A Maturity Framework for Digital Supply Chains in Industry 4.0: A Systematic Literature Review

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Abstract: The Digital Supply Chain (DSC) has emerged as a key concept within the Industry 4.0 paradigm, attracting increasing attention from both academia and industry. However, existing studies lack a comprehensive framework for assessing DSC maturity. This study addresses this gap by developing a conceptual maturity framework based on a systematic literature review (SLR). A structured screening process was applied to identify and analyze relevant studies, resulting in a set of core constructs that define DSC maturity. The findings reveal four key dimensions: leadership and managerial support, emerging technologies, process performance requirements, and strategic outcomes. These dimensions collectively provide an integrated perspective on the evolution and assessment of digital supply chains. The proposed framework contributes to the literature by offering a structured approach for evaluating DSC maturity and supports practitioners in guiding digital transformation initiatives. Future research should focus on empirical validation and refinement of the model across different industrial contexts.

1 INTRODUCTION

Much research has focused on supply chain (SC) integration and its ability to boost company competitiveness. However, with the SC function's growing complexity comes the difficulty of enhancing the performance and reducing costs of companies' activities, as it is responsible for coordinating both internal operations and relationships with customers and suppliers [1]. Consequently, SC members must integrate their processes. Utilizing cutting-edge technological solutions is one approach to accomplishing such integration [2]. Research has been conducted at two stages of SC integration: (a) inter-organizational, which involves integrating suppliers and clients, and (b) intra-organizational, which pertains to the Inside organization operations. The need to integrate supply chain operations is not new, though it is difficult given the increasing operational complexity [3]. Possibilities to link and integrate businesses and their resources to improve financial, time, and resource performance have emerged with the advent of the technologies of the Fourth Industrial Revolution, known as I4.0. This revolution is the outcome of the strong connection between communication and information technologies that link the real (physical) and virtual worlds [4], [5]. According to [1], companies can work together when Industry 4.0 technologies are integrated with SC processes, making information transparent between suppliers and customers. As a result, they can optimize their business processes, increasing their flexibility, productivity, and quality [6], [7]. Academics and businesses alike are increasingly interested in how the SC's processes and activities can be digitalized through the implementation of I4.0 technologies [5]. Nevertheless, the actual positive or negative effects of these technologies on SC are not yet entirely apparent and have not yet been identified [8]. Consequently, this research aims to fill this gap by developing a conceptual framework for digital Supply Chain (DSC) maturity, or what's known as Supply Chain 4.0 (SC 4.0) maturity, based on the core components identified in DSC. This study, therefore, seeks to clarify possible maturity standards and levels for DSC to help fill gaps in the literature and identify areas for future research. Two research questions were formulated. Answering research questions 1 and 2 is the primary objective of the following sections:

- Question 1: What are the core elements of the digital supply chain dimensions (constructs)?

- Question 2: How can a model for assessing digital supply chains be developed?

The following are the seven parts of this paper: The research is contextualized, and the research gap is demonstrated in the introductory section. The concept of "DSC" is introduced in Section 2 to highlight its connections to the Fourth Industrial Revolution. Section 3 presents the definition of a Maturity Model, while Section 4 reviews the pertinent literature. Section 5 describes the dimensions and sub-dimensions of the model. The study's findings are detailed in Section 6, and Section 7 concludes the research.

2 DIGITAL SUPPLY CHAIN

Factories today are implementing I4.0, which has far-reaching effects across the entire supply chain. The supply chain whose ideas and principles are rebuilt around Industry 4.0 technology is known as the Digital Supply Chain (DSC), also known as Supply Chains 4.0 (SC4.0) or Digital Supply Networks (DSNs), and as Smart supply chains. These take advantage of recent advances in digital technologies such as "data collection and analytics, digital fabrication, cloud computing, the Internet of Things, sophisticated robots and artificial intelligence, sophisticated sensors, service-based software, and other novel concepts." [9] to provide supply chain participants with (almost) instantaneous information, enhancing visibility [10], transparency, and cooperation in supply chains [11]. In this way, we can lessen the impact of any disruption, improve the precision of our demand forecast, and reduce the number of no longer needed products [12]. A more comprehensive model in which information flows in multiple directions is promoted by (DSC), facilitating the convergence of the physical and digital realms. This model replaces the traditional linear model, in which instructions flow from the supplier to the producer, distributor, and finally to the consumer [13]. According to a recent report by McKinsey, digitization improves SC in speed, flexibility, granularity, accuracy, and efficiency [14]. DSC also enables more fluid upstream-to-downstream connections within supply chains [8]. In addition, businesses that implement DSC will gain increased market share, improved product availability, and a competitive advantage [15]. As a result, scholars and practitioners across industries have shown great interest in DSC [16].

