

Supply Chain Management 4.0 Research Area Maturity: A Systematic Literature Review

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Abstract

Driven by the Fourth Industrial Revolution, organizations are increasingly striving to gain competitive advantages through the adoption of information and communication technologies. Among the various organizational domains affected by this transformation, the supply chain stands out as one of the most critical in highly competitive environments. Consequently, both academic and industrial researchers have consistently devoted considerable attention to the study of supply chains.

With the advent of Industry 4.0 technologies, a new paradigm known as Supply Chain Management 4.0 has emerged. In response to the growing prominence of this concept, the present study aims to review existing experiences and scholarly research related to Supply Chain Management 4.0. To achieve this objective, a bibliometric analysis was conducted to assess the maturity of research in this field and to identify opportunities for future investigation. The literature was systematically reviewed using the Systematic Literature Review approach. Articles published between 2011 and 2025 were retrieved from nine online databases, resulting in a final selection of 157 articles for bibliometric analysis.

The findings of the bibliometric study—highlighting a dispersed group of contributing authors, a limited number of dedicated journals, weak author collaboration networks, frequent use of exploratory research methods, and a narrow focus on specific keywords—suggest that Supply Chain Management 4.0 remains in the early maturity stages of research area.

Keywords: Supply chain management; Industry 4.0; Digital supply chain; Digital transformation; Smart supply chain; Research area; Maturity.

1. Introduction

Since 2011, when one of the earliest definitions of Industry 4.0 (I4.0) - “a comprehensive transformation of the entire industrial production sector through the integration of digital technologies and the internet with conventional industry”

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- was introduced by German Chancellor Angela Merkel at the Hannover Messe industrial fair, the concept has garnered significant attention from both industrial and academic communities. I4.0 represents the Fourth Industrial Revolution, characterized by the integration of advanced technologies into manufacturing processes.

A key feature of I4.0 is its suite of autonomous capabilities, including self-configuration, self-regulation, and self-optimization, enabling more agile and cost-efficient operations. Moreover, enhanced customer satisfaction is achieved through smart and connected products that enable new data-driven and value-added services (Asdecker & Felch, 2018).

Mohammad (2018) compiled several definitions of I4.0 proposed by various scholars. According to these definitions, I4.0 emphasizes the utilization of intelligent technologies and cyber-physical systems to foster integration, transparency, precision, agility, and real-time decision-making across the entire value chain. Pessot et al. (2023) argue that I4.0 is fundamentally based on automation, communication, and enhanced data exchange—facilitated by digital technologies that connect physical devices, smart machines, and human resources within the factory and across the entire value chain.

Today, the I4.0 paradigm is applied across diverse domains, giving rise to emerging research areas such as Pharma 4.0, HR 4.0, Construction 4.0, Health 4.0, and Supply Chain Management 4.0. These subfields reflect the incorporation of I4.0 technologies into various aspects of business operations.

Among these domains, supply chains have been particularly transformed by the advent of I4.0 technologies. The design and performance of supply chains are undergoing significant changes, ushering in a new developmental stage referred to as Supply Chain Management 4.0 (SCM 4.0).

In the literature, various terms have been used to refer to SCM 4.0, including “smart supply chain,” “supply chain 4.0,” and “digital supply chain.” This study uses the term SCM 4.0. Different definitions of SCM 4.0 have been proposed, for example, Frazzon (2019) defines it as “the integration and synchronization of the product’s entire value chain across different companies, using smart technologies (IoT, IoS, CPS and others) to build an interconnected and transparent system with real-time communication that can manage flows and optimize itself, leading to an autonomous, adaptive, intelligent, agile, and dynamic network that focuses on customers’ requirements.” Similarly, Seyed Ghorban et al. (2019) refer to it as “an intelligent, customer-centric, system-integrated, globally connected, and data-driven mechanism that leverages new technologies to deliver valuable products and services that are more accessible and affordable”. Wu et al. (2016), summarized six characteristics for smart supply chains as Automated, Instrumented, Integrated, Interconnected, Intelligent, and Innovative (known as A5I). Although numerous definitions exist, a universally accepted definition of SCM 4.0 has yet to be established (Chauhan & Singh, 2019). However, it is evident that SCM 4.0 capabilities are rooted in the broader paradigm of I4.0.

SCM 4.0 involves reconfiguring supply chain activities, including design and planning, production, distribution, consumption, and reverse logistics, through the application of I4.0 technologies. Twenty-first-century innovations such as automation, big data, and artificial intelligence are increasingly implemented by companies—especially those in high-income countries with advanced supply chain practices (Tiwari & Shringi, 2021).

The modern business landscape is shaped by volatile demand, growing customer expectations, the need for high quality and reliability, faster delivery, and greater product customization. These dynamics create an uncertain and unpredictable environment for manufacturing companies. Consequently, supply chain managers constantly seek innovative solutions to meet these challenges (Zhao et al., 2020). The competitive pressures of today’s business environment, coupled with rapidly evolving customer needs, underscore the necessity for flexibility and responsiveness—prompting a growing reliance on advanced technological innovations (Fatorchian & Kazemi, 2020).

Technological innovation has thus become a strategic weapon and competitive advantage in today’s marketplace (Frederico et al., 2020). Through SCM 4.0, a variety of methods have emerged to enhance traditional supply chain processes in terms of cost efficiency, agility, reliability, and transparency. Accordingly, modern supply chain managers must go beyond cost reduction to enable deeper operational insight, faster strategic innovation, stronger customer relationships, and the integration of digital technologies into daily operations (Attaran, 2020).

Evidence shows that research on SCM 4.0 is rapidly expanding, with growing interest among scholars. Therefore, a detailed and comprehensive study of this research area’s maturity is essential to identify gaps and opportunities for further investigation. The systematic literature review (SLR) approach has been identified as an appropriate method

for conducting such a study (Rabieh et al., 2023). To assess the maturity of the SCM 4.0 research domain and guide data analysis, this study adopts the framework developed by Oladimeji et al. (2020). The results offer insights into the evolution of the research area and help identify opportunities for academic researchers and industry practitioners.

In recent years, literature review studies have been conducted to explore trends in SCM 4.0, including those by Zekhnini et al. (2021), Ben-Taher and Raja (2022), De Oliveira et al. (2022), Shah et al. (2023), and Buthi (2023). Although these studies have reviewed SCM 4.0 literature, none has conducted a rigorous and comprehensive systematic literature review to thoroughly assess the maturity and research trends in this area. To fill this gap, the present study employs the SLR method to search nine academic databases and extract relevant publications. To achieve the objectives of this study and guide the research process, the following research questions were initially defined:

- How has the literature related to SCM 4.0 evolved over time?
- What is the current state of the SCM 4.0 research area?
- What are the key areas for future work that need to be considered for maturity development from the perspective of authorship characteristics (collaborative author networks), research design, publication characteristics, content features, and the impact of this research area?

The data Obtained from SLR, are analyzed using bibliometric techniques to identify key trends, gaps, and future research opportunities within the SCM 4.0 field, covering the period from 2011 to 2025. The study evaluates the research field from multiple perspectives, including authorship patterns and methodological approaches, to assess the area's development and propose strategies for further advancement. The next section outlines the research methodology, including the scope of the study, search strategy, and exclusion criteria. Section 3 presents the bibliometric analysis results. Section 4 evaluates the maturity of the research domain using the selected framework. Section 5 discusses managerial implications derived from the findings, while Section 6 concludes the paper by summarizing the study, highlighting its limitations, and offering directions for future research.

2. Research methodology

The present study attempts to provide further understanding of the research area maturity based on a systematic literature review and bibliographic analysis. In recent years, many disciplines have begun to adopt more systematic and standardized approaches to evaluate the impact and development of a research area with a stronger emphasis on quantitative techniques. In particular, identifying and analyzing the published literature have become important exercises for many disciplines and methods such as systematic literature review and bibliometric analysis have become more regularly used to obtain a deeper understanding of a research area (Herring et al., 2016).

The method used for conducting the SLR in this research, to cover a wide range of articles in the field of SCM 4.0, is a framework adapted from the studies by Transfield (2003), Oladimeji et al. (2020), and Rabieh et al. (2023). This method enables a structured, evidence-based review of the literature using predefined search strategies and selection criteria to gather, evaluate, and synthesize relevant studies. The SLR process not only reduces bias but also improves the quality and reliability of insights obtained.

Recent trends in research synthesis techniques have led to more systematic, repeatable approaches to literature reviews, including the broader use of analysis methods such as bibliometric analysis (Herring et al., 2016). Thus, bibliometric analysis—applied to the data extracted from the SLR—can support the assessment of the research area's maturity and provide a quantitative evaluation of key trends and developments. One concept that is of particular interest is the maturity, or level of development, of a research area. However, the literature review shows that the maturity of the SCM 4.0 research area has not been examined in any article so far. Table 1 shows a comparison of existing bibliographic research conducted based on six criteria.

