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The Digitalization of the Supply Chain: A Research Model for the Impact of Advanced Technologies

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Abstract:

The digitalization of the supply chain is a research topic that is attracting increasing interest in the current context of globalization and the growing complexity of logistics operations. The development of digitalization and technological innovations has transformed the traditional supply chain into a Digital Supply Chain (DSC). This new trend needs to be well understood to enable supply chain stakeholders to leverage its competitive advantages. Implementing innovative technological solutions allows companies to better meet market demands and improve their performance. Furthermore, the digitalization of the supply chain can also contribute to enhanced value creation by optimizing processes, reducing costs, improving product quality, and increasing customer satisfaction. Companies that successfully integrate supply chain digitalization into their strategy can thus gain a stronger competitive position in the market. In fact, the digitalization of the supply chain can contribute to both business resilience and better value creation by providing greater visibility, improved efficiency, and increased operational agility. The aim of this paper is to review the literature to analyze the topic of supply chain digitalization and its main tools, as well as to present the theoretical model of our research and the key variables we intend to utilize to study this subject.

Keywords: Digital transformation, digitalization, digital supply chain, technological tools

Introduction:

All industries, including logistics, are currently being impacted by a global trend in technological innovation and digitization. According to Büyüközkan and Göçer (2018), the emergence of digitization has transformed the traditional supply chain into a digital supply chain. This increasingly popular concept in the scientific community needs to be clarified to explain how it affects supply chain stakeholders and how it can be leveraged by companies interested in implementing digital supply chains (DSCs).

This involves an ongoing process aimed at keeping supply networks up-to-date, which can only be achieved by integrating technological advancements into all supply chain management processes. Following this technological revolution, supply chains must adapt to new information and communication technologies as well as operational automation to remain competitive and meet current economic conditions. This complicates supply chain management logistically in terms of growing customer demands, product line expansion, and product offer customization. Additionally, meeting the demands of sustainable development presents a new challenge for digital supply chains. [1]

A review of the literature indicates that digitizing a supply chain has several positive effects on both its performance and sustainability. This paper examines the conceptualization of the digital supply chain, its

technological tools, and their effects on supply chain management in scientific literature. It is structured as follows: first, we provide a set of concepts for the "Digital Supply Chain," then describe all the technologies related to this phenomenon, and finally, explain the effects of adopting these technological tools on the supply chain. We conclude this article with a research model to advance future research directions.

1.1 Digitization:

According to Parviainen et al. (2017), digitization has been identified as one of the major trends affecting society and businesses. The potential benefits of digitization are substantial. For instance, digitizing information-intensive processes can reduce costs by up to 90% and improve execution times by several orders of magnitude. Moreover, automatic data collection from software allows companies to better understand process performance, cost factors, and risk causes. Consequently, digitization refers to the direct conversion of analog information into digital form, using digital technology and digitized information to create and harvest value in new ways (Gobble, 2018). [2]

Sabbagh et al. highlight that digitization offers incremental economic growth, with the most advanced countries in this field gaining 20% more economic benefits than those at the initial stage. Digitization also positively impacts unemployment reduction, quality of life improvement, and citizen access to public services. [3]Furthermore, digitization enables governments to operate with greater transparency and efficiency (Maximizing-the-Impact-of-Digitization, n.d.). It is important to note that digitization has extended to all productive sectors, as studies have shown that digitizing a company positively influences its performance (Albiman & Sulong, 2017; Bouwman, Nikou, Molina-Castillo & de Reuver, 2018; Bruno, Elaine & Ney, 2018; Kumar et al., 2016; Skorupinska & Torrent-Sellens, 2017; Venturini, 2015; Vu, 2011), as noted by Fernández-Portillo et al. (2022). [4]

1.2 Digital Transformation:

The term "digital transformation" (DT) refers to the process by which an organization adapts to environmental changes by using digital technologies such as mobile computing, artificial intelligence, cloud computing, and the Internet of Things (IoT) to change how it creates value (Vial, 2019). Additionally, the term "digital transformation" refers to the process by which a company integrates digital technology into all its operations to improve its performance (Allouche & Zerbib, 2020). In this sense, digital technology has altered the functioning of businesses as well as most sectors. [5]