Many businesses are pouring resources into creating their own DSC. A third of respondents in a recent PwC study on the progress of Industry 4.0 said their companies have started digitizing their supply chains, and 72% said they expect to do so within five years [17]. The COVID-19 pandemic has accelerated the adoption of digital technologies [18], [19], and this acceleration is predicted to continue. Thus, Digital Supply Chain is an all-encompassing re-engineering of conventional supply chain management that leverages I4.0 technologies to enhance the chain's operations, interactions, and processes, ultimately leading to substantial strategic gains for all parties involved.

3 DEFINING A MATURITY MODEL

In this context, "maturity" means the "state of being complete, perfect, or ready". Measuring, comparing, describing, and determining a roadmap or course of action are all functions of a maturity model [20]. Maturity models are used to move from inefficient, immature processes to more sophisticated, effective, and qualitatively superior ones, defining the evolutionary path of a company [21]. Companies and production organizations can benefit from using maturity models to gauge their current status in relation to one of the states indicated by the models. This also helps identify where to start when enhancing processes within existing organizations. They can also be utilized to evaluate various companies [22], [23]. Conceptually, a model of maturity is a framework for describing the stages of development or maturity of a particular field. In business, maturity models are valuable tools for defining and measuring how far along the path to success a company is in achieving a specific goal or set of objectives [24]. A maturity model can be conceptualized [21], [25] using maturing stages of increased qualitative or quantitative capability changes to evaluate its progress in relation to specific focal areas. Thus, maturity models are practical tools for assessing the elements' capacities in the process and enhancing their maturity levels through appropriate actions. To reach a certain level of maturity, one must follow a progressive roadmap that starts at the beginning and ends at a specific destination. The purpose of maturity models is to assist organizations in assessing their current state, guiding them through the transformation process, and gathering the necessary data to identify which areas

require additional focus [26]. Typically, maturity models include levels, which are ordinal labels that denote stages of maturity, and dimensions, which represent particular capabilities within their area of interest. According to [27], these models help assess current conditions and categorize capabilities for benchmarking and comparison.

Businesses need to take stock of their digital transformation efforts and Industry 4.0 adoption rates to maintain or gain market position [28]. That is why taking the necessary steps to gauge the extent of Industry 4.0's presence is essential [29]. Without a doubt, the initial stage of a fruitful digital transformation is a thorough understanding of the current level of digitalization. Companies can better explore and take advantage of the opportunities presented by digital technologies if they have a clear picture of their digital maturity [30]. An accurate assessment of their present state and a well-thought-out strategy to steer management through digitalization trends should form the basis of the digital transformation. A company's digital transformation goals can be better met with the help of DSC maturity models, which lead decision-makers to use strategic planning and benchmarking planning [31]. Maturity models "can assist businesses in making quicker and simpler decisions regarding the question of where and how to implement DSC", as stated by [32].

4 METHODOLOGY

To answer the RQs, an SLR was conducted. The three stages of the SLR were planning, conducting, and reporting, as proposed by [33]. This study examines DSC through an SLR from a maturity-level perspective. The goal is to determine how to develop a model for assessing the evolution of the Digital Supply Chain.

4.1 Planning

A comprehensive literature review was conducted to identify maturity models within the DSC framework. The research was to be centered solely on the DSC maturity model. The following were taken into account in the literature review: We used the following keywords and phrases: "digital Supply Chain", "SC 4.0", "Logistics 4.0", "Smart supply chains", "Maturity Levels", and "Maturity Model" in our search. Hrcak, Emerald, Taylor & Francis, Elsevier, IEEE-Xplore, and Google Scholar were the databases used for the search. Because this field is only getting started, we have used Google Scholar to compile practitioner-oriented articles and reports that may shed light on it. For this study, the authors narrowed their focus to methodologies for evaluating business maturity in the context of digital or SC4.0 characteristics and extracted only those findings deemed pertinent. For academic rigor, we solely considered papers published in peer-reviewed journals or presented at official conferences.

