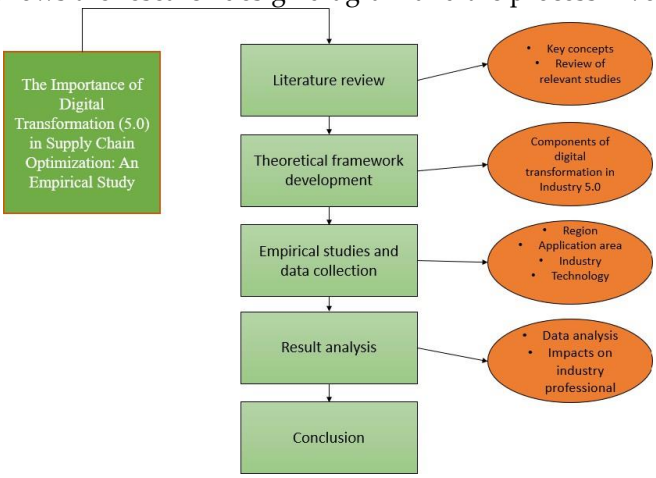

Figure. 1. Research methodology diagram

This research emphasizes the importance of digital transformation in the contemporary competitive corporate landscape. This illustrates the significance of digital transformation in enhancing productivity, adaptability, and competitiveness across various industries, with a specific focus on supply chain management. This section presents essential concepts including Industry 5.0, components of digital transformation, and the impact of disruptive technologies on the transformation process. The literature review systematically compares recent studies, identifying the gaps that the current research intends to address.

This paper presents a theoretical framework that examines the components of digital transformation within the context of Industry 5.0. The discussion encompasses Human-Machine cooperation, customized goods and services, data integration and analytics, digital twins, cybersecurity, skills development, and workforce adaptation. The theoretical framework provides a foundation for understanding the effects of digital transformation on supply chain optimization, particularly within the context of Industry 5.0.

Empirical evidence is presented through case studies selected from relevant research obtained from Google Scholar between 2021 and 2023, aimed at investigating the function and effects of digital transformation on supply chain optimization initiatives. Each case study is summarized, detailing the author, country or region, industrial sector, and application area. The studies encompass various subjects, including the application of technologies such as augmented reality (AR), virtual reality (VR), blockchain, artificial intelligence (AI), digital twins, and data analytics across multiple sectors, including automotive, logistics, agriculture, mold-making, healthcare, and footwear. The empirical studies seek to illustrate the implementation of digital transformation in supply chains by real-world organizations and the resultant outcomes.

The results underscore significant findings from the case studies, emphasizing the beneficial effects of digital transformation on supply chain optimization. The discussion examines the implications of the case studies, emphasizing the significance of real-time data and analytics, collaboration, employee engagement, and change management in achieving successful digital transformations.

The conclusion section summarizes the critical significance of digital transformation in optimizing supply chains. It highlights the incorporation of advanced technologies and

their transformative impact on conventional supply chain management practices. Future research directions include the analysis of dynamics between businesses and suppliers, exploration of factors influencing the implementation of digital transformation, and investigation of the environmental and societal effects of supply chain digital transformation.

The research methodology encompasses a comprehensive approach that integrates a detailed literature review, the formulation of a theoretical framework, and the presentation of empirical evidence via case studies to investigate the effects of digital transformation on supply chain optimization.

Review of Existing Literature

Digital transformation in Industry 5.0 aims to leverage digitalization to enhance human capabilities and foster a better integration between humans and robots. Figure 2 illustrates key components of digital transformation within the context of the fifth industrial revolution..

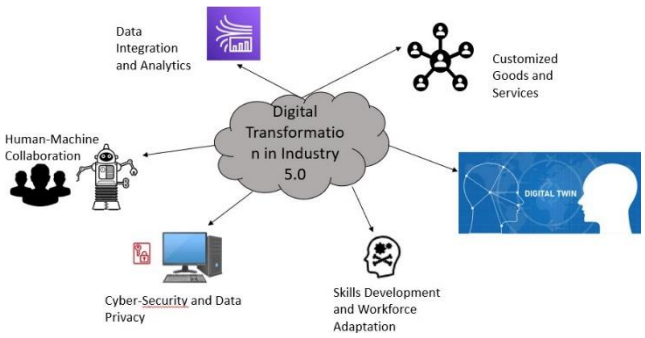

Figure 2. Components of digital transformation in industry 5.0

A concise overview of key components of digital transformation within the framework of Industry 5.0 is provided as follows:

Industry 5.0 emphasizes the dynamics and collaboration between humans and machines in the workplace. Artificial intelligence (AI), the Internet of Things (IoT), and robotics exemplify digital technologies employed to automate repetitive tasks and enhance productivity, thereby enabling individuals to focus on complex decision-making, creativity, and problem-solving (Romanov et al., 2022; da Assis Dornelles and Frank, 2022).