Table 1. Comparison of Bibliographic Studies

Research	Article features						
	Publication	Industry	Authorship	Methodology	Content	Impact	Research area Maturity
Hariharasudan et al. (2021)	×		×			×	
Younis,Wuni (2023)	×		×			×	
Abdirad & Krishnan (2022)				×			
Zekhnini et al. (2020)	×		×				
Seyedghorban et al. (2019)	×		×		×		
Tiwari (2020)	×		×	×			
Frazzon et al. (2019)	×						
Barata (2022)	×		×				
shah et al. (2023)	×		×		×	×	
Current research	×	×	×	×	×	×	×

The research methodology comprises several key steps: defining the scope of the review, formulating search strategies, applying exclusion criteria, and, ultimately, collecting the relevant data. These methodological stages are elaborated upon in Sections 2.1 through 2.4.

2.1 Research scope

To delineate the scope and objectives of this study, a preliminary set of scholarly articles was identified through a systematic yet limited sampling of relevant literature within the research domain. The initial search employed the key terms “Supply Chain 4.0” and “Supply Chain Management 4.0” to capture foundational works. To mitigate the risk of omitting pertinent studies, the search was conducted across nine academic databases (see Section 2.2 for details).

The temporal scope of the review was restricted to publications between 2011 and 2025, a selection justified by the formal inception of Industry 4.0 in 2011. Given this technological paradigm shift, it is reasonable to assume that scholarly discourse on SCM 4.0 would predominantly emerge post-2011.

The preliminary corpus—comprising seminal works by Khan et al. (2022), Ming et al. (2023), Frazzon and Rodriguez (2019), Ben-Taher and Raja (2022), Zekhnini et al. (2020, 2022), Weerabahu et al. (2022), Nahida et al. (2022), Govindan et al. (2022), Marinaji et al. (2023), and Frederico et al. (2020)—primarily addressed the themes: Systematic literature reviews on SCM 4.0, The integration of Industry 4.0 technologies (e.g., IoT, AI, blockchain) into supply chains, Maturity models and frameworks for SCM 4.0 adoption, Implementation strategies and operational challenges, Risk assessment in digitalized supply networks, Barriers and enablers of technological adoption.

Based on the insights derived from this preliminary review, the subsequent search strategy was refined to prioritize articles that explicitly address conceptual frameworks, theoretical foundations, and empirical validations of SCM 4.0.

2.2 Search strategy

The articles identified during the scoping study were carefully analyzed to develop a robust search strategy. This preliminary analysis examined several critical aspects including the keywords employed in relevant literature, author affiliations and disciplinary backgrounds, publication sources, and key reference patterns. These insights proved invaluable for determining the most appropriate search terms and strategies, particularly regarding which article sections to prioritize during searches - whether titles and abstracts alone or full-text content.

For comprehensive coverage of the literature, nine major academic databases were selected: Scopus, Web of Science, EBSCO, ProQuest, Emerald Journals, IEEE Xplore, Google Scholar, Science Direct, and Springer Link. Across all platforms, the search phrase incorporated a carefully constructed combination of keywords and Boolean operators:

("SCM 4.0" OR "Supply Chain 4.0" OR "Supply Chain Management 4.0" OR "Smart Supply Chain" OR "Digital Supply Chain" OR "Intelligent Supply Chain" OR ("Industry 4.0" AND "Supply Chain")).

Recognizing the unique search algorithms and indexing methodologies of each database, we adapted our search terms and syntax accordingly to ensure optimal retrieval accuracy for each platform. This database-specific customization was crucial for maintaining search consistency across diverse digital repositories.

To maximize the breadth of identified literature, the search protocol applied only one substantive restriction - a publication date from 2011 to 2025. This temporal limitation aligns with the emergence of Industry 4.0 concepts in academic discourse. Importantly, no other filters were applied regarding document type or subject scope, ensuring our results would capture the full spectrum of relevant scholarly work without artificial constraints. This inclusive approach was designed to yield the most comprehensive dataset possible for subsequent analysis while maintaining rigorous methodological standards.

2.3 Article extraction criteria

After defining the search strategy and selecting the keyword basket, a comprehensive search was conducted across the selected databases. In each database, articles were screened based on the presence of the predefined keywords in their titles. Duplicate records—those retrieved from multiple databases—were identified and removed. Following de-duplication, an initial screening was performed by reviewing article abstracts to assess their relevance to the research scope. In the final selection phase, non-English articles, articles lacking full-text access, and those unrelated to the research topic were excluded. As a result, a final set of 157 relevant articles was identified. A summary of the systematic literature review (SLR) process employed in this study is presented in Figure 2:

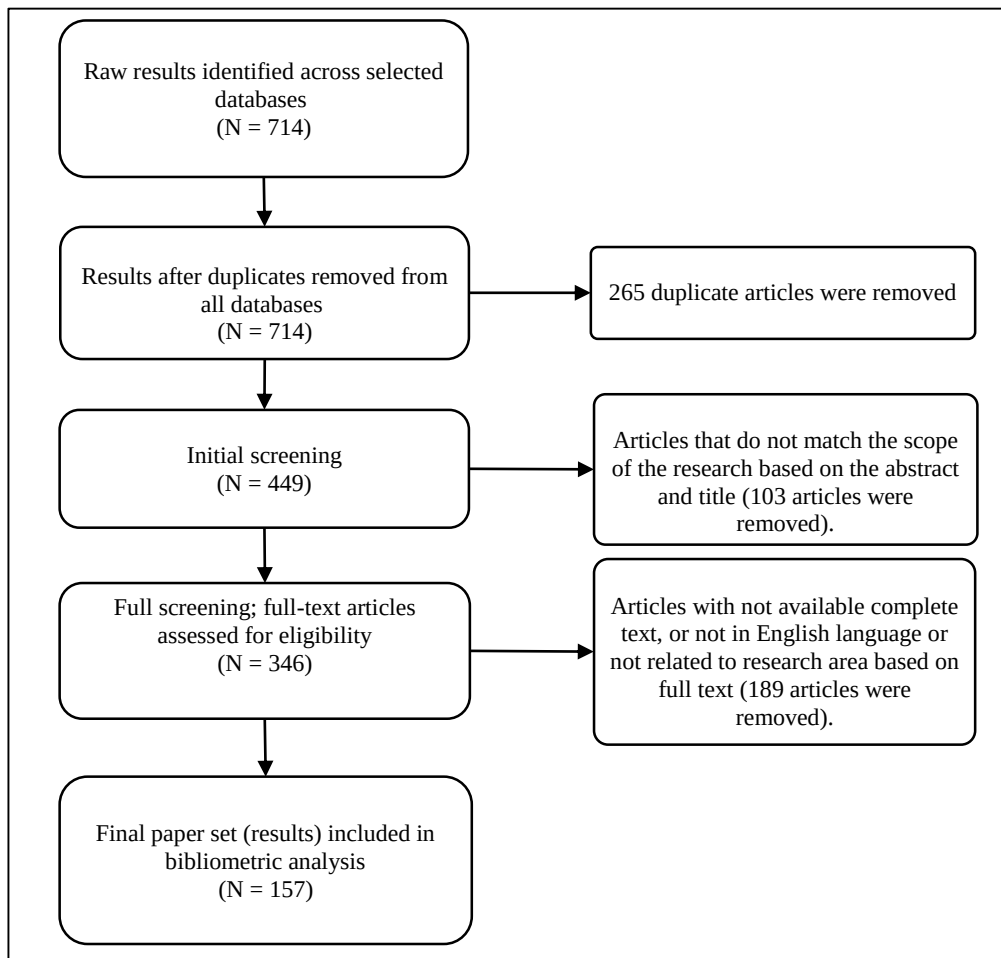


Figure 1. Flow of information for a systematic review (Rabieh et al.,2023)

