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Digital supply chain: literature review of seven related technologies

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Abstract. This paper systematically reviews literature related with digital supply chains (DSC) and investigates the application status and development trend of different digital technologies in supply chain management. The review is conducted from the perspective of seven key digital supply chain technologies, i.e. Internet of Things (IoT) & Radio Frequency Identification (RFID), 5th Generation Mobile Communication Technology (5G), 3D Printing, Big data (BD), Blockchain, Digital Twins (DT), and Intelligent autonomous vehicles (IAVs). It highlights the main limitations and opportunities of the various DSC technologies, provides an overview of prior studies, and identifies knowledge gaps by outlining the advantages, weaknesses and restrictions of individual technology. The paper also aims at providing a development framework as a roadmap for the match of different digital technologies with different strategic goals.

Keywords: Digital supply chain (DSC) / internet of things / RFID / 5G / 3D printing / big data / blockchain / digital twins / intelligent autonomous vehicles

1 Introduction

The introduction of the idea of "digitalization" over the past few decades has resulted in numerous changes and advancements in a variety of fields. The effective use of digital technologies in supply chain management (SCM) has given rise to the concept of a "digital supply chain" (DSC), which transforms and enhances the established supply chain in numerous ways [1]. As businesses search for new methods to deliver products quickly, one of the most important DSC pillars will be the swift matching of information and suitable suppliers [2]. According to a Gunasekaran et al. [3] survey, 82% of CEOs in sectors with active supply chains want to boost corporate spending on digital capabilities. It is anticipated that the whole digital supply chain market will reach $13.679 million by 2030, creating a compound annual growth rate of 13.2% because of the COVID-19 pandemic's pressure on the supply chain sector to accelerate its move toward digital transformation [4]. According to Future of Supply Chain Survey [3], 61% respondents said technology was a source of competitive advantage, and 81% of chief supply chain officers planned to implement but had not yet begun actively to figure a digital supply chain roadmap. It is a challenging problem for businesses to find an appropriate transformation path and economical technology at the early stage of the supply chain's digital transformation.

A large number of researchers have summarized and reviewed existing research in the field of DSC, predicted future developments and challenges, and provided researchers with different perspectives on this issue. For example, Frank et al. [5] and Barata [6] concentrated on supply chain management (SCM) studies in the age of Industry 4.0. These papers offered recommendations for future study while summarizing the trends of Industry 4.0 technology in manufacturing firms. Bongomin et al. [7] and Meindl et al. [8] investigated the applications of Industry 4.0 technologies in the industrial sectors and the SCM areas. However, most of these studies focused on the manufacturing industry, and there were few literature reviews on other business fields, such as the medicine sector and food field. Raj and Sharma [9]investigated different aspects of the digital supply network. One of the most crucial DSC pillars was the capability to react quickly to demand as businesses search for faster methods to deliver goods and overcome fictitious delivery obstacles. Additionally, DSC has the capacity to achieve operational agility by making efficient use of the data gathered and models to quickly adapt to shifting environmental conditions. Through sensor arrays or other cutting-edge technologies, DSC offers ways to improve warehouse management and constantly monitor inventory levels to

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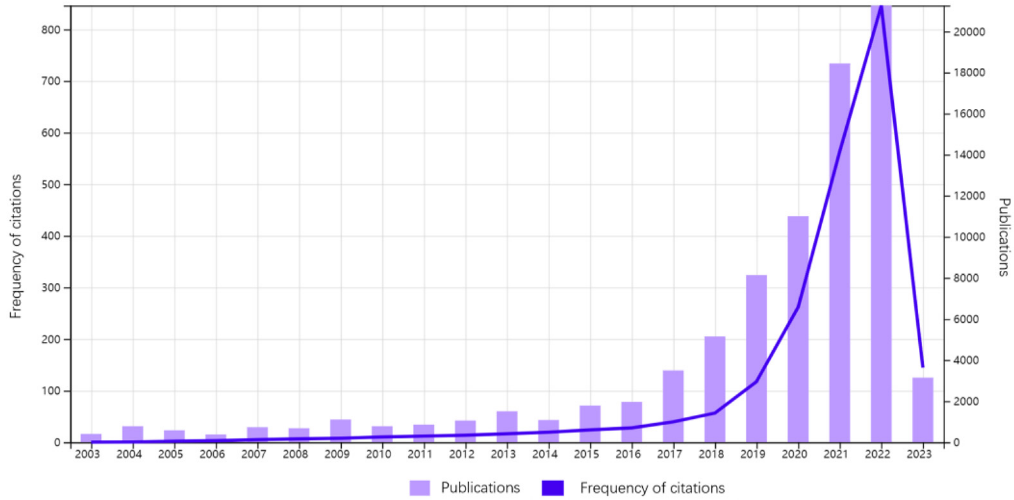

Fig. 1. Average annual number of digital supply chain literature publications 2003–2023.

guarantee the right amount of inventory available to satisfy demand and anticipates future demands for products and services and purchasing trends [10,11]. These studies summarized certain characteristics of DSC. However, the literature summarizing the multiple technologies of DSC in a comprehensive way is insufficient.