Large-scale customization and modification of goods and services have been facilitated by the digital revolution. Digital design tools, data analytics, and 3D printing exemplify advanced technologies that facilitate the production of highly unique and personalized products tailored to specific client requirements (Li et al., 2017).

Data integration and analytics are essential for Industry 5.0, which relies on the collection and processing of large volumes of data from various sources, including sensors, machines, and human inputs. This process is referred to as data integration and analytics (Madzik et al., 2023). Advanced machine learning algorithms and statistical methods are employed to extract valuable insights from data. This enhances decision-making, facilitates predictive maintenance, and optimizes manufacturing processes (Danuso and da Silva, 2022). Digital twins represent a fundamental component of Industry 5.0. They represent virtual counterparts of real assets. These digitized imitations enable instantaneous tracking, simulation, and process optimization of industrial operations, thereby enhancing productivity, reducing interruptions, and improving quality control (Mihai et al., 2022; Alojaiman, 2023).

Cybersecurity and Data Privacy: With the adoption of advanced digital technologies in Industry 5.0, the protection of sensitive data and the maintenance of cybersecurity are essential. To safeguard valuable intellectual property, customer information, and operational data, stringent cybersecurity measures and data privacy regulations are implemented (Pasandideh et al., 2022). Skills Development and Workforce Adaptation:

The digital transformation associated with Industry 5.0 necessitates a focus on enhancing workforce skills to facilitate effective interaction with advanced technologies. Instructional and educational activities are implemented to equip staff members with essential digital skills and to foster a culture of continuous learning and adaptability (Leng et al., 2022).

In the dynamic landscape of modern business, supply chain management has emerged as a critical component that can significantly enhance organizational efficiency and marketability or serve as a barrier to progress. The digital transformation of supply chains has been facilitated by the introduction of digital technological innovations during the fourth industrial revolution. The emergence of Supply Chain 5.0 highlights the significant and transformative advantages of digital transformation within the supply chain. The following are highlighted:

Technological innovations enable instantaneous monitoring and record-keeping of inventory, shipping, and logistical procedures, thereby enhancing visibility. Organizations can achieve a comprehensive understanding of their supply chain due to enhanced visibility, which promotes improved decision-making, proactive problem-solving, and increased collaboration with partners, suppliers, and clients (Shi et al., 2023).

Enhanced Efficiency: Automated and digitalized supply chain processes accelerate operations and eliminate the need for human labor. Consequently, cycle times are accelerated, errors are reduced, and operational efficiency is enhanced. Technologies such as robotics, autonomous driving, and IoT sensors can enhance transportation, inventory management, and warehousing operations, resulting in reduced costs and increased productivity (Twaris et al., 2022).

Digital transformation enhances customer experience by facilitating faster order fulfillment, accurate delivery tracking, and personalized interactions. Organizations can forecast customer demand, modify products and services, and deliver personalized recommendations through artificial intelligence and data analytics, thereby enhancing customer satisfaction and loyalty (Aslam et al., 2020).

Enhanced Flexibility in Supply Chain: Digital technologies increase the flexibility and adaptability of supply chain operations. Data analytics and predictive modeling facilitate the identification of demand trends, the maximization of inventory levels, and the enhancement of demand forecasting precision (Xian et al., 2023).

Decision-making informed by data: The supply chain ecosystem is experiencing a digital transformation, resulting in the generation of vast quantities of data. Organizations can leverage these insights to inform decision-making through the application of advanced analytics and machine learning. Utilizing these insights allows for continuous improvement of the supply chain, while also facilitating strategic planning, streamlining procedures, identifying cost-cutting opportunities, and optimizing workflows (Modgil and Agrawal, 2023).

