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The Evolution of Digitalization Transformation and Industry 4.0 in Supply Chain Management: A Systematic Literature Review †

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Abstract: The digital revolution is rapidly reshaping supply chains, driven by the confluence of Industry 4.0 and digitalization transformations. This research aims to investigate the evolution of the digitalization transformation era by integrating machine learning and big data management into supply chain management (SCM). A systematic literature review and mapping study were conducted, analyzing 223 articles from the Scopus database and 60 from Web of Science, selected through a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) screening process and the Population, Exposure, and Outcome (PEO) framework. This study provides a narrative summary of the evolution of decision-making and consultation processes, recommendation approaches, and guidelines for enterprises to achieve sustainability in their supply chain management. It also identifies potential areas for future research in navigating the world of digitized supply chains.

Keywords: supply chain management; Industry 4.0; digitalization; transformation

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1. Introduction

A significant wave of digitalization is currently permeating industries worldwide. Organizations strive to gain a competitive advantage through their products and services and by developing a digital environment to achieve higher levels of mobility and sustainability. Concurrently, scholars and researchers are deeply exploring the topic of digitalization, delving into this expansive research area. Regarding the general research context, practitioners and scholars emphasize the benefits of implementing Industry 4.0 (I4.0) technology, which are frequently highlighted in the current literature on Industry 4.0 technologies [1]. Several Industry 4.0 technologies embedded in SCM include five key digital technologies: cloud services, artificial intelligence (AI), big data analytics (BDA), blockchain technology, and the Internet of Things (IoT) [2]. These technologies have been implemented for demand management, transportation and delivery, and inventory management [3]. Digitalization entails data collection, generation, and analysis processes to generate value and foster innovation [4]. A good example of "digitalization" is the CAB2IN framework, which stands for five emerging digital technologies: cloud services (C), artificial intelligence (A), big data analytics (B), blockchain technology (B), and the Internet of Things (IN). This research article examines the development of digitalization transformation, the integration of Industry 4.0 in supply chain management, and the implementation of these technologies by enterprises for supply chain operations.

Research Questions:

- RQ1. How has the digitalization transformation developed?
- RQ2. How do enterprises adopt digitalization and Industry 4.0 methods to transform their SCM?
- RQ3. What are the potential research directions in this area?

Regarding the general background of enterprises and industries, managers from large manufacturers and small–medium enterprises (SMEs) are seeking to understand digitalization. SME managers will find managerial implications particularly interesting, as these insights can help them tackle collaboration concerns and enhance their readiness for Industry 4.0, thereby aiding decision-making and policy-making in the supply chain [5]. For larger firms, identifying the limitations of the current supply chain system, adhering to a digital roadmap with the help of digital enablers, and maintaining an agile, flexible, and long-term supply chain management strategy are some of the primary guidelines for pharmaceutical supply chain managers [6]. Additionally, digitalized mobility significantly contributes to business models in the global value chain, impacting long-term sustainable logistics and supply chain operations, especially in the automotive marketplace. The evolution of digitalization transformation in supply chain management is crucial for sustainable mobility as advanced technologies like IoT, AI, and big data analytics are integrated. These technologies enhance the visibility, efficiency, and responsiveness of supply chains. They enable real-time tracking, predictive maintenance, and optimized logistics, reducing waste and emissions. By improving the efficiency of resource use and transportation processes, digitalization and Industry 4.0 significantly contribute to sustainable mobility and overall environmental sustainability in supply chain operations [7]. This paper will conduct a systematic literature review (SLR) in several sections. This research study's conceptual framework is presented in Section 2. Mapping and statistical studies are conducted in Section 3. The relevant literature is reviewed in Section 4, addressing parts of the RQs. Section 5 will conclude the paper and provide insights or future directions for fellow researchers.

2. Materials and Methods

In this article, an SLR process is carried out on the evolution of digitalization in supply chain management. The research design and steps followed by the researchers throughout this paper include defining research questions (RQs), defining the conceptual framework, developing a search strategy, crafting and combining keywords, collecting data points and critically screening them, conducting a full-text review, writing the literature review, and completing the structured report.

An SLR was applied to answer the RQs using two credible databases, SCOPUS and Web of Science (WoS), with articles written in English. A total of 284 articles were selected and used for the research. The PRISMA method was used for literature screening, with keyword selection guided by the PEO framework—a search strategy designed using the Population, Exposure, and Outcome frames as a basis [8].

Population (P) refers to the specific group of individuals/subjects that the research is interested in. Exposure (E) refers to the factors that the population is exposed to. This could be something that the population experiences, like environmental factors or optimization processes, or it could be introduced by the researcher, such as a new platform or technology. Outcome (O) refers to the result or consequence of the exposure of the population. The outcome could be positive, negative, or neutral. It is important to define the outcome clearly so that it can be measured or presented precisely.

