Digital Supply Chain: Conceptualisation of the Research Domain

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Abstract

In this decade, manufacturing companies are facing events that disrupt delicate balances and experiencing tangible challenges that cannot be deferred. Among these, the acceleration of technological transformation to follow the introduction of Industry 4.0, the difficulty in sourcing raw materials and accessing different markets due first to the COVID 19 pandemic and more recently to geopolitical tensions and conflicts. In this scenario, traditional supply chain models need to transform into digital supply chains (DSCs), where functional silos are broken down to enable end-to-end visibility, agility, collaboration, and resilience to such shocks. The literature on the subject is still immature and many concepts are still vague and undefined. In this regard, this article aims to answer the following questions: (i) What are the main research areas within the topic? (ii) What is the development trajectory of the topic? (iii) What are the main digital technologies that can support DSC capabilities? (iv) What can be its research agenda? For this purpose, this paper aims at reviewing the existing scientific production on DSCs, combining a systematic review with bibliometric tools. The resulting framework can serve as a preliminary guide for companies facing the challenges listed above and can open up future research that can validate the results empirically.

Keywords
Digital supply chain, digital capabilities, supply chain management, industry 4.0.

1. Introduction and background

The phenomenon of digital transformation is disrupting all types of supply chains (SCs), also encouraged by the improvement of digital technologies and the spread of the Industry 4.0 paradigm (Queiroz et al. 2019). Although it originated in the manufacturing world, due to its importance and implications on SC processes and activities, the implementation of digital technologies is spreading in the SC world, giving rise to the term Digital Supply Chain (DSC) (Azevedo et al. 2022).

The concept of DSC has been the subject of numerous studies in the scientific literature over time, however it is still developing (Kayikci 2018) and there are several definitions of the concept of DSC (Hanaysha, and Alzoubi 2022).

For example, Agrawal et al. (2019) define DSC as an agile, customer-driven and productive way to develop different forms of returns for companies and to leverage efficient approaches with emerging techniques and data analytic. Similarly, DSC has been conceptualized as an intelligent best-fit technological system that is based on the capability of massive data disposal and excellent cooperation and communication for digital hardware, software, and networks to support and synchronize interaction between organizations by making services more valuable, accessible and affordable with consistent, agile and effective outcomes (Buyukozkan and Gocer 2018). In another study, a DSC system is composed of systems (hardware, software, communication networks) that support interaction between globally distributed organizations, orchestrating the activities of the partners in supply chains (Bhargava et al. 2013). The DSC is thus characterized by two essential elements: one is digital transformation and the second is the integrated adoption of digital technologies (Nasiri et al. 2020).

Indeed, digital technologies are seen as promising means to improve supply chain processes (Ye et al. 2022). For example, IoT has been extensively applied in factories and transportations to monitor the production process, and track and trace the logistics and warehouse operations (Caro and Sadr, 2019). The real-time data collected from the IoT devices, combined with the data from other supply chain processes, has the potential to generate significant business value through the application of Big Data Analytics (BDA) and Artificial Intelligence (AI) (Kache and Seuring, 2017). In addition, Rogerson and Parry (2020) illustrate how the deployment of technologies such as blockchain, RFID, among supply chain members improves the timeliness and accuracy of the information and achieves end-to-end transparency. These emerging digital technologies are not only changing the products and process, but also modifying value chains, renovating business models, and affecting the industrial structures (Ceipek et al. 2020).

Moreover, the DSC aims to solve one of the most important problems of the traditional supply chain, namely digital divides, such as information asymmetry (Chen and Huang 2020). Data availability and data exchange has made it possible for organizations to have effective and efficient coordination and collaboration between their SCs. According to Riemer and Schellhammer (2019), the ability to collaborate and exchange information has provided new forms of working and also new types of virtual organizations, which have given companies the need to adjust their operations. The DSC has thus provided many benefits to the companies, but many benefits sometimes remain only at the potential level (Nasiri et al. 2020). There are many causes why the benefits of digital transformation are not being fully exploited, such as disruption of the nature of transformation, or negligence on the part of managers (Büyüközkan and Göçer, 2018). Though the advantages of digital supply chain management (DSCM) are many, its implementation might be rather slow for several reasons (Agrawal et al. 2019; Dai et al. 2022).