Digital tools and applications facilitate real-time collaboration and communication among supply chain stakeholders. Cloud-based platforms, collaborative websites, and shared databases facilitate real-time information sharing, allowing suppliers, manufacturers, distributors, and clients to communicate effectively, share updates, and coordinate activities. Stronger partnerships are developed, communication gaps are addressed, and supply chain performance is enhanced (De Giovanni, 2023).

Digital technology can enhance sustainability efforts by reducing debris, optimizing transportation, and increasing energy efficiency. Organizations can identify opportunities for sustainable practices, such as optimizing packaging, reducing carbon emissions, and implementing recycling strategies, through real-time monitoring and analytics. Digital transformation enhances supply chain operations' capacity to comply with regulatory standards, fulfill consumer expectations, and achieve sustainability objectives (Ghobakhloo et al., 2023).

In summary, the digital transformation of supply chains in Industry 5.0 offers numerous advantages, such as enhanced customer experience, greater agility, improved efficiency, and data-driven decision-making. These advantages enable businesses to expand, gain a competitive edge, and thrive in a constantly evolving market.

Optimization of Supply Chains in Industry 5.0

Operations and supply chain management are frequently perceived as cost centers that are labor-intensive and significantly dependent on human resources. Supply chain operations exhibit significant output variability, which is intensified by workers skilled at multiple levels of tasks (Dwivedi et al., 2023).

This has rendered the optimization of supply chain operations an ongoing challenge. Achieving optimal outcomes in supply chain activities is challenging due to discrepancies in worker knowledge, skills, and abilities. The Fifth Industrial Revolution, or Industry 5.0, is anticipated to fundamentally alter the industrial sector through the integration of advanced technology and enhanced human-machine collaboration. Supply chain optimization is crucial for achieving resilience, competitive advantage, and operational excellence as organizations navigate this transformative period (Iyanov, 2023). This study explores the key innovations and methodologies that enhance supply chain optimization within the context of Industry 5.0. Refer to Figure 3..

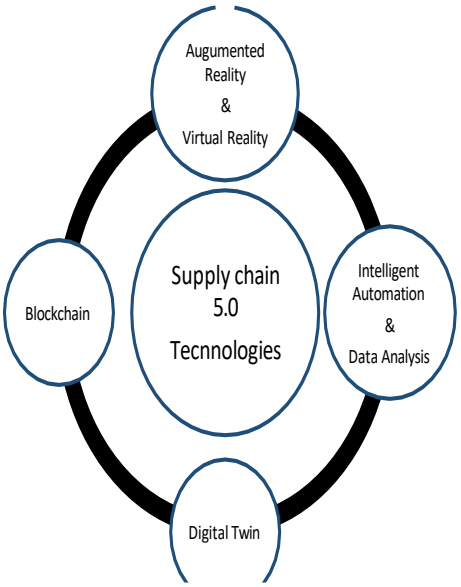

Figure. 3. Innovations for supply chain optimization in industry 5.0

Figure 3 illustrates that the innovations driving supply chain enhancement include blockchain, augmented and virtual reality, digital twin technology, and intelligent automation and data analysis. The following subsections provide further emphasis on these technologies:

Automated Intelligence: Industry 5.0 represents the next phase of intelligent automation by integrating human and machine capabilities. Robotics, artificial intelligence, and machine learning significantly enhance the efficiency of supply chain operations. Cobots (collaborative robots) and autonomous robots enhance the efficiency of order fulfillment, logistics, and material handling processes. AI and ML algorithms enable predictive analytics, demand forecasting, and real-time decision-making, thereby enhancing customer responsiveness and streamlining inventory management (Lv, 2023).

Digital twins, representing virtual counterparts of real assets, systems, and processes, significantly enhance supply chain optimization. Businesses can monitor performance, obtain real-time information, and identify bottlenecks or inefficiencies by creating a digital twin of the entire supply chain. Digital twins allow companies to

simulate scenarios, enhance workflows, and anticipate the impacts of changes prior to their implementation in the real world through the use of statistical analysis, simulation capabilities, and IoT sensors. This technology enhances flexibility, reduces risks, and fosters continuous development (Iyanov, 2023).