As seen in Table 1, these eight keywords perform comprehensively in the search engines of both databases when combined using Boolean connectors. Inclusion and exclusion criteria are formulated later.

Table 1. Keywords developed based on the PEO framework.

Population	Exposure	Outcome
Supply Chain Management Supply Chain	Digitalization Industry 4.0	Recommendation Evolution Consultation Decision Making

3. Results

After the final keyword selection using the PEO framework, the next stage involves searching the databases for quality and relevant papers. Boolean expressions, which combine multiple Boolean values and logical operators (AND, OR, brackets), are used in this process. Both Scopus and WoS generated a substantial number of articles—786 and 587, respectively—during the initial search with the following keyword combination: ("Supply chain management" OR "Supply Chain") AND ("Digitalization" OR "Industry 4.0") AND ("Recommendation" OR "Evolution" OR "Decision making" OR "Consultation"). This combination represents all the keywords in the paper's PEO framework, as shown in Table 2.

Table 2. Number of article selections after three initial searches.

	Scopus	Web of Science
Initial Articles	786	587
Subject Areas (Computer Science, Business, Management, and Accounting; Decision Science, Economics, Econometrics, and Finance)	600	326
Open Access	234	120
Publication Year (2017–2024) and Language	233	119
Removal of Duplication Articles	233	51
Final Paper to Review	284	

Ultimately, the PRISMA method yielded a final result of 49 papers to be reviewed in Figure 1.

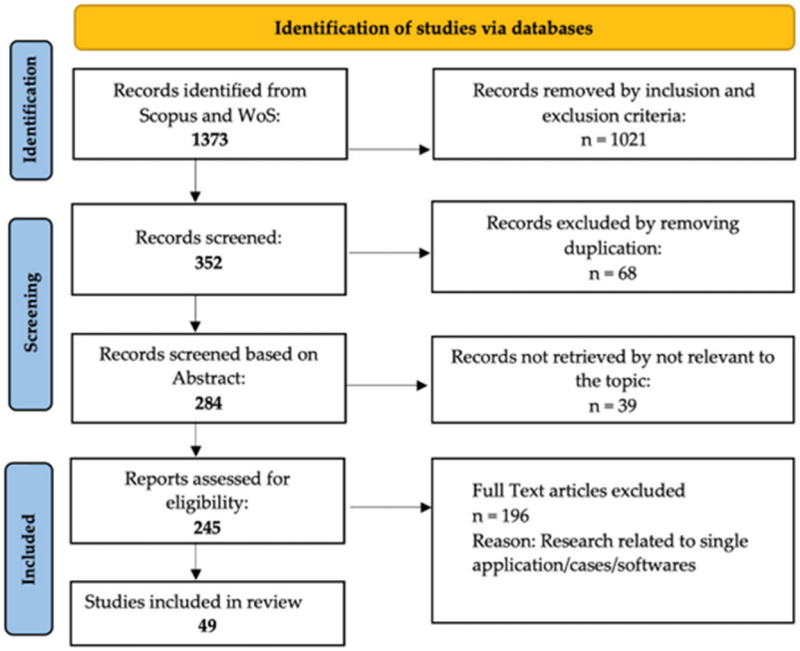

Figure 1. Systematic literature review based on PRISMA method.

As shown in Figure 2, the number of articles published in Scopus has steadily increased from 2017 to 2023. In contrast, the number of articles published in WoS fluctuated, and these articles only started being published in 2019, two years later than Scopus.

To validate the quality of papers from the database used for the SLR, the authors used the SCImago Journal & Country Rank (SJR) which is a publicly available portal for examining journals and assessing scientific domains with sets of indicators. In this case, the H-index (number of citations in each paper) and quartile scores (impacted level) will select two indicators for analyzing the source title of articles' creditability and quality [9].

There is a positive quality of papers, in Q1, as 66 out of 150 sources were consolidated from 284 articles. Along with that is the high H-index, reaching an average of 103 citations per article.

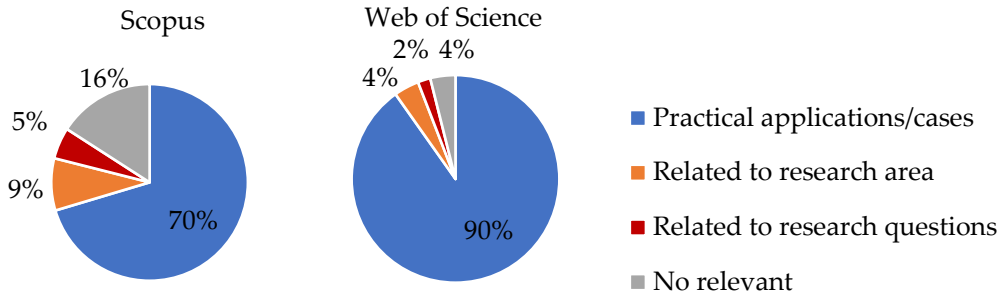

Figure 2. Article category after critically appraising the title and abstract.