On the one hand, implementation of digital technologies make supply chains faster and efficient. On the other hand, they introduce a higher level of complexity and variability into the relationships that require more sophisticated measurements to assess its performance (Rasool et al. 2021). New digital technologies have tremendous implications for the supply chain, but without the human resources the benefits associated with digitalization cannot be realized (Agrawal et al. 2019).

In a traditional supply chain, organizational structures are bound by their geography/function, act in silos and are reluctant to share information openly, while DSC makes systems reliable, agile and effective by distributing information, facilitating collaboration and communications across digital platforms (Rasool et al. 2021). In the traditional supply chain, technology is used to collect, store and present data, while in DSC, technology is used to make strategic decisions (Wei et al., 2019). Therefore, applying novel technologies in traditional linear SCs with a discrete movement of "plan, source, make, deliver and return" changes SCs from a static to a dynamic succession (Liotine, 2020). Moreover, differences in traditional and DSC targets create a barrier to digital transformation. The focus of traditional supply chains regards the reduction of costs and time, while customer-centric approach, flexibility, connectivity, transparency and scalability are the specific characteristics of DSC (Büyüközkan and Göçer, 2018).
The digital transformation has thus completely revolutionized the setting of traditional supply chain, increasing the need to develop digital capabilities in order to gain a sustainable competitive advantage (Bag et al. 2021; Tortorella et al. 2020). In the digital age, therefore, the focus has increasingly shifted towards the development of capabilities based on application of different digital technologies.

The development of DSC is still in its infancy and there has also been a huge increase in publications on the topic (Masvosvere and Venter, 2016). Buyukozkan and Gocer (2018) reviewed existing studies on DSCs and constructed a comprehensive DSC framework. However, due to the possibility of subjective bias and the qualitative summary in their literature review, it is difficult to identify the research hotspots and development trends in DSCs comprehensively and objectively based on their work. In this study, co-occurrence analysis of authors' keywords and the citation network analysis are used in the bibliometrics system.

The specific objectives of this study are to address the following research questions (RQs):

(i) What are the main research areas within the topic?
(ii) What is the development trajectory of the topic, especially considering the recent events?
(iii) What are the main digital technologies that can support DSC capabilities?
(iv) What can be its research agenda?

For this purpose, this paper aims at reviewing the existing scientific production on DSCs, combining a systematic review with bibliometric tools.

2. Method and data

The method used in this article draws inspiration from the SLNA, Systematic Literature Network Analysis, introduced by Colicchia and Strozzi (2012) and further developed by Strozzi et al. (2017). In particular, this article adopts the co-occurrence analysis of authors' keywords and the citation network analysis.

The keyword co-occurrence network analysis is based on the approach developed by Waltman et al. (2010). The approach consists of a combination of clustering and mapping of bibliometric networks implemented in the dedicated software VOSviewer. Clusters are groups of keywords that are most frequently used together to classify articles and their analysis can reveal areas of research within the topic. This makes this method well suited to guide the answer to RQ1. The map is a representation of the network, in which the nodes, i.e., the keywords, have various sizes according to their occurrence weight and their colour corresponds to their belonging to different clusters.

In the citation network, connected components, i.e., nodes representing publications linked by citations, are connected by arrows representing the flow of knowledge. Considering only the connected components, it is possible to identify the main development trajectory of the field by extracting the so-called “main path” component, which represents the “backbone of the research tradition” (Lucio-Arias and Leydesdorff 2008; Colicchia and Strozzi 2012). As stated by Strozzi et al. (2017), indeed, the Main Path highlights articles that build on earlier ones but continue to act as a hub for later work. This certainly assists in elaborating and discussing the answer to research question RQ2. The Main Path extraction was performed using Pajek, a software for analysing and visualising large networks, following the procedure suggested by Colicchia and Strozzi (2012).

The answers to RQ3 and RQ4 are derived from the combined interpretation of the results of both analyses.

This method was applied to a dataset of articles identified through a search in SCOPUS, the largest database of citations and abstracts of peer-reviewed scientific literature (Dan et al. 2020; Ribeiro, Fernandes, and Lopes 2020; Pozzi et al. 2021). The search was carried out by searching for "digital supply chain" in the TITLE-ABS-KEY field. The KEY field includes AUTHKEY (author's keywords) and different types of indexed keywords. Author's keywords are keywords chosen by the authors themselves to describe the specific content of their work. Indexed keywords are vocabulary and thesaurus terms provided by a publication to encompass all features of the content more broadly and comprehensively. In addition to searching for words in the title, the use of the ABS (abstract) field makes it possible to include articles not only exclusively devoted to the topic but also whose abstract contains a reference to it. The search, performed in June 2022, yielded a result of 330 English-language articles.