According to Bygstad and Vrelid (2021), digital transformation is a challenging task that requires reconfiguring organizations, people, and technologies. Similarly, "digital transformation" is defined as "changes in work practices, work functions, and business offerings induced by the use of digital technology within an organization or in the organization's operational environment" (Parviainen et al., 2017). [6] [7] [8]

Digital transformation involves using digital technologies such as social media, mobile devices, analytics, and embedded devices to bring about significant improvements in business areas such as customer experience, streamlining operations, and creating new business models. It is not limited to the simple digitization of existing resources but involves a complete reinvention of processes to create value and revenue from digital assets. Digital transformation is a continuous process that requires constant adaptation to new technologies and market evolutions. Companies that succeed in their digital transformation are those that can innovate quickly, adopt new technologies, and adapt to market changes. [9] [10]

1.3 Supply Chain Transformation:

Agafonova (2020) highlighted that companies and supply chains have undergone significant transformations over the past decades regarding organizational forms, management tools, and technologies. Nowadays, the supply chain consists of a series of siloed stages involving marketing, product development, manufacturing, and distribution before finally reaching the customer. However, thanks to digitization, these silos are abolished, allowing the supply chain to become an integrated and transparent ecosystem for all involved parties (Schrauf & Berttram, 2016). The COVID-19 crisis has confirmed the strategic importance of logistics and SCM, while also highlighting some critical aspects. Moreover, this supply chain [11]transformation faces a multitude of challenges and issues that could make companies more vulnerable and cause disruptions (Büyüközkan & Göçer, 2018). Although this transformation brings new opportunities to companies, it has a considerable impact on supply chain management. [12] [13]

1.4 Digital Supply Chain:

According to Büyüközkan and Göçer (2018), a digital supply chain is primarily based on web capabilities. While many supply chains combine paper and computer processes, a true digital supply chain goes beyond this hybrid model by fully leveraging connectivity, system integration, and the information production capabilities of "smart" components. Due to these advantages, both in practice and in research, the digitization of the supply chain is generating increasing interest. In practice, it seems that more and more companies are now implementing various aspects of digitization, including radio frequency identification (RFID), big data, [14]cloud computing, the Internet of Things, artificial intelligence, and other features to create integrated supply chains that self-optimize and enable proactive responses to the ever-changing nature of markets (Seyedghorban et al., 2020). [15] [16]

Indeed, due to digitization, companies must now rethink how they manage their supply chains. Additionally, technological and digital advancements have enabled companies to conduct more connected operations and maintain open lines of communication with their potential suppliers and customers (Seyedghorban et al.). Kearney and WHU- Otto Beisheim School of Management have developed SC digitization as the best technologies that accelerate and synchronize supply chain processes, including warehousing and transportation systems, radio frequency identification (RFID), advanced order preparation technologies, and cutting-edge order planning systems to quickly resolve issues such as global supply chain gaps. [17] [18] [19]

It is important to note that the digital supply chain has been described as a customer-centric, system-integrated, globally connected, and data-driven intelligent mechanism that relies on new technologies to provide valuable products and more readily available and advantageous services (Bhargava, Ranchal & Othmane, 2013; Büyüközkan & Göçer, 2018; Seyedghorban et al., 2020). The DSC comprises several systems (e.g., software, hardware, and communication networks) that facilitate interactions between organizations dispersed worldwide and coordinate the activities of supply chain partners. These activities include sourcing, production, storage, transportation, and selling of goods (Bhargava et al., 2013). According to Kache and Seuring (2017), digitization offers significant opportunities to improve the supply chain. Indeed, it enables increased information availability and inter-company logistics optimization, as well as enhanced visibility and transparency through real-time access and control of information across the entire chain. It also promotes operational efficiency and maintenance, as well as integration and collaboration among different supply chain actors. Finally, it can foster innovation and product design, as well as more effective inventory management. [20] [21] [22]