4.2 Conducting

Using the criteria established in the preceding step, the search was conducted during this phase. After removing duplicate entries, the search results were narrowed to English-language publications from scholarly journals or conferences worldwide (153 papers). In the second phase of the selection procedure, the writers read both the abstract and the full text of each article. Before reading the entire paper, the studies were screened for adherence by reviewing their titles, abstracts, and keywords. The following four criteria led to the exclusion of (142 articles). The following areas of research were not included: the Assessment DSC or SC 4.0 (19 papers), the Maturity Model of I4.0 (44 papers), supply chain readiness through Industry 4.0 (13 papers), and specialized technical, non-administrative articles (24 papers). These subjects do not pertain to the assessment of supply chain maturity in the domain in question (42 papers). Eleven (11) articles were ultimately chosen following the screening process. The screening aimed to find articles that discussed or proposed the development of DSC from a maturity-level viewpoint. The 11 chosen papers are shown in Table 1 from the comprehensive literature review on the maturity of DSC.

4.3 Reporting Findings

Table 1 displays the Frameworks and paradigms for maturity discovered across the SLR. According to this research, you should start by clearly explaining or defining the framework's core elements, components, and building blocks, and their relevance to the topic. These components are called constructs used in this study. The second point is that. Each construct's features at each development level should be well-defined.

Table 1: Publication about digital supply chain maturity.

Author	Title	Journal/conference/ publishing institution	Database
[34]	Development of an Industry 4.0 maturity model for the delivery process in supply chains	Journal of Modelling in Management	Emerald
[35]	The Framework of Logistics 4.0 Maturity Model	Intelligent Systems in Production Engineering	Research Gate
[36]	A blockchain maturity model in the agricultural supply chain	Information Processing in Agriculture	Elsevier
[37]	A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management	International Journal of Production Economics	Elsevier
[38]	An Industry 4.0 Maturity Model Applied to The Automotive Supply Chain	Revista Gestão & Tecnologia	Research Gate
[39]	Measuring Digital Transformation Maturity of Supply Chain	Tehnički glasnik	Hrčak
[40]	Digital supply chain research trends: a systematic review and a maturity model for adoption	Benchmarking-An International Journal	Emerald
[41]	Towards a Maturity Model for Digital Supply Chains	Logistics Research	Research Gate
[42]	Readiness and Maturity of Smart and Sustainable Supply Chains: A Model Proposal	Engineering Management Journal	Taylor & Francis
[43]	Trends and Recommendations for Enhancing Maturity Models in Supply Chain Management and Logistics	Applied Sciences	Research Gate
[44]	A Maturity Model of Digital Transformation in Supply Chains: A Multi-dimensional Approach	2023 27th International Conference on Information Technology (IT)	IEEE

As a final point, it's essential to clarify the relationships among concepts so people can grasp how they affect one another. The results of the examination of these papers are based on these findings:

1) The constructs offered in the maturity frameworks are generally not well defined, and the process by which the constructs were created is also not explained.
2) The features of the constructs (dimensions) corresponding to each stage of development are murky in specific models.
3) Because of the haziness of the connections between the concepts, it is hard to say how they might influence one another.
4) Regarding the dimensions considered, a unanimous agreement is not possible. Each proposal takes into account a variety of factors.

5 DIMENSIONS AND SUB-DIMENSIONS OF DSC

Based on the systematic literature review (SLR) presented in the previous section, this study identifies a structured framework of the Digital Supply Chain (DSC) consisting of four main dimensions and twenty associated sub-dimensions (application areas).

The four core dimensions are:

- Leadership and managerial support.
- Emerging technologies.
- Process performance requirements.
- Strategic outcomes.

The selection process followed a rigorous screening procedure. Initially, articles were evaluated based on titles, abstracts, and keywords, followed by full-text assessment. A total of 142 studies were excluded due to lack of relevance, including research focused on Industry 4.0 maturity models, supply chain readiness, and purely technical or non-managerial perspectives. Ultimately, 11 studies were retained for in-depth analysis, forming the basis for the proposed DSC maturity framework (Table 1).

The leadership and managerial support dimension comprises seven sub-dimensions: IT infrastructure, coordination, strategic vision, leadership support, awareness, human resource capabilities, and compliance. These elements establish the organizational foundation necessary for the adoption and effective utilization of digital technologies.

The emerging technologies dimension includes key digital enablers such as Internet of Things (IoT), artificial intelligence (AI), big data analytics (BDA), cloud computing, blockchain, robotics, sensors, and

enterprise systems (ERP). These technologies act as drivers of digital transformation within the supply chain.