2-4. Data extraction

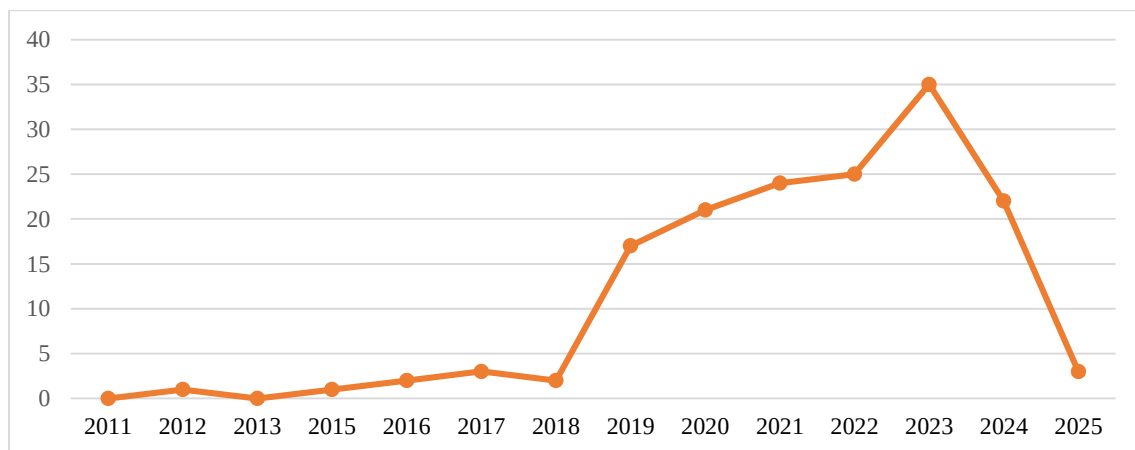
To systematically document, organize, manage, and analyze the data extracted from each article in the final selection, a structured Excel spreadsheet was employed. This file encompassed a comprehensive set of variables related to research maturity, including the Digital Object Identifier (DOI), author names and affiliations, article title, keywords, year of publication, industrial context, citation count, content-related elements (such as research objectives, key findings, and proposed directions for future research), journal name, publisher, research methodology, and research approach. These attributes were selected to assess the evolution of the research domain and to offer insights into its current state of development. The relevant data from each article in the final dataset were extracted and systematically recorded in the spreadsheet. Subsequently, an analysis was conducted based on the identified criteria, the results of which are presented and discussed in the subsequent sections.

3. Results

To gain a deeper understanding of the developmental stage of the research domain related to Supply Chain Management 4.0 (SCM 4.0), various types of information were extracted and analyzed from the selected articles. This information not only characterizes the key features of the research domain but also serves as a basis for evaluating its growth and progression. A review of the collected literature indicates that the earliest relevant publication dates back to 2012. Given the novelty of the topic, the findings suggest that the majority of recent studies primarily focus on identifying and conceptualizing the core dimensions of SCM 4.0, aiming to articulate its features and defining characteristics. In the remainder of this section, the extracted findings that contribute to assessing the maturity of the research field are examined individually to establish a foundation for evaluating its current state of development.

3-1. Publication trends

As illustrated in Figure 2, the findings from the final set of articles reveal an upward trend in the number of publications within this research domain from 2011 to 2024. This trajectory reflects a sustained and growing scholarly interest in the field. It is important to note that the literature search was concluded in April 2025, which accounts for the comparatively lower number of articles identified for the final year.

**Figure 2.** Publication per year (N=157)

The collected data indicate that 80 articles (50% of the total) were retrieved from only one database, while the remaining 81 articles appeared in the search results of multiple databases. The distribution of articles by publisher—limited to those with more than one publication related to the research topic—is presented in Figure 3. As illustrated, Emerald Publishing ranks highest with 30 articles, followed by Elsevier with 28, and MDPI with 15 articles. It is also noteworthy that 32 publishers have each contributed only a single article to this research domain.

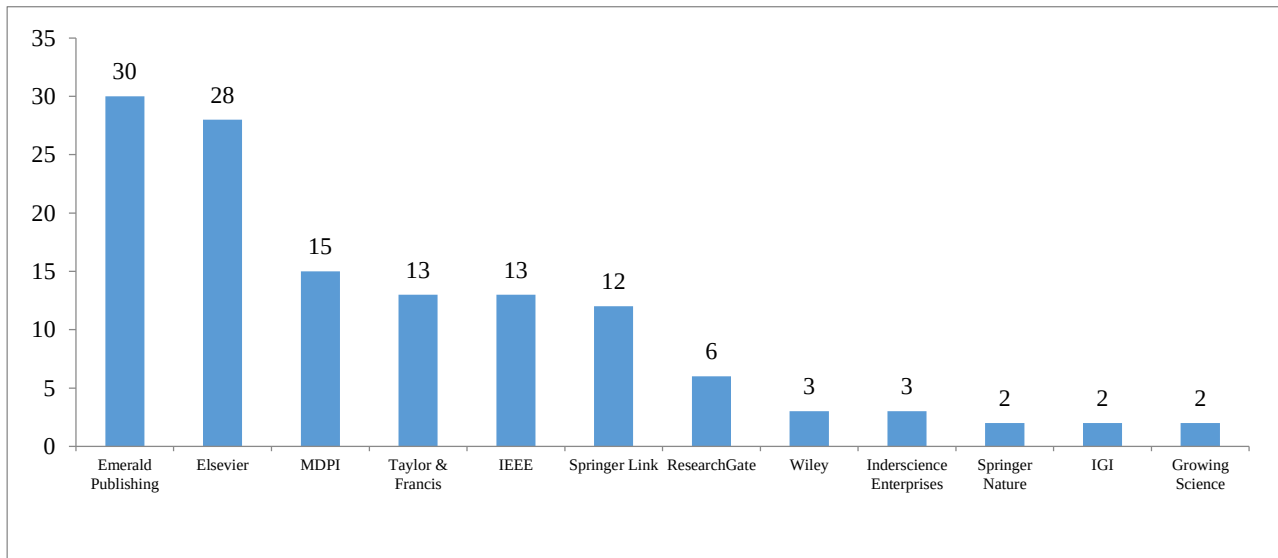


Figure 3. Publishers with more than one published article

Figure 4 illustrates the distribution of articles by publication type. Among the total of 157 articles analyzed, the majority (129 articles, about 82%) were published in academic journals. Conference proceedings contributed 22 articles (14%), while book chapters constituted a smaller proportion (4 articles, 3%). Additionally, one research report (McKinsey, 2016) addressing SCM 4.0 was included in the dataset. Furthermore, within the journal publications, only 28 out of 133 journals featured more than two articles relevant to the research topic (Figure 4.).

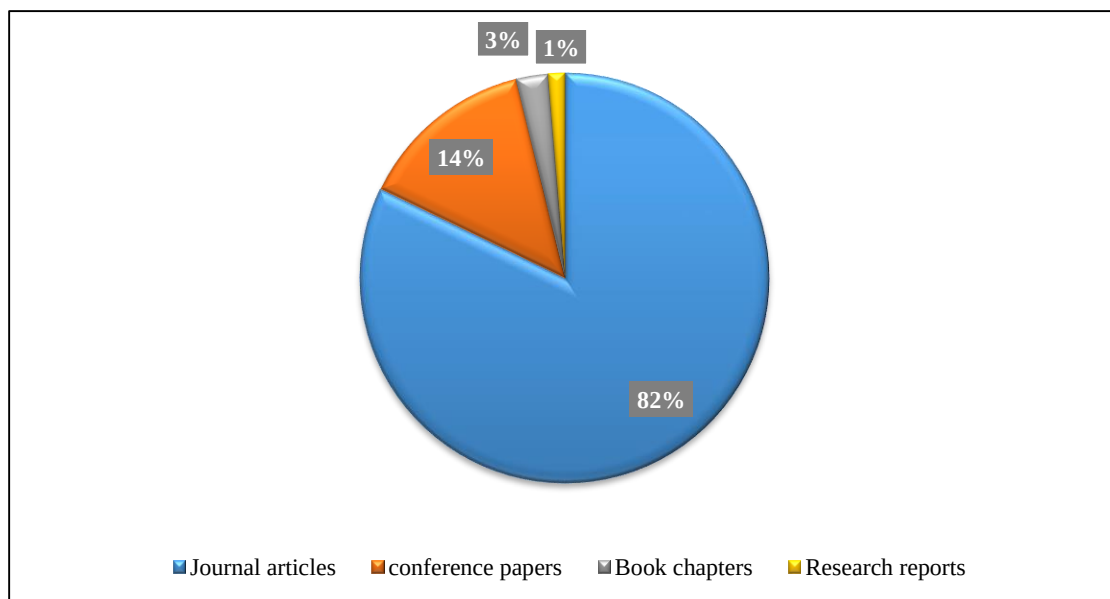


Figure 4. Types of publications according to the number of published articles

The prevalence of journals publishing only a single article on the subject reflects a fragmented distribution of research across publication sources (i.e., databases and journals). This dispersion suggests that the field remains in its nascent stages of development, with a notable absence of specialized sources dedicated to this topic.