In particular, this paper considers the digital capabilities model (DCM) as the reference model to scrutinize the results for RQ3 and RQ4. This model can be considered as a “digital extension” of the Supply Chain Operations Reference (SCOR) model and it includes 6 main digital capabilities, namely: connected customer, digital development, synchronized planning, intelligent supply, smart operations and dynamic fulfilment (Table 1). Although this innovative model was created as a tool purely for use by practitioners, it has already been used in some scientific contributions (Radke et al. 2021; Wuest et al. 2020).

Table 1. Description of digital capabilities of the DCM

Connected Customer	The Connected Customer Capability allows companies to augment traditional transactional interactions to achieve effective and integrated customer engagement.
Digital Development	Digital Development concerns a way of developing and managing products and services that are responsive to customer experience and transformed by smart real-time data, advanced technologies, and agile innovation.
Synchronized Planning	The Synchronised Planning capability enables a business's strategy via planning and operational levers across the entire value network. This capability integrates strategic goals, financial objectives, and tactical supply network plans to create a connected, concurrent, and synchronized business plan.
Intelligent Supply	Intelligent Supply impacts every component of the procurement function to source goods and services from leading suppliers at the best value.
Smart Operations	The Smart Operations capability is a highly responsive, adaptive, digitized, and connected function integrated into the digital supply network that synchronizes all aspects of production and operations.
Dynamic Fulfillment	Dynamic Fulfillment regards an interconnected cross-enterprise system that enhances the customer experience by getting the right product and service to the right customer or node at the right time and in the right quantity

3. Results and Discussion

3.1 keywords clusters analysis: answer to RQ1

VosViewer created nine clusters grouping a set of 67 keywords, the result of the initial 853 keywords after setting a threshold of the minimum number of occurrences of a keyword to 3. The clusters, with the list of keywords in descending order of occurrence, can be found in Appendix A. Figure 1 depicts their map. In the following, nine paragraphs are each devoted to the analysis of a specific cluster. In the clusters, the keyword used in the Scopus search, its synonyms, and generic terms on digitalization are expected to have a high weight of occurrence; therefore, the other keywords, although less frequently occurring, can guide the characterisation of the clusters.

1. Reaction to the covid 19 pandemic

The largest cluster presents many generic terms related to DSC. The most characterising terms relate to the *COVID-19 pandemic*. The *COVID-19* pandemic affected multiple industries and different geographic areas and sectors and led to high volatility of volumes and assortments in supply and demand. This has been called one of the most severe disruptive events in the SC. The resilience of SCs was facilitated in those with a high degree of Industry 4.0 *digital transformation.* In particular, BDA was proven to have helped resilience considerably (Spieske and Birkel 2021). Different rules and lockdowns in different countries and shortage of resources have made *logistics* the weak point for the manufacturing industry since the COVID-19 breakout (Cai and Luo 2020), thus calling for further research on it.

2. Technologies enabling a digital economy

The research area represented by this cluster is digital economy. *Blockchain* is an important technology for the topic as it can increase the transparency of SC information, and, for instance, it can reduce the credit risk of SME financing and operational risk in *supply chain finance* (Li et al. 2019)**.** Blockchain plays a really important role in the *digital economy* and tokens are a demonstration of this, in fact, their range now goes from simple payment (bitcoin) to almost fully electronic securities (security tokens) (Kartskhiya et al. 2020). To facilitate the integration of the digital economy with blockchain technology, the IoT is also utilized to foster network connectivity (Mentsiev et al. 2019). Moreover, a modelling approach based on formal *ontologies* can enable automated inference and verification, which is crucial for financial economic transactions (Kim and Laskowski 2018).