Blockchain technology enhances supply chain management by providing unprecedented transparency, traceability, and security. Blockchain facilitates comprehensive transaction visibility and operates in a decentralized and immutable manner, ensuring data accuracy and legitimacy. Smart contracts, supported by blockchain technology, automate and enforce agreements among supply chain participants, thereby minimizing delays, discrepancies, and administrative costs. These innovations enhance trust, enable seamless communication, and optimize operations such as product tracing, inventory management, and procurement (Zhang et al., 2023).

Virtual reality (VR) and augmented reality (AR) technologies are transforming supply chain operations, particularly in maintenance, training, and logistics. Augmented reality (AR) enhances accuracy and productivity by overlaying digital data onto the physical environment, providing workers with access to equipment maintenance guidance, inventory details, and real-time instructions. Virtual worlds enable the facilitation of virtual training sessions, remote teamwork, and complex scenario simulations. In Industry 5.0 supply chains, these tools enhance training, reduce errors, and improve employee efficiency (Akbari et al., 2022).

Predictive perception and data analysist the substantial data generated by Industry 5.0 presents significant opportunities for enhancing supply chain efficiency. Large datasets are analyzed through advanced analytical methods to reveal practical insights that facilitate commercial decision-making. Predictive analytics enables reliable demand projections, optimized inventory management, and proactive risk management. The integration of real-time data within the supply chain ecosystem facilitates rapid responses to market developments, thereby reducing lead times and enhancing customer satisfaction (Karmaker et al., 2023; Iyanov, 2023).

In conclusion, supply chain optimization is crucial for companies to maintain success in a changing manufacturing landscape as Industry 5.0 progresses. Organizations can attain operational excellence, resilience, and responsiveness through the adoption of intelligent automation, blockchain technology, augmented reality/virtual reality, and data analytics. Supply chains can adjust to evolving market conditions, enhance customer satisfaction, and gain a competitive edge in Industry 5.0 through the application of disruptive technologies. Organizations must employ optimization techniques to fully leverage the advantages of the fifth industrial age. The Materials and Methods section must provide adequate detail to enable replication and further development of the published findings. The publication of your manuscript requires that all materials, data, computer code, and protocols related to the publication be made accessible to readers. At the submission stage, please indicate any limitations regarding the availability of materials or information. New methods and protocols require detailed descriptions, whereas established methods may be summarized and properly cited.

Research manuscripts that present large datasets deposited in publicly accessible databases must indicate the specific location of the data and include the corresponding accession numbers. If accession numbers are not available at the time of submission, please indicate that they will be provided during the review process. They must be supplied before publication.

Intervention studies involving animals or humans, as well as other research requiring ethical approval, must specify the approving authority and the associated ethical approval code.

Lee et al. (2022) analyze the influence of the digital supply chain and its mediating effect on supply chain organizational performance within the Malaysian manufacturing sector. The researchers utilized a quantitative research method and Partial Least Squares

Structural Equation Modeling (PLS-SEM), leading to several hypothetical conclusions. The findings, when implemented by business operatives, can enhance supply chain performance. Nonetheless, there are several gaps relative to our research, which will involve both theoretical concepts and empirical studies of specific cases rather than a generic approach.

Belhadi et al. (2022) analyze the individual and synergistic effects of various techniques, including digital business transformation, organizational ambidexterity, and circular business models, on the relationship between Industry 4.0 capabilities and supply chain performance. Information was gathered from 306 organizations across Europe, Asia, and Africa to develop and evaluate a theoretical model. The study found that Digital Business Transformation moderated this relationship by integrating circular concepts into business model development and improving the sustainability of supply chain performance. Despite the novelty, originality, and relevance of the studies, a gap remains in empirical research and conclusions regarding digital transformation 5.0, as the study focused solely on the fourth industrial revolution.

Zouri et al. (2021) conducted a study to examine the relationship between supply chain resilience and supply chain digitalization. The quantitative research method was utilized to analyze the influence of digital maturity and supply chain digital tools on supply chain optimization within the selected sample. The findings indicated that the adoption of digital tools significantly influenced the overall performance of supply chain resilience. The analysis reveals a gap in our work, as the digital tools available in the fifth industrial revolution were not thoroughly examined.

The researchers conduct a study to examine the effects of digital technology adoption on the supply chains of manufacturing firms. The study employs a literature review method and a conceptual framework centered on the drivers, process, and impact to fulfill its objectives. The findings indicate that the proposed framework and solution may provide guidance to practitioners utilizing digital supply chain management technologies and developing appropriate business plans during different phases of digital transformation (Yang et al. 2021).