Moving forward, a key advancement in SCM 4.0 research could involve a stronger emphasis on translating academic findings into practical industry applications. By bridging this gap, industry professionals could more effectively implement the methodologies and insights derived from published studies, thereby facilitating the adoption of SCM 4.0 in real-world settings.

2-3. Industry application

The industry analysis of the final article set reveals that the majority (89%) did not specify a particular industrial sector, as these publications primarily focused on identifying and delineating the core components and structural frameworks of SCM 4.0. Among the remaining articles, a modest proportion (3%) centered on the automotive industry, while an equal share (3%) addressed the chemical and food sectors. Other industrial domains—including aerospace, military, manufacturing, electronics, steel, and electric toothbrush production—each constituted less than 1% of the sample:

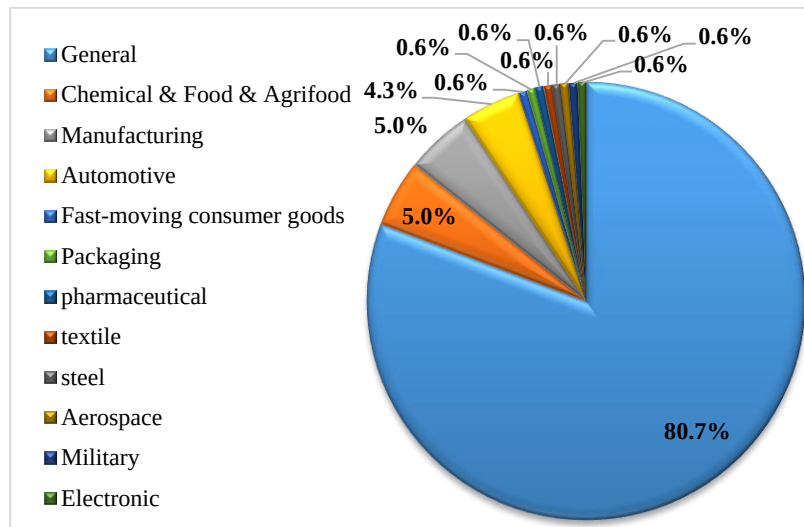


Figure 5. Most common Industries

The findings demonstrate that scholarly investigations of SCM 4.0 have predominantly adopted generalized conceptual approaches rather than industry-specific examinations. Current literature has largely focused on establishing theoretical frameworks and fundamental principles of SCM 4.0 without substantial empirical application to particular industrial contexts. Consequently, this analysis identifies industry-specific implementation studies as a critical gap in the existing body of knowledge and suggests this as a pivotal direction for future research endeavors.

3-3. Impact of publications

The scholarly impact of articles in the final dataset was assessed using annual citation metrics. Total citation counts for all publications were extracted during the literature search and recorded as a key performance indicator. To calculate average annual citations, the total citation count for each article was divided by the number of years since publication. Figure 6 presents the mean annual citation rates for the fifteen most frequently cited studies in the analysis.

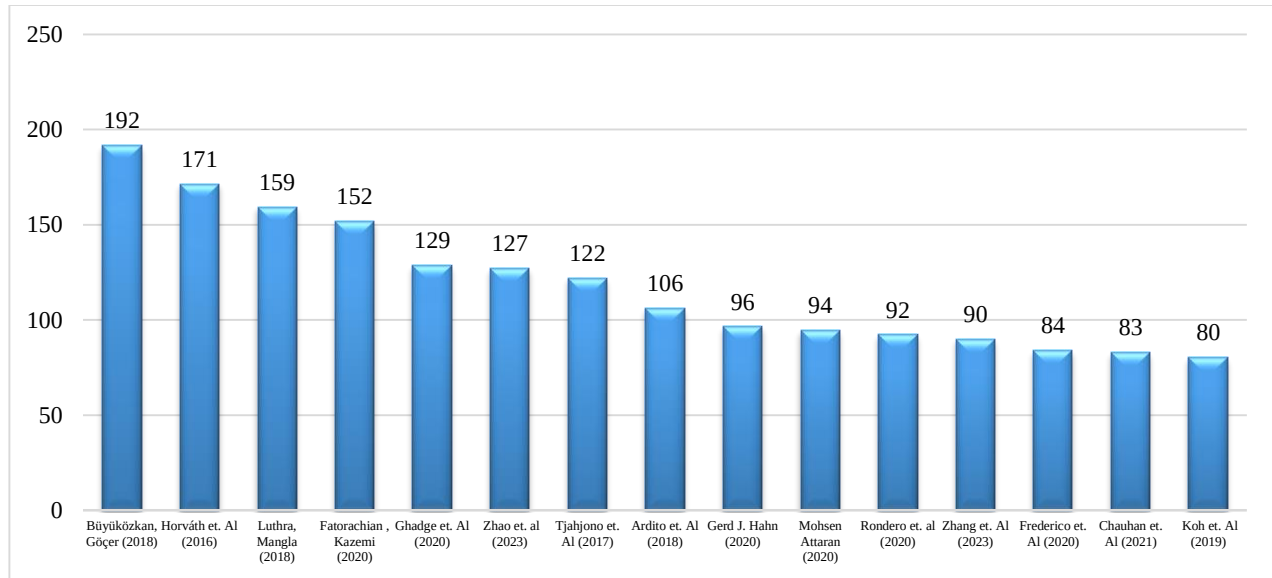


Figure 6. Average citations per year for most highly cited publications

The citation analysis reveals that the most frequently cited publication is the work by Büyüközkan and Göçer (2018), which has garnered an average of 192 annual citations since its publication. Their seminal article, entitled "Digital Supply Chain: Literature Review and a Proposed Framework for Future Research," appeared in *Computers in Industry*. This comprehensive study establishes a formal definition of digital supply chains, systematically analyzes their distinctive characteristics, enumerates their advantages and challenges, and pinpoints critical research gaps in the field. The authors advance a conceptual framework comprising three fundamental components: digitization processes, technological implementation strategies, and supply chain management practices for digital supply chain development.

Among the most cited publications, predominant research themes include: (1) systematic literature reviews of the field, (2) examination of enabling technologies, (3) identification of implementation barriers, (4) analysis of Industry 4.0's impact on supply chain performance metrics, and (5) proposed frameworks for SCM 4.0 implementation. To advance the field, future research should prioritize two key directions: first, the practical application of existing findings across diverse industrial sectors, and second, the empirical identification of critical success factors for SCM 4.0 adoption.

3-4. Authorship characteristics

This section presents an evaluation of author characteristics in the final article set, examining productivity patterns, geographical distribution, institutional affiliations, and co-authorship networks. Analysis reveals that among 515 contributing authors, the vast majority (approximately 96%) have authored only one publication in the dataset, while a small subset (19 authors, representing 4%) have produced multiple works. This limited publication output per author likely reflects both the emergent nature of the research domain and the fact that most scholars have not adopted this as their primary research focus. In either interpretation, these findings suggest a notable paucity of dedicated specialists in this field.

The geographical distribution of authors, determined through institutional affiliation analysis (Figure 7.), shows concentrated research activity in India, followed by the United Kingdom, Brazil, and the United States. Notably, 100 articles (62% of the sample) represent single-country collaborations, highlighting opportunities for enhanced international research cooperation. Furthermore, 19 publications were single-authored works, indicating areas for potential expanded collaboration.

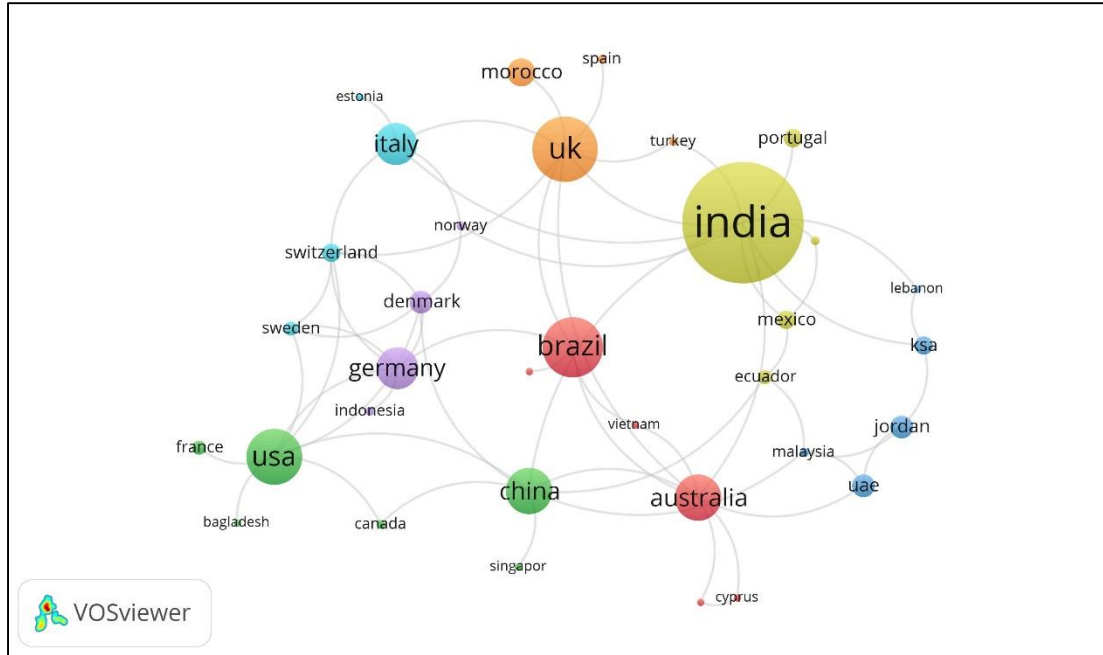


Figure 7. Author geography (based on institutional affiliation)