3. Technologies for a circular and resilient DSC

The research area represented by this cluster concerns technologies that enable a resilient and circular DSC. For example, *Additive Manufacturing* (AM) can decrease the supply *risk* by offering the opportunity to replace missing materials with *3D*-printed components, thus it provides *resilience* to manage the *ripple effect* caused by the disruption in returns at the recycled-material supplier end; furthermore, it can diminish waste by employing just-in-time production (Ivanov et al. 2019; Dev et al. 2021). For this reason, *AM*, together with *BDA* and IoT, CPS, and Cloud Manufacturing, has been identified as the digital enablers of the *circular economy* (Rosa et al. 2019). In particular, *AM* and *BDA* can help in recycling, while the others support the refurbishing, remanufacturing, and reuse processes since they enable tracking and tracing of the products (Hettiarachchi et al. 2022). The role of the DSC *digital twin* will be discussed in cluster 5.

4. Blockchain in DSC

This cluster is dedicated to *Blockchain* in the DCS. *Blockchain* can support *IoT* systems by giving them the *security* they need to ensure that data is not hacked. *Blockchain* can be used to track sensor data measurements and prevent duplication with other malicious data, and in this way, *IoT* sensors can avoid going through a third party to establish trust (Pundir et al. 2019). Blockchain can also be used in combination with AI. In this case, AI can support Blockchain smart contracts by testing them to clean them of bugs (Marwala and Xing 2018). In addition, *AI* agents have capabilities in selection, prioritisation, and goal-oriented behaviour as well as sociability (cooperation, communication, and mutual negotiation). The results of learning and collaboration will be transmitted to the contract layer and the operations layer, thereby optimising the contract design and operation, and realizing the truly *"smart" contract* (Wang et al. 2019).

5. The benefits of a DSC twin

This cluster is devoted to the DSC *digital twin*, i.e., a model that can represent the state of the network at any time and allow complete visibility of the SC system to improve *resilience* and test contingency plans. A *digital twin* can support decision-making on the physical system based on data and quantify its impact. *Simulation* in the *digital twin* can help predict possible disruption propagation and enables efficient testing of recovery policies and the adaptation of contingency plans. A simulation model can activate BI algorithms to search for the causes of problems. Interacting with other SCM tools, a *digital twin* provides a control tower for end-to-end SC visibility (Ivanov et al. 2019). Moreover, a digital twin based on the product life cycle approach can optimally allocate resources where they are most needed improving the SC *sustainability* (Kamble et al. 2022). In general, the literature indicates that digital technologies contribute to SC *viability* improving production flexibility through AM (see cluster 3), demand forecasting through data analytics, and SC visibility through the use of digital twins (Ivanov 2020).

6. Cyber-Supply Chain Risk Management

The keywords of the sixth cluster indicate an area of research related to Cyber-Supply Chain Risk Management, a discipline that combines the expertise of *cybersecurity*, SC management and enterprise *risk management* and is designed to contain the increasing proliferation of DSC attacks that seek illicit access to corporate networks for disruption of operations, theft of financial and intellectual property and competitive espionage. (Boyson 2014; Boyson et al. 2021).The topic is still poorly established and very few companies have mastered the tools to combat this growing threat (Boyson et al. 2021). The difficulties in implementing good *risk management* are even greater for *SME*s, and for them it is convenient to use collaboration platforms that provide such a service (Liu et al. 2022).

7. Real-time systems

Real-time systems are crucial for a DSC and this cluster highlights their importance. One example of the benefits is the use of information technology to capture consumer response and demand signals in real-time for flexible and agile response. In digital *manufacturing* networks, information flows are enabled by *real-time* data analysis to support decision-making for better scheduling and planning of operations. In addition, robotics and automation can enable real-time data collection of material flow, improving production and replenishment. Also, Bluetooth, sensors and RFID are *real-time* location sensing as they provide the ability to track the flow of information along SCs through real-time data analysis (Büyüközkan and Göçer 2018; Ho et al. 2022). The keyword *'literature review'* also appears in this cluster. In fact, 48 articles of the 330 identified are reviews. This may suggest on the one hand the interest and need to consolidate and define the topic, on the other hand room for application cases.

8. 4.0 Scheduling

This cluster is open to two different interpretations, i.e. either the use of DSC technologies for scheduling the various phases or considering issues related to DSC *disruptive technologies* as *scheduling* problems.