Various industries are experiencing substantial transformations as a result of technological advancements. The supply chain industry is significantly affected by digital transformation. To optimize operations, businesses are adopting digital tools in their supply chain processes, leading to improved efficiency, cost-effective practices, and increased customer satisfaction. This section examines empirical studies on the impact of digital transformation on supply chain optimization.

A study by Bun et al. (2021) in collaboration with an external software development firm serving Polish industrial enterprises in the automotive sector found that prior factory floor implementations identified noise and Wi-Fi as the most significant and problematic conditions. Consequently, these two conditions were identified as the primary focus for the team's improvement initiatives. Various augmented reality and virtual reality interventions were implemented to enhance factory conditions, including soundproofing and improved Wi-Fi coverage (Bun et al., 2021).

Das et al. (2023) aimed to identify and analyze the key factors facilitating the rapid adoption of Artificial Intelligence in the food grain supply chain, thereby promoting Agri 5.0 and a circular economy in India. A causal model of the identified enablers was constructed utilizing the fuzzy decision-making trial and evaluation laboratory method. The F-DEMATEL technique clarifies the process of researching enabling interactions. Research findings indicate a significant impact of incorporating artificial intelligence in FGSC. The results possess considerable implications for policy. The findings may facilitate the acquisition of additional funding and assist Indian decision-makers in advancing artificial intelligence initiatives. Angelopoulos and Mourtzis (2022) introduced an Intelligent Product Service System (IPSS) for the adaptive maintenance of Engineered-to-Order industrial equipment utilizing augmented reality (AR). Their work involved

validating the EDM module and the AR application through a real-life case study from the mold-making industry in Greece. The findings indicate that enhancing manufacturing process efficiency is attainable by establishing effective communication channels among the end-user, the OEM, and the energy provider. The primary objective of this study is to present an innovative and comprehensive framework for supplier evaluation in the context of Industry 5.0. This involved the evaluation of a global medical equipment manufacturer headquartered in Taiwan, employing a data-driven decision support system. The findings illustrate the progression of businesses towards Industry, informed by literature on agility and resilience, in relation to humanitarian supply chain design and risk management. System dynamics simulation and network optimization are employed to analyze the operation of the humanitarian supply chain within the Yemeni logistics cluster. The findings, when applied, can assist decision-makers and relevant stakeholders in facilitating resilient decision-making for human supply chain managers and their sponsors.

This article by Arunmozhi et al. (2022) analyzes the potential of blockchain-based smart contracts and artificial intelligence (AI) to enhance sustainable supply chain operations. The Margin Indicator (MI) is a design component developed to deliver reliable predictive analytics outcomes derived from widely used machine learning algorithms. The implementation occurred at a Singaporean company (ABC) that provides autonomous vehicles in Singapore and neighboring countries in Southeast Asia. The developed framework improved product traceability, transaction transparency, and sustainable economic growth within autonomous vehicle supply chains. The rapid advancement of blockchain and artificial intelligence technologies supports this development.

Table 1 presents a summary of the case studies concerning year, author, region, sector, and application area. Table 1 indicates that the prevailing trend in digital transformation technologies is oriented towards AI, real data analytics, and blockchain technology, as noted in the introduction. These innovations are applicable across all sectors, irrespective of the region.

Table 1. Results of empirical studies

Year	Author	Country/ region	Sector	Application area
2021	Bun et al.	Polland	Automotive	AR & VR
2022	Stewart and Ivanov	Yemen	Logistics	Blockchain
2022	Arunmozhi et al.	Singapore	Automobile	Blockchain and AI
2023	Das et al.	India	Agriculture	AI
2022	Angelopoulos Mourtzis	Greece	Mold-making	AR
2023	Lo	Taiwan	Health	Real-time data and analytics

Year	Author	Country/ region	Sector	Application area
2023	Ahmed et al.	Bangladesh	Footwear industry	AI

Digital transformation, real-time information sharing, and changes in organizational culture can influence 5.0 (Lo, 2023).