The emerging scenarios of technology applications in future DSC demand high coverage, high data transmission rate, low latency, high security, high reliability and multi-device connectivity [12]. According to Tan and Sidhu [13], RFID and IoT played an important role in meeting customer needs in the supply chain. Farajpour et al. [1] stated that they had reviewed a large body of literature on pragmatic approaches to the implementation and utilization of 3D printing, digital twins, RFID and Intelligent autonomous vehicles. Brinch [14] proved that big data was an important innovation in DSC. Taboada and Shee [15] and Musigmann et al. [16] summarized that 5G and blockchain technologies had a wide range of applications in supply chain management. Hofmann and Rüsch (2017) highlighted that future research should investigate and explore the availability of technology for different business sectors or areas of application to comply with Industry 4.0. Another important study conducted by Ben-Daya et al. [17] reviewed recent literature on digital technology applications in SCM and found the following gaps: a lack of clear guidelines for IoT and cyber-physical system (CPS) adoption in a supply chain context, a lack of a roadmap that addresses supply chain problems in a new technological environment, and a number of obstacles to implementation. Therefore, this paper fills the gap by carrying out a systematic review, summarizing the advantages, characteristics, and challenges and integrating the current state, limitations, and future trends of the seven technologies, i.e., Internet of Things (IoT) & Radio Frequency Identification (RFID), 5th Generation Mobile Communication Technology (5G), 3D Printing, Big data (BD), Blockchain, Digital Twins (DT), Intelligent autonomous vehicles (IAVs), in manufacturing industry and some other business sectors. The following research questions are proposed.

RQ1. What are the main features of the technologies of DSC?

RQ2. What are the current states of research and practices of the technologies of DSC?

RQ3. What are the trends and limitations of the DSC technologies?

2 Method of study

Figure 1 shows the distribution of published literature from 2003 to 2023. Research on digital supply chains began to grow significantly year on year from 2017, perhaps due to the popularity of integration of Internet and computer with business and industry. There will be over 800 published articles in 2022, which is certainly an emerging field. This search revealed that although practitioners widely identify and discuss, the concept of DSC with different technologies are still in the early stages of study in academics.

Figure 2 ranks the subthemes of DSC in order of popularity. The most popular theme is management, with 641 publications (19.055%). This is followed by the combination of DSC and engineering, including engineering electrical electronics and industrial engineering. In addition, scholars have focused a great deal of their attention on the fields of sustainability and computer science, which suggests the active role of DSC research in this area.

This study uses a systematic literature review (SLR) approach, consisting of three stages: planning, screening, and reporting, to conduct a qualitative literature assessment of the relevant literature [18]. The planning step includes developing search criteria and scoping the database. Relevant publications are located with the help of a detailed online search to collect, organize, and synthesize existing DSC literature with different technologies. The following major online databases were employed: Web of Science, Elsevier's Scopus, ScienceDirect (Elsevier), ProQuest (ABI/INFORM), and IEEE Xplore. The second step is screening. The relevant literature are obtained and