The process performance requirements dimension encompasses critical operational capabilities, including interoperability, flexibility, integration, collaboration, responsiveness, efficiency, transparency, lean practices, and performance measurement.

Finally, the strategic outcomes dimension reflects the expected organizational results, particularly in terms of customer and supplier integration, competitiveness, cost reduction, and overall supply chain performance.

6 DSC MATURITY FRAMEWORK

The proposed DSC maturity framework is structured into four progressive levels: Initial, Intermediate, Advanced, and Cutting-Edge (Table 2). Each level reflects the degree of development across the four DSC dimensions.

Table 2: Digital supply chain maturity framework.

DSC Strategy Path			
Initial	Intermediate	Advanced	Cutting-Edge
Results for Strategy: 1. There is no cost decrease due to the lack of DSC technology. 2. Clients and suppliers cannot realize the advantages of SC operations 3. There is no added value and no competitive advantages.	Results for Strategy 1. Some cost decreases can be achieved by adopting DSC technology. 2. Clients and suppliers have advantages equitably from SC operations. 3. The SC contributes to achieving a limited margin of added value with some cost reduction.	Results for Strategy: 1. Significant cost reduction resulting from the DSC strategy. 2. clients and suppliers generate value from SC. 3. The SC contributes to achieving value-added margins while reducing costs.	Results for Strategy: 1. A very significant cost reduction resulting from the strategy of DSC. 2. Clients and suppliers generate very high value from SC. 3. The SC contributes significantly to the value-added margin while significantly reducing costs.
Process Performance Requirements: 1. Processes are not integrated, transparent, and well-studied. 2. There is no integration between machines, and they cannot be controlled by information technology. 3. Poor cooperation between members of the SC. 4. Poor responsiveness and flexibility.	Process Performance Requirements: 1. Some processes are integrated, transparent, and well-studied. 2. Some machines can be controlled by information technology or integrated. 3. Achieving some cooperation between members of the SC. 4. Response is average, as is flexibility.	Process Performance Requirements: 1. Most processes are integrated, transparent, and well-studied. 2. Machines and infrastructure can be controlled by information technology and are partially integrated. 3. Achieving excellent cooperation between members of the SC. 4. High responsiveness and flexibility.	Process Performance Requirements: 1. Integrated, transparent, and thoughtful processes. 2. Machinery and infrastructure can be fully controlled and fully integrated. 3. Full cooperation between members of the SC. 4. Outstanding response and flexibility.
Emerging Technologies: 1. Digital technologies have not been implemented, and there are no plans for implementation. 2. Random benefits can be achieved in DSC operations due to the implementation of the underlying technologies. 3. The traditional manufacturing method is used in the organization.	Emerging Technologies: 1. Some technologies have been implemented, and some are planned to be created. 2. It can generate some benefits partly in DSC processes. 3. Additive manufacturing methods are used in reserve material warehouses.	Emerging Technologies: 1. Digital technology is used extensively and comprehensively, but some cutting-edge technology can be studied. 2. The growing benefits of technologies in DSC operations. 3. Additive manufacturing methods are used in engineering design processes (or in manufacturing processes or warehouses for spare materials).	Emerging Technologies: 1. The organization can be considered the reference for the best practices in SC 4.0. 2. The process benefits can eventually be fully realized for DSC. 3. Additive manufacturing methods are used in design and engineering processes, manufacturing processes, and spare material warehouses.

Table 2 (continued): Digital supply chain maturity framework.