Ahmed et al. (2023) seek to enhance Supply Chain resiliency by identifying, evaluating, and prioritizing the AI-based imperatives of Industry 5.0 through an integrated strategy that employs Pareto analysis, the Bayesian approach, and the Best-Worst Method (BWM). Following the COVID-19 pandemic, the framework was implemented in the footwear industries of Bangladesh. The results indicate that the B-BWM has been integrated into the framework to enhance efficient group decision-making. This assists businesses in selecting optimal AI technologies to enhance supply chain resilience during the COVID-19 crisis.

Alice and Khumbulani (2022) discuss the applications of a blockchain-based information system and a cloud manufacturing process system within the supply chain management framework of a railcar manufacturer in South Africa. The findings indicate that SMEs and manufacturers benefit from the implementation of blockchain technologies, aligning with Industry 5.0, where the system improves the Internet of Things and enhances employee working conditions. It enhances business-to-business interactions and overall supply chain optimization through collaboration and privacy.

Stewart and Ivanov (2022) propose a design redundancy through the application of a digital twin approach. This research examines the risks associated with humanitarian supply chains, particularly in conflict zones. This method, which is

The results from these cases demonstrate that digital transformation is essential for enhancing multiple facets within this field. Empirical evidence from these studies indicates an increase in visibility into processes. Effective collaboration among stakeholders in the process flow, coupled with optimized inventory management practices, has been recognized as crucial for driving significant improvements in organizations across various sectors undertaking digital transformation initiatives. Therefore, they are essential for effectively directing decision-making processes intended to enhance strategies for optimization across various global supply chains.

3. Results And Discussion

The review of related works identified gaps in existing knowledge as highlighted by previous studies (e.g., Lee et al., Belhadi et al., Zouri et al.). The identified gaps motivate the empirical studies undertaken, thereby addressing the necessity for more comprehensive theoretical frameworks and empirical research.

The review identifies limitations in existing studies, including the lack of coverage regarding the fifth industrial revolution (e.g., Belhadi et al.). This was addressed by examining the works of Daas et al. and Ahmed et al. The necessity for additional empirical studies and conclusions, as highlighted by Zouri et al., was addressed by examining cases that concentrated on recent technologies such as AI, blockchain, and real-time analytics, as illustrated in summary table 1.

The empirical studies directly reference and build upon the literature, demonstrating how each study contributes to addressing identified gaps or extending existing knowledge. The case studies presented in Table 1 directly relate to the themes and areas addressed in the literature review.

The empirical studies validate theoretical concepts from the literature, such as the impact of digital transformation on supply chain resilience, as discussed by Zouri et al., emphasizing the significance of digital transformation in enhancing supply chain optimization. In these instances, the firms enhanced their supply chain processes through the application of Digital Transformation 5.0 technologies, such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, and data analytics. The implementation of these technologies resulted in enhanced operational efficiency, greater visibility, improved collaboration, and heightened customer satisfaction.

Table 1 indicates that the application of artificial intelligence has increased in recent years across various sectors.

Real-time data and analytics capabilities consistently emerged as a significant theme across the case studies. The studies provided valuable insights into operations through the real-time gathering and analysis of supply chain data, enabling the identification of inefficiencies, enhancement of inventory management, and optimization of procedures. The incorporation of predictive analytics enabled proactive management of potential interruptions and informed decision-making, thereby enhancing supply chain performance.

The case studies demonstrated the significance of partnerships and teamwork in achieving successful digital transformations. Firms that promoted collaboration with suppliers, clients, and other participants in the supply chain ecosystem achieved superior results. Digital technologies have enabled collaborative platforms that facilitate information exchange, activity coordination, and synchronization. Consequently, there has been an increase in productivity and adaptability.

The case studies highlighted the importance of employee involvement and change management in digital transformation initiatives. The successful adoption and acceptance of digital tools and processes were facilitated by effective change management strategies, which encompassed clear communication, training programs, and the engagement of employees across all levels. Employers who engaged their staff in the transformation process observed heightened levels of dedication and productivity.

The implications of these case studies are essential for businesses contemplating a change in their digital supply chain operations. The findings provide valuable insights and implications derived from real-world cases. These examples illustrate how the implementation of Digital Transformation 5.0 technology and the reliance on data-driven decision-making can enhance supply chain performance in quantifiable terms. Similarly, in the execution of digital transformation initiatives, the importance of change management, collaboration, and employee engagement is paramount.