1.5 Value Creation:

Value creation can be defined in various ways depending on the authors and literature. Generally, value creation refers to a company's ability to generate profit that exceeds its costs and those of its competitors. Michael Porter, one of the most influential authors on the subject, defines value creation as the difference between the total production cost of a product or service and the perceived value by the customer. According to Porter, value

creation occurs when the perceived value by the customer exceeds the total production cost, enabling the company to generate profit margins above the industry average. Other authors focus on shareholder value creation, which occurs when the company generates returns above investor expectations. This definition emphasizes maximizing profit and creating wealth for shareholders. Others highlight the importance of value creation for stakeholders, including employees, suppliers, customers, shareholders, and the community. In this perspective, value creation is viewed as a holistic approach that considers the economic, social, and environmental impacts of the company. In summary, value creation can be defined as a company's ability to generate profit that exceeds its costs while considering the needs and expectations of its stakeholders. [23] [24] [25]

2. Technologies of the DSC:

This section examines the main digital technologies capable of effectively transforming the traditional supply chain into a digital supply chain (DSC), as mentioned by various scientific researchers. Authors such as Büyüközkan Feyzioğlu and Gocer (2018), Dubey et al. (2020), Frederico et al. (2019), Iddris (2018), Ivanov et al. (2019), Koh et al. (2019), Lohmer et al. (2020), Queiroz et al. (2019b, 2020), and Queiroz and Telles (2018) have primarily cited digital technologies like the Internet of Things (IoT), robotics, cloud computing (CC), blockchain (BC), cyber-physical systems (CPS), big data analytics (BDA), and artificial intelligence (AI). These technologies have been selected for their ability to digitize supply chain processes. Below is a detailed description of these technologies. [26] [27] [28]

2.1 The Internet of Things (IoT):

According to Fortino and Trunfio (2014) and Wortmann and Flüchter (2015), the Internet of Things (IoT) is a network of objects connected to an intranet that can communicate with each other without human intervention. Okano (2017) describes IoT as an internet-based technical infrastructure that enables the exchange of goods and services throughout the global supply chain network. Queiroz et al. (2019a) found that IoT allows a set of objects to communicate with each other without human means. Additionally, scientific literature indicates that IoT connects objects, making them interoperable and able to connect to a database to store object data. Wortmann and Flüchter (2015) highlighted that IoT generates numerous opportunities for businesses, as almost all objects can be connected. Finally, Porter and Heppelmann (2014) concluded that IoT allows connected products to improve their usage, interoperability, and reliability. Furthermore, Büyüközkan Feyzioğlu and Gocer (2018) added that IoT provides complete data access for goods and services throughout their lifecycle (including planning, production, control, and feedback). IoT provides crucial data to the DSC for all supply chain partners, enabling both supplier simplicity and customer notification in case of delivery delays (Kumar et al., 2016). [29] [30] [31] [32] [33]

2.2 Artificial Intelligence (AI):

Artificial Intelligence (AI) is an interdisciplinary research field aimed at creating machines capable of performing tasks that normally require human intelligence, such as speech recognition, natural language understanding, problem-solving, decision-making, and visual perception. AI relies on several techniques, including natural language processing, machine learning, and deep learning, which allow machines to learn from data and adapt to new situations. The ultimate goal of AI is to create machines capable of reasoning, learning, and adapting like a human, but with greater speed and accuracy. AI research has implications in many fields, including medicine, finance, industry, education, and security, and raises debates about the ethical and social implications of creating intelligent machines.

According to Haenlein and Kaplan (2019), AI is defined as a set of "theories and techniques used to create machines capable of simulating intelligence." It involves using computers to model intelligent behavior with

minimal human intervention. In other words, AI indicates that machines learn autonomously and behave similarly to humans (Wamba-Taguimdje et al., 2020). These authors also illustrated AI with technologies such as machine learning, deep learning, chatbots, neural networks, virtual assistants, strong or weak AI, cognitive cybersecurity, natural language processing, virtual reality, and pattern/visual recognition (Wamba-Taguimdje et al., 2020), which allow companies to modify their organizational processes according to their business areas. Di Francescomarino and Maggi (2020), Lee et al. (2018), and Sikdar (2018) emphasized that to fully grasp AI opportunities, especially in information management, it is necessary to transform cultures, mindsets, and skills within firms.