4. Discussion

A narrative summary was conducted to evaluate and synthesize the existing research on this topic. According to the detailed analysis of 284 papers, the studies from the literature can be divided into four categories, as shown in Figure 2.

The blue sector occupies by far the largest proportion of the articles. Starting in 2017, scholars began researching the integration of supply chains with advanced technologies, exploring niche areas such as smart shipping, Logistics 4.0, and automatic guided vehicles (AGVs) [10]. Moving on to 2018, the emergence of technologies continued to spread across different parts of the supply chain, with complex proposals involving barcodes, QR codes, and the Internet of Things (IoT) for food supply traceability [11]. By 2019 and 2020, the number of papers exploring a wide range of technology enablers had increased, focusing on common industries such as healthcare, food chains, and agriculture, driven by the impact of the COVID-19 pandemic on manufacturers transitioning to a digitalized world [12]. From 2022 to the present, Chavez [13] discussed the importance of the data-driven decision-making (DDDM) model, highlighting that while all businesses recognize the potential of data utilization for sustainability purposes, sustainable development in mobility has reached a more complex level of digitalization. In 2024, the focus is on business models that incorporate data collection, management, and interconnection, with the expectation that mobility models can evolve and be applied to any value chain [7]. The orange sector explores the expected results from the supply chain management exposures.

Evolution: Most methodologies, such as MCDM, DEMATEL, and BWS, are examined in this topic to evaluate digital tools or data processing for transformation. The authors of [14] explored the most important strategies and criteria, calculated the criteria weights, and ranked the alternatives, ultimately developing a comprehensive framework for digital transformation in the supply chain. Recommendation: The authors of [15] probed the key influence factor for reconfiguring the supply chain design by the emergence of a digital environment along with mitigating risk level. As many enterprises struggle to enter this digital environment to enhance their supply chain network's efficiency and responsiveness, this recommended reconfiguring model expands new approach realms for them. One paper [16] questioned the challenge of selecting the finest strategy for the supply chain digital transformation for an organization and later using the multi-attribute decision-making model (MADM) procedure to assess the strategy. Consultation and Decision-Making: The journals tend to combine data science and decision science in any model or system on this topic. Reis and Saraiva contributed to the research world with their conceptual framework on data-driven process systems engineering and process analytics, which supports a robust decision-making workflow [14].

The red sector has the smallest occupation of articles in Scopus and WoS. Nevertheless, these papers are of the highest quality and are closest to the author's research aim, fulfilling the RQs. The author categorized them into three colors corresponding to three research

areas: blue for practical applications, orange for demonstrating the expected outcomes (O) in the PEO framework, and red for directly answering the RQs.

5. Conclusions

In conclusion, using the PRISMA method, the present research paper has thoroughly demonstrated its findings through an SLR of 284 articles from Scopus and WoS sources. The PEO framework, along with Boolean connectors, was applied to aid in precise keyword selection and organization, enhancing the effectiveness of the database search. After applying predefined inclusion and exclusion criteria, a detailed analysis of 245 relevant and qualified articles was conducted to address three RQs. RQ1 is addressed by the increasing number of articles on the topic and the evolution of keywords throughout the research period from 2017 to 2024. Additionally, the literature review provides an overview of the transformation in the development of advanced technologies used in practical applications and cases. Regarding RQ2, the success of organizations entering the digital world can be seen in cases where firms have invested in and benefited from key digital tools and big data for decision-making models. However, selecting the optimal transformation strategy remains a significant challenge for organizations integrating these technologies into their business. In the case of RQ3, the future research direction section proposes addressing the limitations of this paper by following two conceivable paths: collecting secondary data and examining the flow from a self-proposed model. However, the author perceived that the evolution has not reached its comprehensiveness and excursively presented in different applications and different industries since these populations coming from the researched firms/industries pursued the terms "digitalization transformation" and "Industry 4.0" in many segmentations for their SCM. Thus, the future research direction could be delineated in the following two commands: data collection for empirical viewpoints and process examination for an author's suggested process. The former approach is achieved by conducting a deep analysis from organizations' points of view, which can be retrieved from surveys or the interview responses of managers. The latter tests the feasibility of a model that could be adopted in the digital world. In summary, this SLR emphasizes the development of digitalization transformation and Industry 4.0 in supply chain management. By embracing this evolution, organizations can position themselves at the forefront of the digital era and drive sustainable growth in the ever-changing supply chain market. Fellow scholars can utilize this paper to analyze this revolutionary era in various contexts.

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