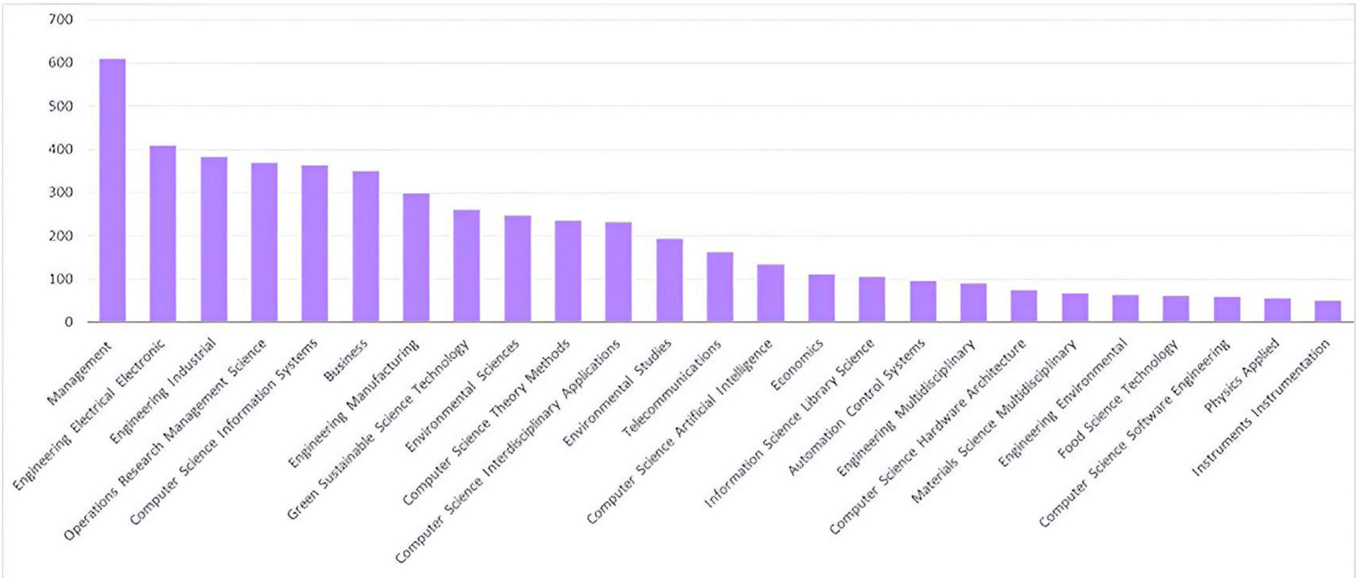

Fig. 2. Subthemes of DSC in order of popularity.

filtered, classified, and analysed. This study classifies the literature into seven areas, including emerging technologies that are widely discussed in the DSC field, i.e. IoT & RFID, 5G, 3D Printing, Big data, Blockchain, Digital Twins, and Intelligent autonomous vehicles, which were not predetermined before the search but they had gradually emerged during the comprehensive reading process that took place while drafting this study. The reporting step involves a literature review that meets the requirements to facilitate a quick overview of the field for other scholars.

3 Literature classification and review

Currently, digital supply chains can solve the disruption problem caused by information asymmetry, by data analytics to improve efficiency, sustainability, traceability, and customer responsiveness. Digitalization also brings challenges to traditional supply chains, such as uncertainty in the application of technology, infrastructure development, and the organization's ability to control costs and risks. However, digital supply chains will surpass traditional supply chain management strategies in the future, enhancing communication between companies and their suppliers, and the ability to deal with unforeseen events [9]. After analysing articles on the DSC literature, the following review is based on the seven main technologies mentioned above.

3.1 IoT and RFID

3.1.1 Overview

With the development of the Internet, enterprises need to face increasing amount of information, and how to address information asymmetry and achieve effective supply chain coordination. The Internet of Things (IoT) connects all objects to facilitate interaction with each other, forming an interconnected network [19]. IoT enables the virtualisation of supply chains and brings several capabilities to improve supply chain management, such as product tracking, inventory accuracy and cost-saving [20]. Sensing layer of IoT, integrating different types of 'things', such as RFID tags, sensors, actuators, can collect supply chain-related data, which will increase the efficiency of supply chain management [21]. Supply chains embedded with IoT offer potential opportunities for Industry 4.0 transformation to improve operational efficiency and fulfil the requirements of the fourth industrial revolution [22].

3.1.2 Application of IoT and RFID

Most reviews for IoT technology have focused on the food and manufacturing supply chains. This section takes a look at IoT technologies with a focus on impacts on supply chain management in different application areas. IoT enables digitalization in agriculture. Ruiz-Garcia and Lunadei [19] argued that IoT-related technologies, such as radio frequency identification (RFID), had the potential to help transform numerous agricultural operations, which offered excellent chances for agricultural study, development, and innovation. Tzounis et al. [23] discussed the ongoing challenges and prospects of IoT data management in the agricultural supply chain. Yan et al. [24] introduced IoT into smart production and growth of fresh agriculture produce (FAP), to manage cold chain logistics during FAP transportation, monitor the quality, offer technical support for locating and tracking, and coordinate FAP supply chain.

IoT has also applied in the field of food supply chain management (SCM). It was suggested to use an IoT-based prepackaged food supply chain management platform, which tracked the prepackaged food supply chain in real time and eventually guaranteed a safe and secure food consumption environment [12]. During COVID-19, food shortages occurred in several South African countries, and implementing IoT is essential to resolve this issue and establish a sustainable food supply chain. IoT is compatible with other business processes and systems of supermarkets to predict the demand for food more accurately [25].

In the medical industry, with the emergence of epidemics, DSC has become crucial in the vaccine industry. To address concerns with demand forecasting, vaccination quality, and stakeholder trust in the vaccine supply chain, an intelligent system for vaccine monitoring was created. IoT technology was used by this system to track vaccine quality throughout the supply chain (Hu et al., 2023).

RFID technology may have an effect on the application of IoT-related technologies in SCM. Jangirala et al. [26] developed an RFID authentication protocol for the SCM utilizing a portable blockchain that offered a better trade-off between security and functional features, communication and computational costs for the 5G mobile edge computing environment. The use of IoT made it possible to gather a lot of data on the shop floor, and a comprehensive big data strategy was recommended to frequent trajectories from many RFID-supported shop floor logistics data [27].