Initial	Intermediate	Advanced	Cutting-Edge
Leadership and Managerial Support: 1. DSC is not part of the plan but merely a desire. 2. There is a lack of backing from the leaders and no organizational direction. 3. The IT infrastructure is unable to accommodate DSC fully. 4. Organizations and individuals unable to implement DSC.	Leadership and Managerial Support: 1. DSC is part of the plan but has not yet become standard. 2. Backing from the leaders exists but is insufficient to fully assist DSC initiatives, and some organizational direction is needed. 3. Your IT infrastructure can accommodate some DSC technologies. 4. The organizational structure and personnel skills are still evolving.	Leadership and Managerial Support: 1. DSC is an integral part of the plan. 2. Backing from the leaders is high but not yet completely vested. 3. IT infrastructure can accommodate most technologies. 4. The organizational structure and people skills have been extensively developed.	Leadership and Managerial Support: 1. DSC is a crucial plan driver. 2. Higher priority for full backing from leadership and organizational direction. 3. The IT infrastructure fully accommodates and enhances DSC. 4. The organizational structure and individual capabilities are distinct.
Emerging Technologies: 1. Digital technologies have not been implemented, and there are no plans for implementation. 2. Random benefits can be achieved in DSC operations due to the implementation of the underlying technologies. 3. The traditional manufacturing method is used in the organization. 4. Virtual reality is not used.	Emerging Technologies: 1. Some technologies have been implemented, and some are planned to be created. 2. It can generate some benefits partly in DSC processes. 3. Additive manufacturing methods are used in reserve material warehouses. 4. VR is used in a few processes, such as acquiring skills, production, preparing models, or contacting the customer, and then the customer can see the product in VR.	Emerging Technologies: 1. Digital technology is used extensively and comprehensively, but some cutting-edge technology can be studied. 2. The growing benefits of technologies in DSC operations. 3. Additive manufacturing methods are used in engineering design processes (or in manufacturing processes or warehouses for spare materials). 4. Virtual reality is used in some operations.	Emerging Technologies: 1. The organization can be considered the reference for the best practices in SC 4.0. 2. The process benefits can eventually be fully realized for DSC. 3. Additive manufacturing methods are used in design and engineering processes, manufacturing processes, and spare material warehouses. 4. Virtual reality is mainly used in all manufacturing and service operations in the company.
Leadership and Managerial Support: 1. DSC is not part of the plan but merely a desire. 2. There is a lack of backing from the leaders and no organizational direction. 3. The IT infrastructure is unable to accommodate DSC fully. 4. Organizations and individuals unable to implement DSC.	Leadership and Managerial Support: 1. DSC is part of the plan but has not yet become standard. 2. Backing from the leaders exists but is insufficient to fully assist DSC initiatives, and some organizational direction is needed. 3. Your IT infrastructure can accommodate some DSC technologies. 4. The organizational structure and personnel skills are still evolving.	Leadership and Managerial Support: 1. DSC is an integral part of the plan. 2. Backing from the leaders is high but not yet completely vested. 3. IT infrastructure can accommodate most technologies. 4. The organizational structure and people skills have been extensively developed.	Leadership and Managerial Support: 1. DSC is a crucial plan driver. 2. Higher priority for full backing from leadership and organizational direction. 3. The IT infrastructure fully accommodates and enhances DSC. 4. The organizational structure and individual capabilities are distinct.

At the Initial level, organizations exhibit limited technological adoption, weak managerial support, and poorly defined processes, resulting in low strategic performance. In contrast, the Cutting-Edge level is characterized by strong leadership commitment, full integration of advanced technologies, optimized processes, and superior strategic outcomes.

The intermediate stages represent gradual improvements in capabilities, where organizations

enhance their technological infrastructure, strengthen coordination mechanisms, and improve process efficiency.

The framework adopts a bottom-up logic, where leadership and managerial support enable the adoption of emerging technologies, which in turn enhance process performance and ultimately lead to improved strategic outcomes.

Despite being grounded in a systematic literature review, the proposed framework requires further empirical validation. Nevertheless, it offers a comprehensive and structured approach for assessing DSC maturity and provides practical guidance for managers seeking to enhance digital transformation within supply chains.

7 CONCLUSIONS

This study aimed to identify the key dimensions of the Digital Supply Chain (DSC) within the context of Industry 4.0 and to develop a conceptual maturity framework based on a systematic literature review (SLR). The analysis resulted in the identification of 20 sub-dimensions, which were structured into four core constructs: leadership and managerial support, emerging technologies, process performance requirements, and strategic outcomes. These constructs provide a comprehensive answer to the first research question concerning the foundational elements of DSC.

To address the second research question, a four-level DSC maturity model (Initial, Intermediate, Advanced, and Cutting-Edge) was developed. The model explains how organizations can progressively enhance their digital supply chain capabilities through the alignment of managerial, technological, and operational dimensions.

The study contributes to the literature by offering an integrated and structured framework for assessing DSC maturity, addressing an existing gap in prior research. From a practical perspective, the proposed model provides managers with a clear roadmap for evaluating current capabilities and guiding digital transformation initiatives.

However, the study is limited by its reliance on SLR methodology. Future research should focus on empirical validation through surveys, case studies, and statistical modelling to test the relationships between the proposed constructs. Further studies may also refine the framework by examining its applicability across different industries and supply chain contexts.

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