Regarding the first interpretation, many articles highlight that the use of 4.0 technologies in SDC, such as cyber-physical systems, cloud computing, IoT, and BDA, enable real-time scheduling that makes the system responsive and flexible (e.g., Mitra et al. 2022; Jiang et al. 2022). Regarding the second possible interpretation, the study by Dolgui (2020) is the first that demonstrates that the blockchain-oriented smart contract design problem can be presented as a flexible flow shop *scheduling* and propose a dynamic event-driven approach to solve this problem.

9. Data analytics in the DSC

The literature on DSCs indicates that *data analytics*, particularly associated with IoT, has an effect on various *performances*, including cost savings, consumer satisfaction, and operational excellence; furthermore, data analytics can support the development of green suppliers, fundamental for a circular economy *strategy* (Saryatmo, and Sukhotu, 2021). The article by Hallikas et al. (2021) analyses the benefits of data analytics in procurement. The authors show that decision-making processes based on big data lead to improvements in logistics *performance*, enhanced inventory control, and overall cost of the procurement function; however, these benefits of data-driven decision-making require an established knowledge conversion and flow of information within the organisation; these features are possible only if the analytics capabilities are closely aligned to the corporate *strategy*.

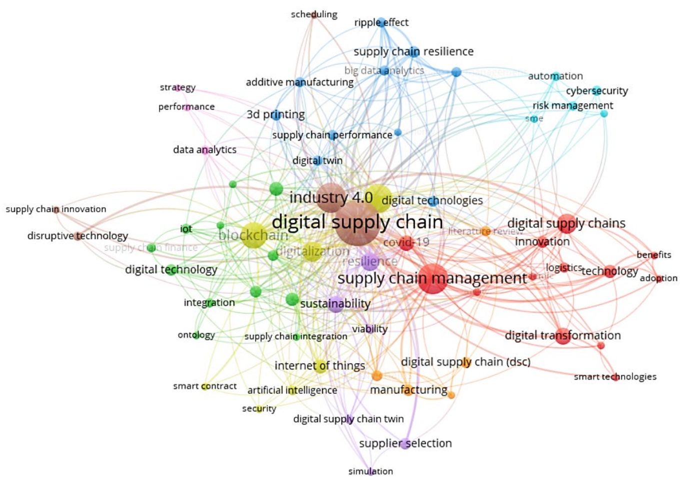

Figure 1. Authors keywords' co-occurrence network

3.2 Main-path analysis, answer to RQ2

The citation network of the 330 collected articles has many isolated nodes, i.e., articles that are not cited due to their recent date of publication or to their scope, which may be niche compared to most other articles. The network also includes eight connected components. This study considers only the largest connected component, which comprises 51 nodes, and extracts its main path. The Pajek software, with the predefined rank numbers of the key-paths, i.e., from 1 to 10, extracts a global main path indicating two main trajectories, the first consisting of 3 nodes and the second of 13 nodes (Figure 2). The papers are connected by arrows indicating the presence of a citation and whose direction goes from the cited paper to the one that is citing it, thus representing the flow of the knowledge transfer.

3.2.1 First component of the main path: focus on data security

The first component of the main path (figure 2.a) includes the three papers by Bhargava et al. (2013), Korpela et al. (2017) and Rasool et al. (2022). The topic common to all three papers is data sharing. One advantage of DSCs is that technologies can directly connect suppliers and customers and vice versa. This brings challenges on the security of the data to be shared, including the need to improve the end-to-end integration of product data and to measure data security as a metric of a DSC's performance. Regarding the topic in general, the article by Bhargava et al. (2013), reports that the main fear in 2013 was the risk of unauthorised disclosure and data leakage of information shared between partners, across multiple domains. The challenges were the lack of mechanisms to communicate the owner's policies associated with the information to the partners' protection frameworks; the lack of common information sharing and data protection standards; and staying up to date with the rapid transformations in the field. To solve these problems, the authors propose an approach that relies on the use of trust broker and taint analysis.

The paper by Korpela et al. (2017) supports the use of an open-source blockchain technology that seems to offer functionality beyond that of traditional technologies. Moreover, the authors state that technology offers data security and cost-effective transmission of transactions in peer-to-peer networks without a central system, overcoming or at least lessening the above-mentioned challenges. As such, blockchain technology simplifies B2B integration and enables IoT integration at the micro level, and, according to the authors, bypassing the trusted third party so performing the transaction quickly and at a very low cost. However, the authors recognise that the integration of DSCs still requires standards for system interoperability, which blockchain technology in itself does not offer, and that there is still research to be conducted on it.