RFID technology is often highlighted as a solution to one of the major inconsistencies between inventory and demand, as the complete transparency of inventory. For example, Heese [28,29] found that supply chain coordination was enhanced and inventory record inconsistencies were reduced due to RFID technology. Additionally, it can save lead times, increase ordering accuracy, improve inventory losses, and lower error rates. Fan et al. (2015) concluded that RFID can adjust the order quantity to reduce cost and increase inventory availability. They also found that retailers should focus more on tag prices and the percentage of fixed RFID expenses by the newsvendor model. In addition, RFID could be applied to production, planning, and scheduling. The movement of materials might be tracked in real time once RFID has rationalized the logistics within manufacturing sites such as warehouses and workshops [30]. Zhong et al. [31] applied RFID technology to the manufacturing sector, acquiring more accurate and logical assessments and eventually achieving real-time advanced collective intelligence. Lu et al. (2016) argued that the positioning of automated guided vehicles, widely used in manufacturing and supply chain management, could be enhanced by RFID technology.

A mass of theoretical models were proposed to better apply RFID technology in SCM. In the context of production and logistics, Wamba and Chatfield [32] proposed a contingency model that analysed five weighted factors and created value in a RFID-enabled SCM. Sari [33] found that integrating RFID technology in the supply chain could provide more advantages when participants engaged in more extensive collaboration. These advantages were more pronounced when market demand was less uncertain and delivery periods were longer. A framework was proposed for considering RFID applications from the perspective of location identification and remanufacturing process optimization [34].

3.1.3 Future trends and problems faced by IoT and RFID in DSC

There are some constraints to apply IoT and RFID. Companies might face technical or economic problems if tagged on individual items [35]. To make it more economically or technically sound, examples include increasing the readability of RFID tags, properly integrating RFID data collection and decision support tools, extending the life of active tag batteries, improving processing capabilities, and developing low-cost RFID tags. It is also noted that innovation will be the driving force behind RFID adoption, rather than merely cost reduction [36]. The deployment of IoT imposed different requirements on enhancing security in various domains [37]. These include, for instance, viruses and hackers launching malicious assaults and losing control over information. Future research could focus on improving data analysis tools, establishing an early warning system. Existed problems related to IoT and RFID are classified in Table 1.

3.2 Big data (BD)

3.2.1 Overview

Big data (BD) describes a way of collecting, managing and analysing large amounts of data. BD is mostly referenced with the four Vs, i.e. volume, velocity, variety and veracity (Dietrich et al., 2014; Sathi, 2014). Volume describes the increasing size of data and data bases. Variety relates to the various forms of data: text, sound, video, multimedia, structured and unstructured, etc. Velocity represents the large amounts of data that arrive in real-time irregularly. If a further usage is necessary, the data arriving fast has to be handled. Veracity characterizes the data quality and accuracy, which determines both the credibility and suitability of the data [38].

Big data analytics (BDA) is the ideal way for decision-makers to cope with problems associated with huge volumes of data in today's competitive environment. Applications of BD in the supply chain are concentrated on managing complexity and assisting decision-making by optimizing supply chain visibility to handle risks and interruptions. The BDA and supply chain sectors should collaborate to create new, efficient models and methodologies as the complexity of global supply chain networks rises (Awwad et al., 2018). For example, companies use big data (BD) to control inventory and optimize and improve production processes, which helps them reduce internal costs associated with all processes [39].

3.2.2 Applications of BD

Giannakis and Louis [40,41] firstly advocated to combine BD with semantic web services in agent society to support the creation of multiagent-based management (MAS) system. Singh and Singh [42] constructed a theoretical framework and demonstrated that a company's past success in handling supply chain interruptions did not

Table 1. Problems description in IoT&RFID literature.

Authors	Year	Research object	Problems description
Heese	2007	Inventory management	Conduct empirical research
Fan et al.	2015	Inventory management	More different scenarios Wholesale price contracts other than the contract should be considered
Dai et al.	2012	Real-time manufacturing	More labor cost is needed More Advanced technology is needed
Zhong et al.	2015	Production planning and scheduling	Lack of extension Make more use of RFID production data logistics tracking
Lu et al.	2016	Locating approach	Reduce cost Verify feasibility and practicality
Wamba & Chatfield	2009	Supply chain network projects	The model needs to be tested and validated Upstream suppliers involved in different logistics SCM networks should be considered
Sari	2010	Supply chain performance	More complex SCM structures should be simulated Many other strategies should be considered
Ferrer et al.	2011	Remanufacturing operations	Hardly applying to every component More money and technical support on tagging individual items The RTLS tag should be used
Jangirala et al.	2019	Authentication protocol	Lack of Implement in a real-world environment
Zhong et al.	2015	Logistics trajectory Discovery	Mined invaluable knowledge will be used A method based on entropy should be studied
Ruiz-Garcia & Lunadei	2011	Agriculture	Improve the readability of RFID tags Reduce the cost of RFID tags Properly integrate RFID data collection and decision support tools Extend the battery life of active tags Improve the processing power
Tzounis et al.	2017	Agriculture	Solve information risk
Yan et al.	2017	Fresh agricultural products	More variable is needed
Li et al.	2017	Food supply chain	Evaluate the scalability and compatibility in the actual situation Data analysis tools should be further explored Establish an effective early warning system
Njomane, & Telukdarie	2022	Food supply chain	More sustainable front
Hu et al.	2023	Vaccine supply chain	Build complex models that take into account various factors Reduce cost

Table 2. Problem description in BD related literature.