The geographical distribution analysis reveals a concentrated pattern of research output, with institutions from just 11 nations accounting for approximately 70% of all affiliations across the 52 countries represented. These predominant contributors comprise both advanced economies and emerging markets, specifically: India, the United Kingdom, Brazil, Italy, Australia, China, the United States, Morocco, Germany, Denmark, and Jordan.

3-5. Co-authorship analysis

Co-authorship patterns were examined through network analysis to investigate collaborative relationships among prominent researchers in this field. Author collaboration networks were constructed using VOSviewer software, with the resulting visualization presented in Figure 8. The software's algorithm determines node size according to each author's publication count, while connecting lines indicate co-authorship relationships.

The network reveals a fragmented collaboration landscape characterized by isolated clusters with limited interconnectivity. The central node represents Frederico (6 publications), surrounded by secondary contributors including Garza-Reyes (3 publications), and Hellingrath, Chauhan, Garcia-Reyes, Hurriat, Buhaddo, Kannan, Shahbazkhan, Deepu, and Ravi (2 publications each). Notably, among the 515 unique authors identified, the vast majority (excluding those mentioned above) have contributed only a single publication.

This dispersed network structure suggests both limited scholarly interaction and minimal specialization within the research domain. As Oladimeji et al. (2020) suggest, such conditions may be ameliorated through targeted academic conferences and specialized research workshops designed to foster collaboration.

3-6. Methodologies

To examine the methodological approaches employed in the research domain, relevant data were systematically extracted and analyzed from the final article set. As illustrated in Figure 9, the distribution of research techniques reveals that scholars in this field are primarily engaged in knowledge development. The figure specifically presents methodologies appearing in at least two publications (specially for data analysis methods).

Among these approaches, literature reviews and systematic literature reviews (SLRs) emerge as the most prevalent, while PRISMA¹ guidelines represent the least frequently employed data collection framework. Notably; Makris et al.

¹ Preferred Reporting Items for Systematic Reviews and Meta-Analysis

(2019) combined literature analysis with expert interviews to assess Industry 4.0's impact on supply chains, Lee et al. (2023) employed questionnaire surveys to investigate correlations between digital technologies and smart supply chain implementation, and Akbari et al. (2023) conducted semi-structured online surveys, subsequently applying advanced statistical techniques including regression analysis and Monte Carlo simulation for data interpretation.

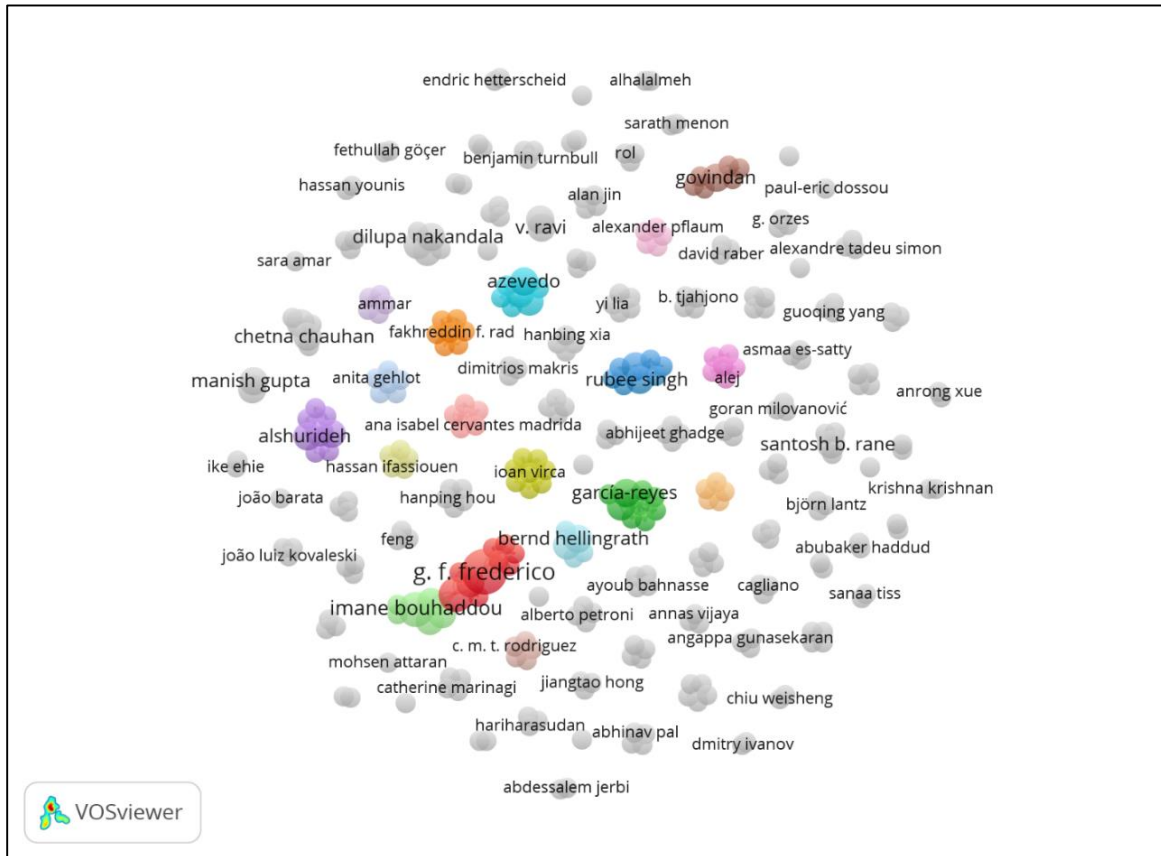


Figure 8. Co-Authorship network.

The methodological review reveals that current research in SCM 4.0 predominantly adopts an exploratory approach, concentrating on conceptual development and theoretical framework establishment within this emerging domain. The majority of studies seek to delineate the fundamental dimensions and underlying principles of SCM 4.0.

Quantitative analysis demonstrates that over 90% of the examined articles employed qualitative research methodologies, primarily utilizing interview protocols and survey instruments for data acquisition. Furthermore, an equivalent proportion (90%) of the studies offered practical managerial implications, specifically addressing organizational transformation requirements for successful SCM 4.0 implementation.