The article by Rasool et al. (2022) deals with a broader topic, namely the definition of metrics concerning the performance of a DSC. Among these, it also defines data security, which includes implemented standards and protocols. Data security is thus defined as a KPI that must necessarily be monitored to reveal the gaps in systems and help companies protect their information and make integrations and interactions smooth and agile.

3.2.2 Second component of the main path: general development of the topic

The second component of the main path (figure 2.b) shows the development of the literature on the subject in a general, high-level perspective. It presents initial papers on the technologies and general characteristics of DCS, before more specific developments and applications only in the last year and a half. The trend of this trajectory is also confirmed by the structure of the network; in fact, it is tree-like, with branches that become denser and denser, representing an ever-increasing level of specialisation. The first papers in this component, those of the 'trunk' and main 'branches', attempt to trace the technologies and main features of DSC in the Industry 4.0 paradigm and its technological pillars. Among these papers, the first is the one by Queiroz et al. (2019), a literature review that seeks to identify the capabilities and related 4.0 enabling technologies of the DSC.

This paper plays a key role in the development of the topic as it analyses for the first time, before the publication of the DCM, the capabilities needed to support a DSC, and formalises an initial framework that can guide practitioners and researchers. The topic is evolving fast and has experienced the formalisation of the DCM and the advancement of the integration technologies and models, but this study provides the foundations and a preliminary overview on which the subsequent literature is based. However, most of the general concepts provided by Queiroz et al. (2019) still need empirical validation. The authors also suggested the need to investigate the critical success factors of a DSC implementation and the interest in studying their potential link with digital capabilities.

The paper by Sharma and Joshi (2020) deals with the selection of suppliers, a topic still related to the formation of the DSC and the definition of its characteristics, in this case, the necessary competencies of the suppliers. Technologies are still the main topic as this study provides a comparative basis for identifying the best suppliers based on the digital technologies they use.

The paper by Li et al. (2020) stands out in the main path for introducing the important concept of DSC platforms. Specifically, the paper demonstrates with a survey that DSC platforms mediate the effects of digital technologies on economic and environmental performance, important axes of sustainability at the centre of attention in the 4.0 era. Furthermore, the paper shows that mediation effects are enhanced in the presence of a high degree of environmental dynamism. However, the paper refers to digital technologies including only the Internet of Things, cloud computing, and BDA; the latest technological developments in DSC may require more extensive investigation.

By introducing the environmental theme, the paper by Li et al. (2020) opens up for more specific developments in the last year and a half; indeed, the paper by Sharma et al. (2022) conducts an empirical analysis of the impact of environmental dynamism on low-carbon practices and DSC networks to improve sustainable performance; the chapter written by Nowicka (2021), provides a specific perspective for the definition of DSC business models, namely that of the values of the circular economy, a theme already analysed in the authors' keyword clusters.

The articles by Attaran (2020) and Cagliano et al. (2021) are still about digital technologies relevant to the DSC. Attaran (2020) conducts a literature review analysing the main 4.0 technologies but concludes the article with a consideration about the importance that 5G technologies will play in industry and DSC and a suggestion to conduct research on this. The article by Cagliano et al. (2020) conducts an ANOVA analysis to understand the influence of several social and economic factors on the implementation of DSC technologies. The results reveal that economic factors such as GDP per capita or the level of foreign investment play a key role in driving the application of individual technologies. Furthermore, they show that Big Data requires significantly more economic effort than other technologies. The authors suggest further research to investigate how the initial economic funding affects the adoption of each technology and how its success drives the global adoption patterns of DSC technologies.

The paper by Nasiri et al. (2020) plays an important role in the main path, in fact, it is a hub from which six other publications branch off. This paper also analyses the role of smart technologies, in particular demonstrating with a survey that smart technologies fully mediate the relationship between digital transformation and relationship performance. Among the articles based on Nasiri et al. (2020), Khan et al. (2021) proposes a knowledge-based expert system for assessing DSC readiness, to help organisations assess their current status in the transformation from traditional SC to DSC and develop a plan to achieve full digitisation. The papers by Souza et al. (2021) and by Chauhan et al. (2021) are not accessible. However, the former is a qualitative study on the links between Industry 4.0 with its technologies and DSC; the latter is a case study on the digital transformation of a biomedical company. On the other hand, the study by Muafi et al. (2022) analyses the link between Green Intellectual Capital, SC Integration, DSC, SC Agility, and Business Performance. While the article by Dai and Wu (2022) analyses the characteristics of the time-delayed DSC driven by cybersecurity.