However, Waibel et al. (2017) indicated that continuously developing new computing skills for human resources is a major challenge for companies regarding data science and AI. Queiroz et al. (2019a) stressed the indispensable nature of qualified human resources in implementing the DSC, while Barreto et al. (2017) asserted the need for companies to consider the integration and interaction between human resources and machines. The scientific literature also indicates that AI increases operational efficiency, supports supply chain operations, optimizes processes, and enhances the customer experience.

2.3 Robotization

Robotization is widely used in various manufacturing industries, characterized by its flexibility, autonomy, intelligence, and ability to communicate and cooperate with other systems (Kamble et al., 2018). Robotic systems in the digital supply chain can perform tasks such as picking, packing, and unloading, ensuring a steady supply of parts and products (Hofmann & Rüsch, 2017). Furthermore, management literature suggests that robotic systems are effective in allocating and distributing products across different links in the supply chain.

Robotization involves the development, implementation, and use of robots in industrial and commercial applications to perform tasks traditionally done by humans. Robots are programmable machines capable of executing repetitive or complex tasks with high precision and consistent speed, thereby improving production efficiency and quality. Robotization can be applied in various fields, such as manufacturing, logistics, healthcare, and surveillance. It is often associated with features like flexibility, autonomy, intelligence, and the ability for self-communication and cooperation between systems. [34] [35] [36]

2.4 Blockchain

Blockchain is a technology for storing and transmitting information transparently, securely, and in a decentralized manner. It enables the creation of a digital ledger distributed and shared among multiple users who can verify and validate transactions without needing intermediaries or central authorities.

Blockchain has evolved from its initial use in facilitating Bitcoin transactions to a versatile approach applicable in various domains for dematerializing all types of transactions (DHIBA & Alaoui, 2020). Blockchain is a distributed digital ledger that records transaction data in a network of multiple members, storing these data in blocks chronologically chained together. There are two types of Blockchain: public, where users can remain anonymous and transactions are public and permissionless, and permissioned, where access is controlled by a consortium of members (Wüst & Gervais, 2017). [37] [38]

In the context of the supply chain, Blockchain offers several advantages such as enhanced transparency, secure information sharing, data integrity validation, and providing a solid foundation for smart contracts and automation throughout the supply chain. It also improves agility, responsiveness, and disintermediation, reducing costs and increasing process efficiency for businesses. Blockchain allows real-time sharing of supply

chain data among various partners, ensuring high transparency and facilitating the use of resources and services between suppliers and customers in virtual markets (Queiroz et al., 2019b; Culot et al., 2019).

2.5 Cloud Computing (CC)

Cloud Computing is a model for delivering computing services that provides access to shared resources such as servers, applications, data, and storage via the Internet or a private network. Users can access these resources on-demand and pay only for what they use, rather than owning and managing their own IT infrastructure. Cloud Computing offers significant flexibility, scalability, and increased efficiency for businesses and individuals.

According to Armbrust et al. (2010), Cloud Computing encompasses hardware and software associated with data that enable access to resources such as services, applications, and storage via Internet servers. Mell and Grance (2011) highlight that Cloud Computing facilitates information sharing between different systems and computers through these servers.

Morabito (2014) divides Cloud Computing into three levels: Software as a Service (SaaS), which includes applications and programs provided over the network; Platform as a Service (PaaS), which provides a platform for developing and managing applications without the need to build underlying infrastructure; and Infrastructure as a Service (IaaS), which offers resources such as virtual servers, memory, and storage. Additionally, Cloud Computing is a service outsourcing program associated with a data management system that enables managing data transactions generated by products and services (Vazquez-Martinez et al., 2018).

Cloud Computing also plays a crucial role in synchronizing supply chain management with technologies and information systems within companies, contributing to scalability, cost reduction, accessibility, and operational efficiency (Iddris, 2018). It enables remote control of the entire network (Porter & Heppelmann, 2014) and enhances cost optimization (Korpela et al., 2017).