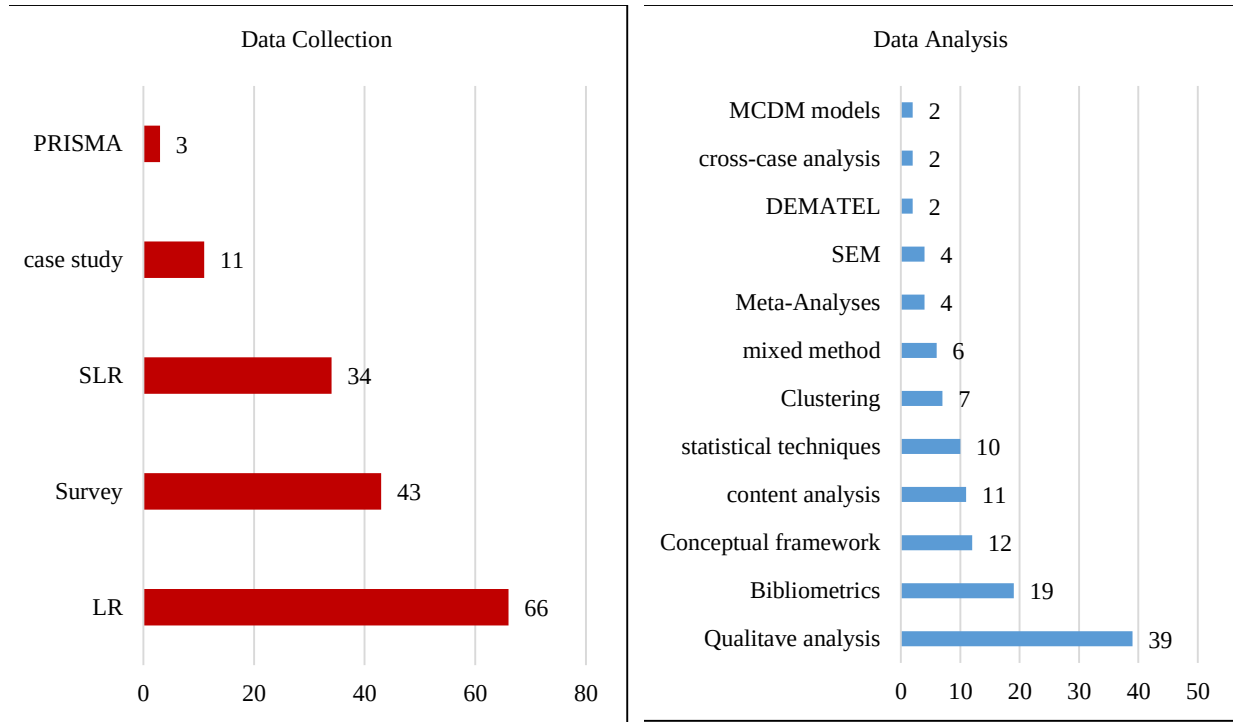


Figure 9. Data collection and analysis methods used in articles

3-7. Keyword analysis

Keywords serve as semantic encoders that reflect researchers' conceptual perspectives on a given field of study. Given the accelerated scholarly attention to supply chain digitalization in recent years, analyzing predominant research themes through keyword examination offers valuable insights for guiding future investigations. Building on the framework proposed by Bigliardi et al. (2022), keywords can be systematically classified according to two key dimensions: dominance (quantitative frequency) and durability (temporal persistence), resulting in four distinct categories: core, trendy, intermittent, and emerging.

Applying this analytical method, we first computed the mean values for both frequency and durability (each averaging 2), then categorized the 258 identified keywords accordingly: core (26 keywords, 10%), trendy (3 keywords, 1%), intermittent (54 keywords, 21%), and emerging (175 keywords, 68%). The core terminology cluster featured prominently recurring concepts including: Industry 4.0 (77.9), SCM (52.8), SCM 4.0 (29.4), IoT (17.7), Digital Supply Chain (14.5), Digitalization (13.6), and Smart Supply Chain (12.6), where parenthetical values represent combined frequency-durability metrics.

The substantial proportion of keywords classified as emerging (68%) and intermittent (21%) underscores both the relative novelty of this research domain and its ongoing developmental trajectory. Figure 10 presents a keyword co-occurrence network visualization generated through MAXQDA qualitative analysis software, depicting term frequencies across the final article corpus.



Figure 10. Keywords map

The keyword co-occurrence analysis presented in Figure 10 reveals several prominent conceptual clusters, with the following terms demonstrating particularly high centrality: Industry 4.0, Supply Chain 4.0 (alternatively denoted as SCM 4.0), Smart Supply Chain, Digital Supply Chain, Supply Chain Management (SCM), and Internet of Things (IoT). Secondary but recurrent terminology in the literature corpus includes: Internet of Things technologies, blockchain applications, cyber-physical systems, simulation methodologies, cloud computing architectures, and big data analytics.

3-8. Content of articles

To conduct a thematic categorization of the final article set, we systematically analyzed the objectives, findings, and suggested future research directions across all publications. Following a comprehensive review, we classified the identified themes from these three perspectives based on conceptual similarity. The resulting thematic framework is presented in Table 2.

Table 2. Classification of articles based on content (objectives - findings - future research suggestion)

Content	Section			Description
	Objectives	Findings	Future Suggestions	
SCM 4.0 Strategy and Government	▪	▪	▪	Providing strategies to realize SCM 4.0 globally or nationally, providing a digital governance platform architecture.
Introduction of enablers, challenges and risks	▪	▪	▪	Introducing drivers and enablers, identifying internal and external obstacles and challenges and risks of implementing the SCM 4.0.
Adoption and implementation	▪	▪	▪	Assessing the current state of industry 4.0 technologies adoption in the SC, experiences of technology adoption in organizations and different layers of the SC, introducing drivers for industry 4.0 technologies adoption in the SC and introducing a

				reference model for implementing the SCM 4.0 to achieve agility, resilience and reliability in SC.
Recognition improvement	▪		▪	Providing approaches for scenario creation and managerial decision-making regarding the application of the SCM 4.0, or how to redesign the SC and realize digital transformation, looking at the emerging technologies of the industry 4.0 and the characteristics and advantages of the SCM 4.0 .
Identify future research directions	▪			Introducing future research avenues in SCM 4.0 research area, analyzing new trends or researching the applicability of conducted research in supply chain digitization concept.
Studying the role of SCM 4.0 technologies	▪	▪	▪	Introducing industry 4.0 technologies and their relationship with SC elements and processes, identifying their role in supporting supply chain management encountering new changes in the business environment, and the impact of emerging processes on improving the performance of SCM 4.0 .
Framework/maturity model/road map design	▪	▪	▪	Designing the conceptual framework for SCM 4.0, providing a maturity model or comparing existing maturity models for it, or providing a roadmap for digital transformation and realizing the SCM 4.0 .
Review knowledge updates and discover developments	▪	▪		Searching, discovering and displaying developments in the SCM 4.0 research area, reporting the current state of knowledge, introducing innovative technologies and recent technological developments in the field of SC in order to facilitate decision-making and planning of SC managers.
Dimensions, features and advantages of SCM 4.0		▪		Identifying the elements and characteristics of the SCM 4.0 and its effect on various aspects of the SC by achieving advantages such as agility, responsiveness, flexibility, efficiency, productivity, safety, etc.
Supply chain stakeholder's collaboration			▪	Developing studies related to SCM 4.0 at the level of global SCs and investigating the effect of collaboration between SC partners on SC network performance.
SCM 4.0 in various industries			▪	Conducting the necessary studies to identify the components of the SCM 4.0 in various industries, especially with a focus on small and medium enterprises (SMEs), with the aim of developing knowledge in research area and the possibility of comparing the results obtained between different industries in order to generalize the concepts of the SCM 4.0.
Applying various research methods			▪	Applying quantitative or mixed methods, in a larger sample size, using more effective search methods, using a larger community of experts to collect data in order to describe, understand and define concepts in the new SC paradigm.

To facilitate a comprehensive understanding of the thematic categorization, we quantified the frequency distribution of thematic titles, with results presented in Figures 11 through 13. As evidenced in Figure 11, analysis of study objectives reveals that researchers predominantly focused on examining the functional role of SCM 4.0 technologies. Secondary research emphasis was placed on investigating implementation enablers, potential risks, and operational challenges within the SCM 4.0 field.