The papers branching off from Nasiri et al. (2020) confirm the topic's evolutionary trajectory. Indeed, those published in early 2021 still deal with the general characteristics and definitions of a DSC and its enabling technologies, while those published in the last year and a half focus on more specific topics.

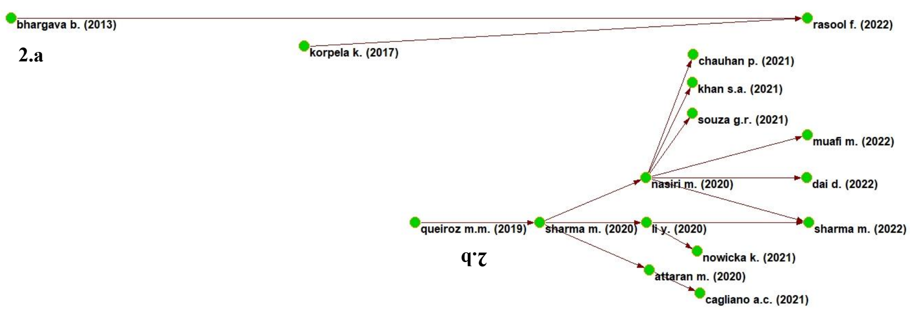

Figure 2. Main path of the citation network (2.a: first component; 2.b: second component)

3.3 Main digital technologies that can support DSC capabilities: answer to RQ3

In this section, the DCM model is adopted in the form of a table (Table 2) to guide the synthesis of the results of the analyses with reference to the technologies to be used to improve or foster each capability. The items on the right of each capability are the second-level capabilities suggested by the model itself. Only those identified are shown. Future studies may pursue the completion of all of them.

Table 2. Main digital technologies that can support DSC capabilities

Connected Customer	**Tracking and monitoring:** IoT, CPS, and Cloud Manufacturing (cluster 3)
Digital Development	
Synchronized Planning	**Inventory and supply optimization:** DSC digital twin (cluster 5)
Intelligent Supply	**Supplier analytics:** IoT, BDA (cluster 9)
	Smart sourcing execution (procurement): BDA (cluster 9)
	Intelligent contract management: Blockchain smart contract, IoT and AI (cluster 4) **(risk management):** Cybersecurity (cluster 6)
Smart Operations	**Optimum operations (scheduling):** CPS Cloud Computing, IoT, and BDA (cluster 8) Robotics and smart machines (cluster 7)

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	Operations command center and dynamic visibility: DSC digital twin and simulation (cluster 5)
Dynamic Fulfillment	**Supply network traceability:** Bluetooth, sensors and RFID (real-time location sensing) (cluster 7)

3.4 DSC research agenda: answer to RQ4
In summary, research on the topic has increased considerably over the past few years, but some issues are still unresolved or need further investigation. The main ones that emerged from the analysis conducted are listed below.

- Integration of DSCs still requires standards for system interoperability.
- Further research should also provide advice on companies' implementation of Supply Chain Risk Management
- The definition of digital capabilities, the relationship to digital technologies, and the link to critical success factors for the implementation of a DSC need further study and empirical validation of the results already found.
- Future research should attempt to develop a framework to guide companies in implementing a DSC by identifying technologies and steps to follow for each DCM capability.
- Future studies should review these issues such as digital platforms, environmental impacts, and business performance in relation to a broader and more up-to-date set of technologies.
- Literature should further explore the role of 5G technologies in DSC. Research opportunities could include assessing their benefits and costs and developing recommendations on product and process characteristics for which this new technology can be particularly useful (Dolgui and Ivanov, 2022).
- Further research is needed on logistics improvement, a weak point of the DSC after COVID-19.
- Further research should investigate how the initial economic funding affects the adoption of each technology and how its success drives the global adoption patterns of DSC technologies.