Authors	Year	Research object	Problem description
Giannakis et al.	2016	Supply Chain Agility	Addressing increasing complexity of the supply chain Security vulnerabilities in the use of information systems
Singh & Singh	2019	Supply Chain Risk Management	BDA's risk response to disruption events
Kaur & Singh	2018	Sustainable Supply Chain	Difficult to choose methods for processing large data Capture of real-time parameters by big data techniques Increase computation time
Mageto et al.	2021	Sustainable Supply Chain	Cyberattack and IT skills gap Complex in implementation
Bag et al.	2020	Sustainable Supply Chain	Poor Supply Chain Sustainability Talent Skills for BDA High level of uncertainty in the environment Need cooperation with other entities
Choi et al.	2021	Circular Supply Chain	Implement and support a circular supply chain is needed
Alshawabkeh et al.	2022	Supply Chain Performance	Need a fast response to data speed Data uncertainty due to data inconsistency and data incompleteness A large number of resources in data extraction
Dev et al.	2019	Supply Chain KPIs	Offline collaboration approaches should be integrated Rapid change in performance measures Sequencing of performance measures at decision time
Zhan & Tan	2020	Supply Chain Performance	Information Islands

necessarily mean its future success in handling disruptions. Therefore, businesses can actively improve supply chain risk resilience within their organizations by investing in big data analytics capabilities [43].

By fusing sustainable supply chain concerns with BDA, Kaur and Singh [44] suggested an ecologically friendly purchasing and logistics model, which incorporated BD techniques into supply chain modelling to enable businesses to make the best choices between economic revenue and environmental responsibility by minimizing procurement and carbon emissions costs. Mageto [45] used the Toulmin argument model to establish a link between BDA and sustainable supply chains in manufacturing supply chains. This assisted business managers in choosing the best BDA tools for monitoring sustainable supply chain activities and enhancing competitiveness, performance, and productivity. Circular supply networks were additionally suggested by Choi and Chen [46], which focused on how large-scale group decision-making might materialize and promote circular supply chains in the age of BD.

It is believed that big data and predictive analytics (BDPA) are great tools for maximizing enterprise value and improving business performance (Gunasekaran, 2017). Alshawabkeh [47] discovered that the performance of the supply chain was greatly and favorably influenced by BA using a supply chain operations reference model. As a result, businesses can use big data's distinctive indicators, such as volume, speed, diversity, accuracy, and value, to enhance the efficiency of their supply chains. Dev et al. [48] proposed a heuristic method that can quickly process unstructured supply chain key performance indicator (KPI) data derived from simulation results and combined discrete event simulation, fuzzy analytical network processes, and the technique for order preference by similarity in a BDA environment to help find critical KPIs throughout the supply chain to guide managers in decision making. Integrating BDA into information quantifying and generation can support decisions making in new product development. Bag et al. [49] revealed that BDA management competence had a strong and considerable influence on the creation of new green products, and a weak but significant impact on sustainable supply chain outcomes and employee development.

3.2.3 Future trends and problems faced by BD in DSC

There are some advantages to BD technologies adoption to improve supply chain performance, build sustainable supply chains, and handle supply chain risk challenges [40,48]. However, the main challenges faced by BDA at the supply chain level are governance and compliance, integration and cooperation, information, IT capabilities, cybersecurity and infrastructure. Future trends in this area will focus on finding solutions to these four major issues so that BDA can raise the supply chain's value to the company. Existing literature related to BD and supply chain are listed in Table 2.