Despite the positive impacts, it is crucial to acknowledge the limitations of the case studies. Despite the examination of numerous firms, the results may not accurately represent all potential markets and scenarios. Future research may explore additional case studies to enhance and expand the conclusions. The case studies highlighted the impact of digital transformation on supply chain efficiency. The financial impact, sustainability implications, and long-term effects of these alterations warrant further investigation.

4. Conclusion

This study examined the significant importance of digital transformation (5.0) in supply chain optimization. The integration of advanced technologies, including human-machine cooperation, cybersecurity, data privacy, predictive analytics, digital twins, blockchain technology, intelligent automation, and the Internet of Things, has transformed traditional supply chain management practices, facilitating operational efficiency, cost reduction, and improved customer experiences. Organizations that implemented digital transformation initiatives improved their supply chain processes and

made data-driven decisions. This study identifies that digital transformation facilitates real-time data collection, analysis, and sharing, thereby improving visibility and responsiveness within the supply chain.

The findings of this study yield several practical implications Adoption of Digital Transformation 5.0 Technologies: Industry experts are encouraged to embrace technologies such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and data analytics. The case studies demonstrate that the implementation of these technologies leads to improved customer satisfaction, enhanced collaboration, increased visibility, and better operational performance.

Enhanced collaboration and communication are emphasized as critical elements of successful digital transformations. Industry professionals are advised to promote collaboration among suppliers, clients, and other stakeholders within the supply chain ecosystem. Digital technology in collaborative platforms facilitates the seamless flow of information, coordination of activities, and synchronization, leading to enhanced productivity and adaptability.

Strategic Supplier Appraisal: The literature indicates that enhanced supplier selection, evaluation, and performance tracking facilitated by modern technologies can lead to improved supply chain performance. Industry experts must select and assess suppliers meticulously, taking into account the potential of digital technology to improve these processes.

Real-time data and analytics facilitate informed decision-making. Companies and industrial leaders can now oversee inventory, demand, and logistics in real time. Facilitating early identification of disruptions. Effectively manage risks. Additionally, they should optimize their operations accordingly. The enhanced visibility fosters collaboration and communication among supply chain stakeholders, resulting in improved coordination and expedited problem resolution.

Continuous learning and adaptation are essential for industry experts, given the rapid evolution of digital technology. Organizations can sustain competitiveness and innovation in supply chain management by staying abreast of the latest advancements in artificial intelligence, blockchain, and real-time analytics.

Organizations can improve demand planning accuracy by utilizing these technologies, thereby minimizing stockouts, reducing excess inventory, and optimizing transportation costs. The research conducted by Alice and Khumbulani (2022) indicated that the organization achieved notable enhancements in these domains, resulting in decreased operational costs and increased customer satisfaction.

Furthermore, digital transformation enables the implementation of advanced technologies such as blockchain, which enhances supply chain security, authenticity, and accountability. Businesses can utilize blockchain technology to establish secure transaction archives, verify product authenticity, and trace items throughout the supply chain. This facilitates the prevention of counterfeit goods and ensures legal compliance, while also enabling businesses to enhance consumer loyalty and improve brand recognition.

The practical consequences collectively indicate a deliberate and comprehensive strategy for digital transformation that emphasizes employee engagement, technology adoption, teamwork, and a wider awareness of societal and environmental impacts. These insights assist industry experts in making informed decisions and formulating strategies for optimizing supply chain operations.

This paper presents practical case studies that underscore the importance of digital transformation (5.0) in supply chain optimization. However, several avenues for future research remain that could enhance understanding and uncover new insights. Possible domains for investigation encompass:

Examining the dynamics and interactions between businesses and their suppliers within the framework of digital transformation initiatives. This study indicates that the

performance of the supply chain can be improved through enhanced supplier selection, appraisal, and performance monitoring facilitated by modern technologies.

Analyzing the factors that facilitate or hinder the implementation of effective digital transformation initiatives across diverse industries and sectors. Additional research may investigate the role of organizational culture and leadership in facilitating digital transformation, along with the critical success factors, challenges, and strategies for addressing resistance to change.

Examining the impact of supply chain digital transformation on environmental and societal factors. This study examines the application of digital technology to enhance sustainability, reduce carbon emissions, and ensure ethical practices throughout the supply chain. Focusing on these research areas enhances our understanding of the role and impact of digital transformation on supply chain optimization, revealing new strategies for organizations to achieve a competitive advantage in a dynamic business environment.

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