4. Conclusion

4.1 Theoretical Contribution
This study answers four RQs relating to the DSC. Beyond mapping the current research areas and trajectories in extant literature, this study sheds light into main digital technologies. Thereupon, possible areas for future research are presented. In doing so, this study contributes to the better understanding of the DSC, attempting to integrate several successful enablers across different research areas that are currently found in different clusters of literature. For this study, the paper identifies nine clusters of extant research that are logically interconnected to derive a better understanding of the DSC.

In summary, the study contributes to a better understanding of the emerging concept of a DSC (Kayikci 2018), that is still lacking a comprehensive conceptualization and definition of the concept of DSC. Through identification of the nine clusters and logically arranging them, this study is able to further shed light on the conceptualization of the DSC (Agrawal et al. 2019; Hanaysha, and Alzoubi, 2022).

4.2 Managerial Implications
The current state of this study is a starting point for the development of a framework to guide a targeted interpretation of the factors required to fully exploit all capabilities related to a DSC. Most notably, the study highlights the roles of developing a DSC through a) data generation with a DSC digital twin, such as of inventory and stock levels as well as tracing goods in the supply chain. In logistics processes, Bluetooth, sensors and RFID enable data generation in real-time. Additionally, CPS and Cloud Manufacturing allow to interconnect logistics and production in enterprises. Robotics and smart manufacturing are further enablers to generate production and manufacturing data for the DSC. Further, b) data transmission along the entire supply chain through the IoT allows data to be available for all supply chain partners, allowing supply chain transparency. Thereupon, through c) data analytics and BDA, the DSC can highlight potentials for optimization. Further, this allows to d) make decisions autonomously and implement, for instance, autonomous decisions such as procurement or smart contracts through AI. Not to be neglected, e) framework conditions such as cybersecurity must be fulfilled in order to implement the DSC successfully.

4.3 Limitations

This paper presents several preliminary results, such as with regard to Table 2, which is required to be enhanced in future studies. Further, the authors attempt to enrich the present results with further insights. More concretely, the formalization can be enriched by other elements beyond the simple list of technologies.

Additionally, the current perspective is focused on the DSC itself and can be enhanced by integrating the view of Green Supply Chain Management and the requirements of the Circular Economy. For instance, future research could investigate more in detail the co-requirements and compound effects of DSC and sustainability, as described in recent research publications, such as in, for instance, Lerman et al. (2022).

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Julian M. Müller is Professor at Kufstein University of Applied Sciences (Austria). He holds a PhD from Friedrich-Alexander University Erlangen-Nürnberg (Germany). His research interests include Industry 4.0, supply chain management, technology and innovation management, and sustainability. He is part of several projects on the integration of Industry 4.0 in supply chains. In this regard, the integration of small and medium-sized enterprises (SMEs) in their role within entire supply chains is a core research topic. Further, he published several reports for the European Commission, such as on “Future Technology for Prosperity” for “Horizon Europe” or on the “Industry 5.0” concept of the European Commission. He authors several journal articles and edited two books on Industry 4.0.

1. **Reaction to the covid 19 pandemic**	**2. Technologies enabling a digital economy**	**3. Technologies for a circular and resilient DSC**	**4. Blockchain in DSC**	**5. The benefits of a DSC twin**	**6. Cyber-Supply Chain Risk Management**	**7. Real-time systems**	**8. 4.0 Scheduling**	**9. Data analytics in the DSC**
supply chain management	digital supply chain management	supply chain resilience	supply chain	resilience	cybersecurity	manufacturing	digital supply chain	data analytics
digital supply chains	digitization	3d printing	blockchain	sustainability	automation	digital supply chain (dsc)	industry 4.0	performance
digital transformation	blockchain technology	digital technologies	digitalization	supplier selection	risk management	supply chains	disruptive technology	strategy
covid-19	digital technology	additive manufacturing	internet of things	digital supply chain twin	internet of things (iot)	literature review	scheduling	
technology	digital economy	big data analytics	artificial intelligence	viability	sme	real-time systems	supply chain innovation	
innovation	iot	digital twin	security	simulation				
logistics	integration	ripple effect	smart contract					
adoption	supply chain finance	supply chain performance						
agility	ontology	supply chain risk management						
benefits	supply chain integration	circular economy						
collaboration	supply chain visibility							
pandemic	technology implementation							
smart technologies								

APPENDIX A
Clusters of authors' keywords