2.6 Cybersecurity Systems (SCS)

Cybersecurity systems are digital systems that ensure the control of physical processes through feedback loops, enabling real-time synchronization of information and physical flows. These systems include network infrastructures with embedded devices such as sensors, allowing self-management of physical processes and their feedback. Characterized by the integration of physical and digital components, these systems are used to protect industrial systems, critical infrastructures, telecommunications networks, and other complex systems against cyberattacks. Cybersecurity is a major concern for governments, businesses, and organizations worldwide, given the growing risks associated with cyberattacks and potential disruptions to related physical processes.

According to Helu et al. (2017), cybersecurity systems also facilitate the collection, transmission, and sharing of data and information throughout the product lifecycle in a fast, reliable, and secure manner. Jansen (2016) noted that tasks related to cybersecurity systems are performed by objects, intelligent machines, interface tools, sensors, and integrated communication devices such as Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP), and Customer Relationship Management (CRM), which are examples of cybersecurity systems. These systems ensure the control and monitoring of operations and information exchange.

In the context of the Digital Supply Chain (DSC), literature highlights that cybersecurity systems must align with other technologies such as the Internet of Things (IoT) and Cloud Computing (CC) to achieve high production levels by enhancing security and sharing information across supply chain networks.

2.7 Big Data

Big Data refers to the massive sets of structured or unstructured data generated and stored in organizational information systems. Analyzing and exploiting this data can offer competitive advantages to businesses, enabling them to make informed decisions and better understand their environment. Big Data Analytics (BDA) refers to advanced data analysis techniques and tools used to extract actionable insights from these massive data sets. These techniques can include statistical methods, machine learning algorithms, artificial intelligence, natural language processing, and more.

Data can come from various sources such as social networks, sensors, transactional systems, mobile devices, IoT devices, and other sources. Data analysis helps identify trends, patterns, correlations, and relationships that may not be evident through manual analysis.

However, the use of Big Data and BDA also raises important issues regarding privacy, security, and ethics. Organizations must be aware of the potential risks associated with data collection and use, and implement appropriate practices and policies to protect data and respect user privacy. According to Morabito (2014), Queiroz and Telles (2018), and Wamba et al. (2017), Big Data analytics follows a 5V approach, considering the volume, velocity, variety, veracity, and value of data. In an increasingly digital environment, companies are increasingly aware of the importance of analyzing massive data sets to make real-time informed decisions (Lee et al., 2017). BDA solutions enable the collection and analysis of data from diverse sources, facilitating decision-making based on analysis results (Bahrin et al., 2016). According to Tan et al. (2015), Big Data analytics can significantly impact the supply chain by reducing order-to-delivery times, improving customer relationships, and increasing the efficiency and competitiveness of the logistics chain.

Authors such as Akter et al. (2016), Dubey et al. (2020), and Wamba et al. (2017) have highlighted the positive impact of BDA solutions on business performance. These solutions enable the collection of large quantities of data from various sources, such as videos and social networks. However, several challenges must be addressed to fully benefit from these tools (Kamble et al., 2018). Challenges include data quality, qualified data analysis capabilities, consistency, and privacy for complex and long supply chains. For companies, the challenge lies in collecting and analyzing all the data produced by supply chains in real-time to remain competitive. Developing effective data analysis capabilities and implementing quality protocols to ensure the relevance and reliability of the data used in decision-making is crucial.

3. Impact of Information Technologies on the Supply Chain

The adoption of technologies in the field of logistics has significantly changed how companies manage their operations and logistics processes. The emergence of the Digital Supply Chain, or Supply Chain 4.0, offers new opportunities for companies seeking to improve operational efficiency and meet changing consumer needs. Technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, and Augmented Reality are used in Supply Chain 4.0 to automate processes, optimize resource use, and improve supply chain visibility. Implementing these technologies allows companies to reduce costs, improve product quality, increase productivity, and shorten delivery times.

However, adopting Supply Chain 4.0 also poses significant challenges for companies. Implementing new technologies often requires substantial investments and training new employees to manage new processes. Additionally, data security becomes a major concern with the increased amount of data exchanged between different supply chain actors. Finally, Supply Chain 4.0 also impacts inter-company relationships and collaboration within the supply chain. Smart technologies facilitate communication and collaboration among various stakeholders but can also create tensions when it comes to sharing data and defining responsibilities among different supply chain actors.