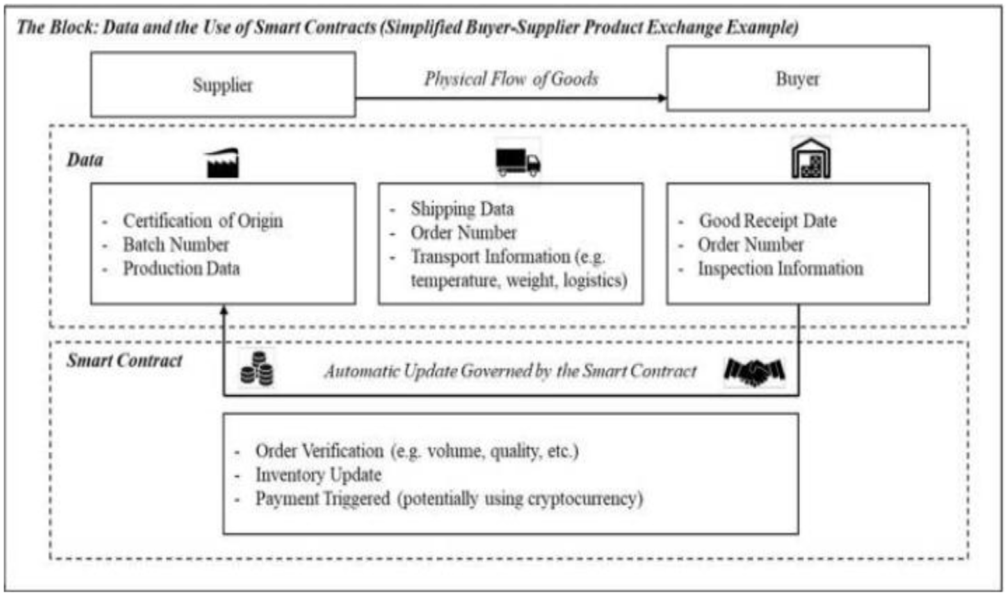

Fig. 3. Details in a block – a simplified example (adapted from [50,103]).

3.3 Blockchain

3.3.1 Overview

In the supply chain, the information created during operation is opaque and retained in separate systems, reducing the efficiency of the entire supply chain. Blockchain technology (BCT) can effectively address the issue of information silos, provide more sources of information and higher-quality data information, lower the risk of data leakage, and ensure the security and effectiveness of the supply chain based on BD analysis (Behl, 2022). For instance, the food and pharmaceutical industries have started using blockchain technology to ensure the quality and safety of their products, which safeguards businesses' reputations and the safety of their clients. In the context of operations and supply chain management, the block may contain data or trigger a smart contract. The development of the block is shown from requesting a new transaction, transaction broadcasted to the P2P Network, verification to the completed block being appended to the chain. Through a simple buyer-supplier example as Figure 3, the details in the block are shown about the data recorded at each stage and how the smart contract increases value to the process [50].

3.3.2 Applications of Blockchain

Blockchain in a SUPPLY CHAIN setting has been covered in an expanding corpus of literature [51,52]. This section focuses on three main applications of BCT, i.e. supply chain finance, traceability and security, and intelligent contract management.

An increasing number of businesses are starting to use BCT to support supply chain financing [53]. Supply chain finance problems are solved by blockchain for the transparency features in some different sectors. The fabric BCT platform was developed for logistics businesses in finance, where the private information of logistics firms was encrypted while smart contracts are created to simplify the loan and payback procedure for the companies (Fu et al., 2022). Additionally, Blockchain technology could help small- and medium-sized enterprises (SMEs), addressing their time-consuming, costly, and finance constrained issues. Su et al. (2022) used evolutionary game theory to create a three-party game model of SMEs and showed the dynamic developmental route of supply chain financing techniques with BCT.

Security and traceability are two primary applications of blockchain. Many instances of food fraud, contamination, and adulteration are documented every day in numerous nations or regions, highlighting the urgent need to modernize the decentralized supply chain paradigm. From farm to table, blockchain enables the tracking of products' basic materials and origin to ensure food quality for consumers [54]. Khanna et al. [55] developed a platform for supply chain in dairy industry using BCT, which could guarantee the security and traceability of dairy products across the supply chain. Li et al. (2022) proposed a new BCT-based model for quality and safety traceability management of traditional Chinese medicine supply chain. In short, distinct blockchain solutions have been studied and put into practice to address the issues of traceability and security, depending on the characteristics of different industries.

Smart contracts are another important blockchain application in the supply chain. BCT can assist in offering a digital solution and guaranteeing immutable and real-time tracking of all supply chain transactions, accompanied by conflicts of interest [56]. In addition, BCT can lower transaction costs by minimizing the number of intermediate proofs [57]. Chang et al. [58] suggested a blockchain-based framework with smart contracts. This facilitated the creation of multilateral collaboration networks among supply chain participants in addition to making it simpler to share and synchronise tracking data. To manage group

Table 3. Problem description in blockchain literature

Authors	Year	Research object	Problem description
Khanna et al.	2022	Safety and Traceability	Real-time complexity Difficult to interconnect multiple dairy supply chains operating in different regions
Zhang et al.	2020	Safety and Traceability	Supply chain information management is still unverifiable in terms of the credibility of the information collected versus the questions asked
Li et al.	2022	Safety and Traceability	Structured data is well researched, but storage and traceability queries for unstructured data such as video are still more difficult Credibility of data sources cannot be guaranteed
Fu et al.	2022	Supply chain Financing	Manual data entry is vulnerable to tampering The consensus mechanism of BFS is not yet perfect
Su et al.	2022	Supply chain Financing	Parameters affecting the choice of financing strategy are not adequately considered The company's reputation and the uncertainty of the market environment are not taken into account. No dynamic incentive mechanism designed Autonomy and protection issues, privacy issues
Haque et al.	2021	Smart contract	Large amounts of data will affect latency and further research will be required on off-chain transactions Off-chain architecture will need to be used to preserve the raw data
Chang et al.	2019	Smart contract	Privacy concerns, a lack of standards and protocols, legal issues, and an intolerance for mistakes Does not apply to all supply chain cases and applicability to certain scenarios still needs to be kept in doubt
Omar et al.	2021	Smart contract	Lack of transparency and trust among stakeholders Poor leadership, poor communication, conflicts of interest, cost savings