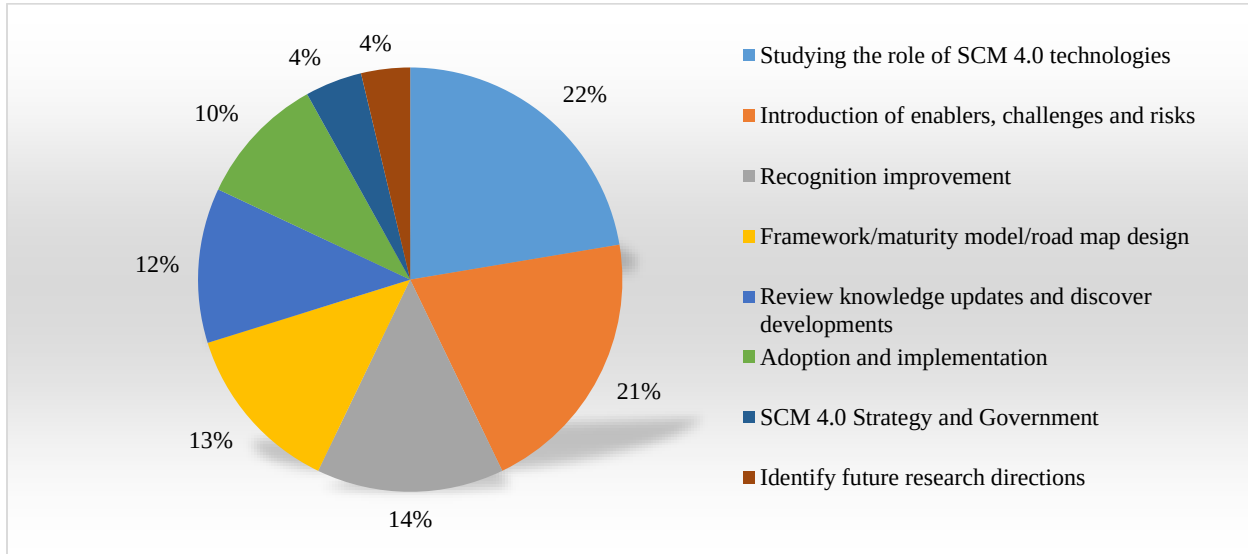


Figure 11. Articles by Objectives content

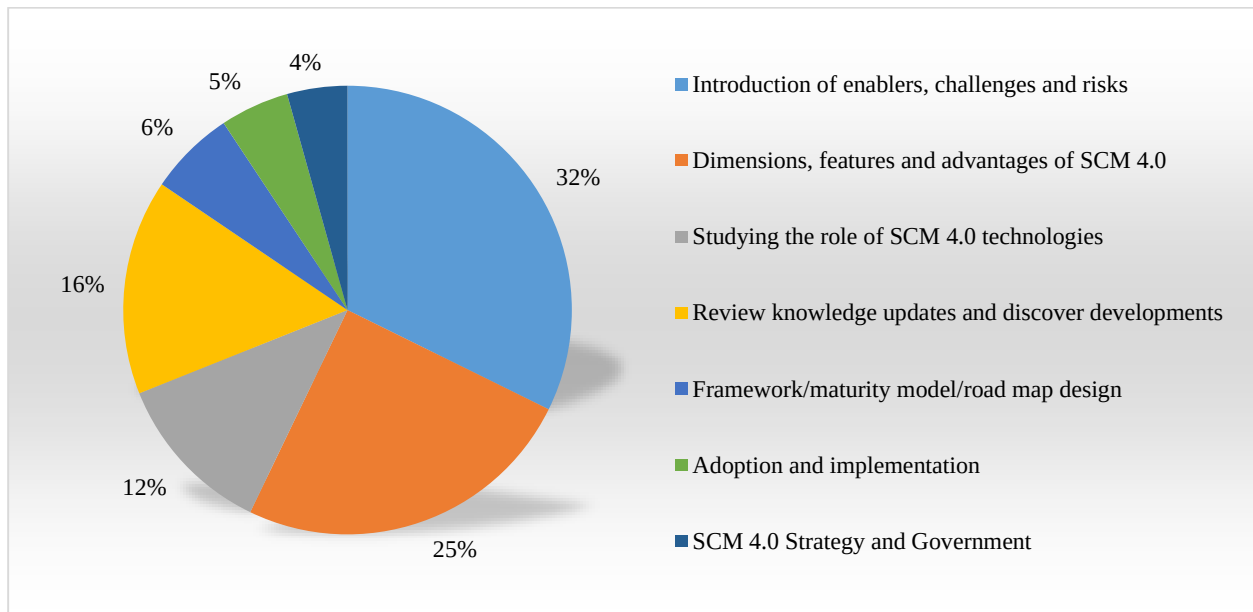


Figure 12. Articles by Findings content

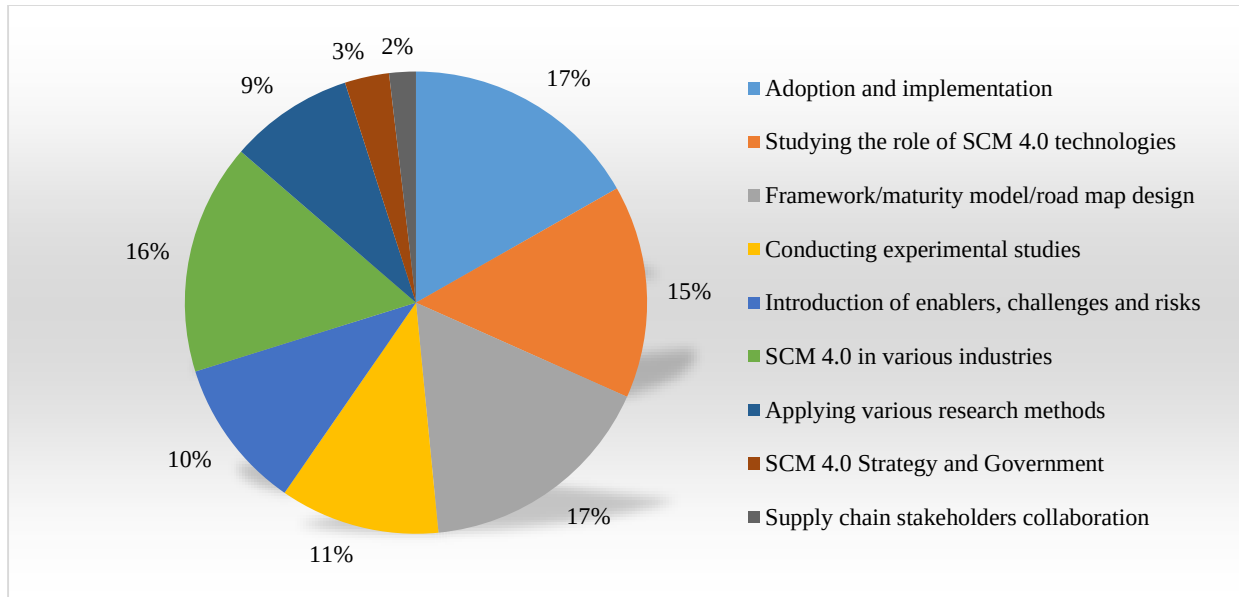


Figure 13. Articles by future suggestions content

The analysis of research findings (Figure 12) reveals that the most prevalent themes concern the enablers, challenges, and risks associated with SCM 4.0 implementation. This is followed by findings examining the functional role and competitive advantages of Industry 4.0 technologies in supply chain transformation. Conversely, proposed implementation strategies for SCM 4.0 represent the least frequent category among key findings.

Regarding future research directions (Figure 13), scholars predominantly emphasize investigating adoption and implementation pathways for SCM 4.0 as priority areas for further study. Secondary research recommendations focus on: (1) examining the application of Industry 4.0 technologies in supply chains, and (2) developing implementation frameworks, models, and roadmaps for SCM 4.0. In contrast, proposed studies on strategic approaches to SCM 4.0 and inter-organizational collaboration within global supply chains received minimal attention in the reviewed literature.

4. Discussion on research area maturity

This section presents the findings of a bibliometric analysis conducted to evaluate the current developmental stage of the research domain, utilizing the framework established by Oladimeji et al. (2020). The analysis categorizes research maturity into three distinct levels: emerging (low), developing (medium), and mature (high).

The emerging phase (represented by the inner hexagon in Figure 14) characterizes an exploratory research field exhibiting three key features: (1) limited employment of sophisticated methodologies, (2) a small cohort of specialized researchers, and (3) numerous conceptual frameworks serving primarily diagnostic functions. At the developing level (middle hexagon), research demonstrates: (1) more systematic descriptive approaches, (2) enhanced methodological complexity, (3) growing specialist participation, and (4) practical application of analytical models for both process evaluation and operational implementation. The mature phase (outer hexagon) reflects an advanced research ecosystem marked by: (1) well-established academic infrastructures, (2) robust interdisciplinary collaboration among research groups, and (3) practical implementation of sophisticated methods that effectively inform organizational decision-making across all levels.

The maturity evaluation framework, depicted in Figure 14's radar chart, encompasses six principal assessment dimensions adapted from Herring (2016): (1) publication metrics, (2) industry integration, (3) authorship distributions, (4) methodological rigor, (5) content sophistication, and (6) scholarly influence.