According to Maier et al. (2011), the Digital Supply Chain (DSC) offers several advantages, such as cost reduction and service efficiency improvement, and creates value for various supply chain stakeholders, including businesses, suppliers, employees, and customers. The DSC also provides better efficiency in information sharing, bringing new value to supply chain actors in decision-making, visibility, and forecasting. In summary, the DSC provides the right information to the right people at the right time, which is key to improving supply chain efficiency and profitability.

In conclusion, adopting Supply Chain 4.0 offers new opportunities for companies but requires rigorous management to overcome challenges related to implementing new technologies and organizational changes. Implementing the DSC has several positive impacts on the supply chain. According to Gunasekaran et al. (2017), the DSC integrates physical.

Research Level	Independent Variables	Dependent Variables
Level (1): The impact of the digital supply chain on logistics resources (Transparency and traceability, Speed and precision, Agility and resilience)	Digital supply chain: - Artificial intelligence in supply chain - Big data in supply chain	- Transparency and traceability - Speed and precision - Agility and resilience
Level (2): The impact of the human and organizational environmental context on the relationship between the digital supply chain and logistics resources	- Macro and micro supply chain - Human capital - Collaboration and connectivity	Digital supply chain Logistics resources
Level (3): The role of logistics resources in the value creation process	- Transparency and traceability - Speed and precision - Agility and resilience	- Improvement of perceived value by customers - Improvement of customer value of the company (customer capital)

- Hypothesis 1

The impact of the digital supply chain on logistics resources (Transparency and traceability, Speed and precision, Agility and resilience).

- Hypothesis 2

The impact of the human and organizational environmental context on the relationship between the digital supply chain and logistics resources.

- Hypothesis 3

The role of logistics resources in the value creation process.

These hypotheses cover three levels of analysis: the direct impact of digitalizing the supply chain, the influence of the human and organizational context, and the role of logistics resources in creating value for customers and the company.

Conclusion

This paper addresses Supply Chain 4.0 and delves into the concepts of the Digital Supply Chain, along with the various technologies associated with this significant digital transformation. Supply Chain 4.0 represents a paradigm shift in the way supply chains operate, leveraging advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, blockchain, and robotics to create more efficient, responsive, and transparent supply chains.

Current research on this topic primarily consists of conceptual articles, reflecting the novelty of the subject and the still limited adoption of these advanced digital technologies within businesses. Many companies are in the early stages of exploring and implementing these technologies, which means that empirical data on their impacts is not yet widely available. As a result, much of the existing literature focuses on defining concepts, identifying potential benefits, and outlining the challenges and opportunities associated with digital supply chains.

Future research challenges in Supply Chain 4.0 involve moving beyond these conceptual discussions to conduct empirical studies. Such studies are essential to explain the concrete impacts of technological tools on various aspects of supply chain performance. This includes examining how digital technologies can enhance the agility, resilience, and visibility of supply chains, which are critical factors in responding to market changes and disruptions. Additionally, there is a need to develop robust theoretical conceptual models that can guide empirical research. These models would help in systematically studying the effects of digital transformation on supply chains and provide a framework for analyzing the complex interactions between different technologies and supply chain processes.

Empirical research in this area could involve case studies of companies that have successfully implemented Supply Chain 4.0 technologies, quantitative analyses of performance metrics before and after digital transformation, and comparative studies across industries or regions. Such research would provide valuable insights into best practices, potential pitfalls, and the overall effectiveness of different technological interventions.

Moreover, exploring the human and organizational dimensions of Supply Chain 4.0 is crucial. This includes understanding the skills and competencies required for managing digital supply chains, the impact of digital transformation on workforce dynamics, and the change management processes necessary to facilitate successful adoption of new technologies.

In conclusion, while the current body of research on Supply Chain 4.0 provides a solid conceptual foundation, there is a significant need for empirical studies and theoretical models to advance our understanding of this field. By addressing these research challenges, scholars and practitioners can better comprehend the full potential of digital technologies in transforming supply chains and driving business performance.

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