purchasing organization (GPO) contracts in the healthcare supply chain, Omar et al. [59] created a blockchain-based system, given a cost analysis and a security study. To protect and manage participant data and automate the purchasing process of the oil supply chain, Haque et al. [60] proposed the blockchain Hyperledger concept, regarding the supply chain's upstream operations in transactions and smart contracts.

3.3.3 Future trends and problems faced by blockchain in DSC

BCT has a lot of potential in the supply chain industry, however there are still certain challenges and limitations. Since not all businesses are interested in pursuing openness, therefore, future research should focus on choosing or improving a consensus mechanism that is appropriate for BCT to distribute advantages within the system and achieve consistency. The constraints on the data format, make it challenging to store and perform traceability queries on unstructured data types, like video. In addition, BCT and IoT technology can be used together to assure the acquisition and reliability of data and achieve complete data authenticity. The literature related to blockchain are summarized in Table 3.

3.4 5G

3.4.1 Overview

Mobile communication technology plays an indispensable role in human production and life and has now reached its fifth generation, namely, 5th Generation Mobile Networks (5G) [61]. The fifth generation of mobile, cellular technologies, networks and solutions – 5G, has the potential to deliver at 10 Gbps data rates, less than 1 ms latency, improved network capacity supporting billions of devices, high levels of security and reliability, and substantial energy savings [62,63]. The global market for 5G technology is predicted to reach $277 billion by 2025, which is a bright prospect [64,65]. The New Radio Network enables the New Radio (NR) and the 5G Core Network (5GC) that are the two components of the 5G architecture [66]. 5G allows to digitalise many local processes in the supply chain, such as manufacturing, warehousing, and transportation. Local digitalization can lead to fully digitalized supply chains by facilitating digital processes at the network level [67].

3.4.2 Application of 5G

Although some 5G applications, such as cloud gaming and amusement video streaming, have a stronghold in the

Table 4. Problem description in 5G-related literature.

Authors	Year	Research object	Problem description
Sriganesh et al.	2018	Industries 4.0	Need for cross-industry collaboration Need to consider training a highly skilled workforce and the unemployment associated with automation
Lagorio et al.	2023	Logistics	High costs, including workforce training and improved network infrastructure
Khatib et al.	2021	Logistics	5G networks are likely to be overloaded Big data predictions may fail when no data exists Real-world complex traffic environments present new tests of program stability
Küpper et al.	2022	Real-time location system (RTLS)	High industry demand Battery life needs to be improved Network latency issues need to be mitigated Future research needs to focus on focusing on realistic industrial scenarios to use complex environments.

market for consumers, they have not yet gained widespread adoption in the industry, especially in logistics systems [68]. The main applications of Industry 4.0 in the logistics sector include identification and traceability, robots and autonomous systems for material handling, and decision support tools [69]. Khatib and Barco [70] developed a model to upgrade traditional logistics using 5G networks with the objective to satisfy support needs while optimizing the distribution of available resources for various types of traffic. Additionally, 5G can be combined with the radio real-time-locating system (RTLS). After interviewing twenty-eight industry experts, Küpper et al. [71] argued that 5G had high accuracy and could be developed into a worldwide universal positioning system. 5G is currently in the early stages of development due to the higher requirements for infrastructure development, including long-lasting battery life and low-latency networks. Therefore, 5G positioning technology is a future research trend to enable 5G technology to assist the logistics and manufacturing industries to improve efficiency and reduce costs in complex environments in the real world.

3.4.3 Future trends and problems faced with 5G in DSC

As an emerging technology, 5G has a significant impact on supply chain digitalization [67]. However, there still exist some unresolved issues. Since 5G technology is universal, it is necessary to enhance cross-industry collaboration between the manufacturing industry and the upstream and downstream entities of the supply chains. Besides, technical facilities need to be improved, including device battery life and network latency [72]. 5G, as a communications technology, is extremely data-intensive, which can improve the accuracy of predictions [73]. For researchers, model testing of complex environments in the field can be conducted to further determine its stability. The detailed challenges of 5G literature in the digital supply chain are shown in Table 4.