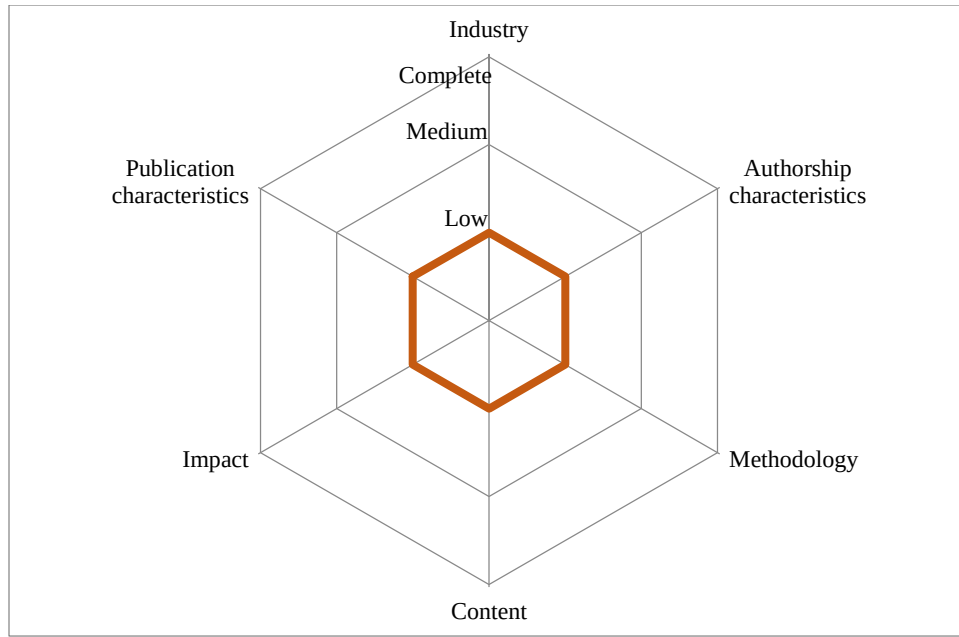


Figure 14. Maturity levels of research area

The research area currently appears to have low maturity across all dimensions. The analysis of publication characteristics, using outputs, trends, and publication types, reviewed. Publications in this field are very scattered, and even specialized journals have published only a few relevant articles. Additionally, publication trends show increasing interest in the research area, indicating early stages of developing the SCM 4.0 concept. To improve the maturity of the research area, more publications in business journals or journals focused on production or SC can help advance this research area.

The analysis of authorship characteristics examined three key dimensions: publication quantity, disciplinary diversity, and collaborative patterns among contributing scholars. The findings reveal significant opportunities for enhanced academic collaboration within this research domain. Examination of co-authorship networks demonstrates considerable fragmentation, with merely 8% of the 515 unique authors having multiple publications in the field. Moreover, sustained collaborative relationships remain exceptionally rare among contributors. These results suggest that strategic partnerships with industry practitioners could substantially enrich the practical applicability of SCM 4.0 research. Also, more interdisciplinary engagement, particularly with industry specialists and adjacent academic fields, would likely accelerate the field's maturation by broadening theoretical perspectives, enhancing methodological approaches, strengthening practical applications, and fostering more robust research networks. The integration of diverse viewpoints could significantly advance both the academic rigor and real-world relevance of SCM 4.0 studies. Finally, the analysis of authorship characteristics indicates an emerging field of maturity, as co-authorship shows a sparse network with few nodes and connections.

Research design characteristics examined through the research methods used in the final article set. This analysis shows that literature reviews, case studies, and research using interviews or questionnaires are most commonly used data collection methods, and less advanced methods like action research or experimental and field methods used less frequently.

Examining articles from the perspective of SCM 4.0 studies in different industries (industry application) shows that the research area of SCM 4.0 has been studied less in a specific industry, and most articles address it generally without mentioning the industry type. However, applying this research area in various industries can help develop knowledge, and investigating SCM 4.0 in different industries can be an interesting topic for future research.

Comprehensive analysis of article content, encompassing research objectives, principal findings, and proposed future directions, reveals that scholarly efforts remain predominantly focused on foundational investigations into SCM 4.0.

Current research primarily seeks to establish fundamental dimensions, conceptual components, and potential applications of this emerging paradigm. Numerous studies have identified the development of implementation frameworks, theoretical models, and adoption roadmaps as critical avenues for future inquiry. This systematic examination clearly demonstrates that SCM 4.0 research remains in a nascent phase of intellectual development. Collectively, these findings position SCM 4.0 as an emerging field with limited academic maturity. Consequently, existing empirical evidence requires cautious interpretation, as significant research gaps persist regarding validation, generalization, and the establishment of evidence-based best practices for SCM 4.0 implementation. The field would benefit substantially from more rigorous empirical studies and broader theoretical development to advance beyond its current preliminary stage.

5. Managerial Implications

The increasing complexity of supply chains and the pressing need to enhance their responsiveness and resilience have made digital transformation an essential strategic priority. Consequently, organizations require a profound understanding of how SCM 4.0 can be effectively implemented. The results of this study offer managers valuable insights into the potential of SCM 4.0 and how they can prepare for and drive this transformation. The practical implications for managers can be summarized as follows:

Strategic Vision: Managers must develop a clear strategic vision for implementing SCM 4.0 that aligns with the organization's broader goals. This includes identifying key areas within the supply chain that can benefit from digital technologies and outlining a phased roadmap for integration.

Change Management: Transitioning to SCM 4.0 requires organizational change at multiple levels. Managers should anticipate resistance, promote a culture of innovation, and provide training and support to ensure employee engagement and readiness for digital transformation.

Technology Adoption: Managers need to assess and prioritize which Industry 4.0 technologies—such as IoT, big data analytics, blockchain, AI, and robotics—are most applicable to their supply chains. The selection should be based on their specific operational challenges, available resources, and desired outcomes.

Collaboration and Integration: SCM 4.0 emphasizes the integration of systems and collaboration across supply chain partners. Managers should invest in technologies and processes that enable real-time data sharing, improve coordination, and foster trust among partners.

Talent Development: The implementation of SCM 4.0 necessitates new skills and capabilities. Managers should invest in workforce development initiatives to build digital literacy and attract talent with expertise in data science, analytics, and digital technologies.

Performance Measurement: To evaluate the success of SCM 4.0 initiatives, managers should define appropriate KPIs that capture the impact of digital transformation on supply chain efficiency, responsiveness, and sustainability.

In conclusion, the shift toward SCM 4.0 presents a transformative opportunity for supply chain management. However, to fully realize its benefits, managers must adopt a proactive, strategic, and holistic approach that encompasses technological, organizational, and human factors. The insights derived from this study provide a foundational guide for managers to navigate this transition effectively.

6. Conclusions and Future Research

This study presents a systematic literature review (SLR) and bibliometric analysis of research in the SCM 4.0 domain. The investigation identifies critical research gaps while proposing strategic directions to enhance the field's academic maturity. While bibliometric indicators reveal growing scholarly interest, evidenced by increasing publication outputs, author participation, and citation impact, the analysis simultaneously highlights substantial opportunities for advancing the field's development. Key findings from our comprehensive assessment include:

1. The publication of articles has increased in recent years, indicating growing interest in researching the concept of SCM 4.0.
2. There are many opportunities to explore the concept of SCM 4.0 in various industries. Currently, over 80% of existing articles examine this concept generally.

3. The weak network of collaboration between authors indicates a need for more collaboration among researchers in this field, as the network has few nodes and connections, and only a small percentage of all researchers (about 9%) have participated in author collaboration networks. Thus, more interaction between authors could help develop the research area and improve the collaboration network settings.
4. Authorship analysis shows that Guilherme Francisco Frederico has the highest number of articles in this field and centrally positioned in the author collaboration network. This suggests Frederico has played a significant role in developing the research area.
5. The institutional affiliation of authors is mainly from India, UK, Brazil, Italy, Australia, China, and the United States. Therefore, another opportunity in this research area is collaboration among authors from different organizations and countries.
6. The three most recurred goals in studies in this field, respectively, are examining the role of Industry 4.0 technologies in the SC, designing frameworks or conceptual models and maturity models for SCM 4.0, and introducing enablers, challenges, and risks of SCM 4.0.
7. Among the findings of the studied articles, the three most recurring include drivers, challenges, barriers, and risks of SCM 4.0, the advantages of SCM 4.0, and the introduction of SCM 4.0 technologies.
8. The three most recurred topics among future research suggestions include studying the adoption of SCM 4.0, studying the application of Industry 4.0 technologies in the SC, and presenting new models or validating previously presented models concerning SCM4.0.

Points 6 to 8 indicate the novelty of the SCM4.0 research area and show that researchers are currently seeking to clarify its dimensions and constructs. The provided framework for assessing the maturity of the research area confirms the research area is still underdeveloped and in the early stages of evolution. To make progress in this field, researchers should focus on more collaborations to improve the content and theoretical concepts in the research area. Additionally, using different methodological approaches will enhance the diversity of research. Finally, deeper research on the adoption and implementation of SCM 4.0 in various industries can help grow knowledge in this area.

As limitations of this research, this study is limited to publications indexed in the nine electronic databases mentioned in the introduction section and only includes articles in English that were accessible. Moreover, this study focused on articles that generally dealt with the concept of SCM 4.0 and did not include articles that examine or apply a specific I4.0 technology in the SC. Additionally, this paper only includes bibliometric analysis using extracted data.

This study provides important insights into the maturity of this research area through bibliometric analysis. To expand this analysis, conducting a content analysis of the literature can also be useful for a more comprehensive understanding of the existing themes in the research area.

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