3.5 3D printing

3.5.1 Overview

3D printing technology is also known as additive manufacturing (AM), which produces parts by adding material layer by layer onto a 3D solid computer model. Fixtures, cutting tools, coolants, and other auxiliary resources are not necessary. 3D printing technology is cost-effective and the higher the production volume is, the lower the average cost. Once applied on a large scale, it will inevitably reduce energy consumption and resource requirements, thus driving the digitization of traditional supply chains (Gebler et al., 2014). 3D printing can have remarkable impacts on downstream segments of the supply chain, such as manufacturing and distribution, as its integration with the supply chain is crucial in fulfilling the demands of customers of low cost and customization [74,75]. In particular, 3D printers make the supply chain more agile and flexible to react to changes in the marketplace, which reduce transport costs, holding costs and reduce waste in factories when demand is uncertain [76].

3.5.2 Application of 3D printing

There is great potential for 3D printing applications in the areas of manufacturing supply chain, medical product customization and environmental sustainability. Scholars tended to combine 3D printing technology with the medical field, such as designing customized medical implants [77,78]. In recent years, 3D printing technology has become more integrated with environmental sustainability and the circular economy in the manufacturing industry [79,80]. More academics and business managers are investing more in AM to achieve Industry 4.0 and smart factories.

Agnusdei and Del Prete [81] conducted a literature review that currently divided 3D printing technology into three research categories, i.e. technologies and materials,

Table 5. Problem description in 3D printing literature

Authors	Year	Research object	Problem description
Agnusdei & Del	2022	Sustainability	Need to analyse from a macro perspective Insufficient research to analyse AM from a production process perspective
Ahmad et al. [122]	2023	Operation	Suppliers need to maintain production consistency across the supply chain in terms of technology Businesses need to analyse the supply chain with a more systematic perspective
Xiong et al.	2022	Circular supply chain	Emerging technologies need to be considered in the future, such as IoT, 5G, etc. Many poor regions have poor supply chain infrastructure
Thomas et al.	2022	Circular supply chain	Need to consider changing consumer demand Production, retail, and distribution sectors can be combined to develop more circular economy models
Chan et al.	2018	Manufacturing and legal	Need to strengthen IP protection Failure to reach large-scale adoption
Sun et al. [123]	2017	Food supply chain	Some ethical issues, which are yet to be resolved

additive manufacture for sustainability, and additive manufacture for design. Each of these three categories can be linked to the digital supply chain [82]. Beltagui et al. [83] described the impact of AM technologies in the supply chain, from internal operations to society. They provided a model outlining the various levels of AM adoption and contended that consistency should be guaranteed at all levels, including the operational level, strategic level, and contextual level, to accomplish AM's contribution to the organization, supply chain, market, and society. Scholars have empirically studied the performance of AM in SMEs [84,85]. They recognized local production of highly customized goods by AM had significant advantages for SMEs, including increased flexibility, easier logistics management, and lower production costs.

Regarding environment and sustainability, 3D printing technology has become very useful in waste management. Thomas and Mishra [86] proposed a circular sustainable circular economy system in the plastic industry that helped alleviate the problem of carbon emissions and maximize profit by reducing waste and ordering costs. Customers could refer to circular indexes when choosing commodities. There is a great potential opportunity for 3D printing technology to drive the development of the "reverse supply chain".

Sun et al. [87] implemented 3D printing technology in the food supply chain, providing means for tailoring and modifying foods processing based on customer-specific requirements, thus enabling food manufacturing processes wherever necessary.

3.5.3 Future trends and problems faced by 3D printing in DSC

The gradual expansion of 3D printing technology from medical applications to manufacturing, logistics and transportation has brought opportunities as well as challenges to the supply chain. Firstly, 3D printing technology has been extensively used in circular supply chains or SMEs, while it may not be advantageous to non-manufacturers or large firms. Another barrier for companies to use this technology is the high cost of materials, equipment, operation, purchase, depreciation, and maintenance. Besides, the industry-wide unreliability of quality assurance procedures is another concern. In AM, there is a general lack of appropriately trained workers, and little chances for cooperation and idea exploitation [88]. Lastly, it is worth noting that the various sectors of business, as well as the government, need to legislate on the intellectual property rights of 3D printing technology and develop norms and guidelines to address various issues in a timely manner [89]. The problems faced by 3D printing technology are shown in Table 5.

3.6 Digital twins (DT)

3.6.1 Overview

The digital twins (DT) concept was first developed based on Product Lifecycle Management in aerospace engineering, but it has become a booming area since incorporated with other fields [90]. The DT concept typically involves the following three components: (1) a physical object; (2) its 'digital' or 'virtual' representation; and (3) the way in which the two and DTs are connected. The concept of a "digital twin" is broader than just a virtual digital representation of a system. It seeks to real-time digitally record the essential elements of a dynamic physical system. A digital replica of an actual logistics system reflects the whole supply chain network in real time at any given time [91]. The digital twins supply chain (DTSC) may replicate past, present, and future events using historical data. Decision-makers can simulate a supply chain before making a choice, increasing operational efficiency, by giving a thorough understanding of the real-time activities of all pertinent entities, such as inventories, purchasing, and sales [90,92]. The digital model and the physical status of a DTSC are frequently synchronized, real-time, system-

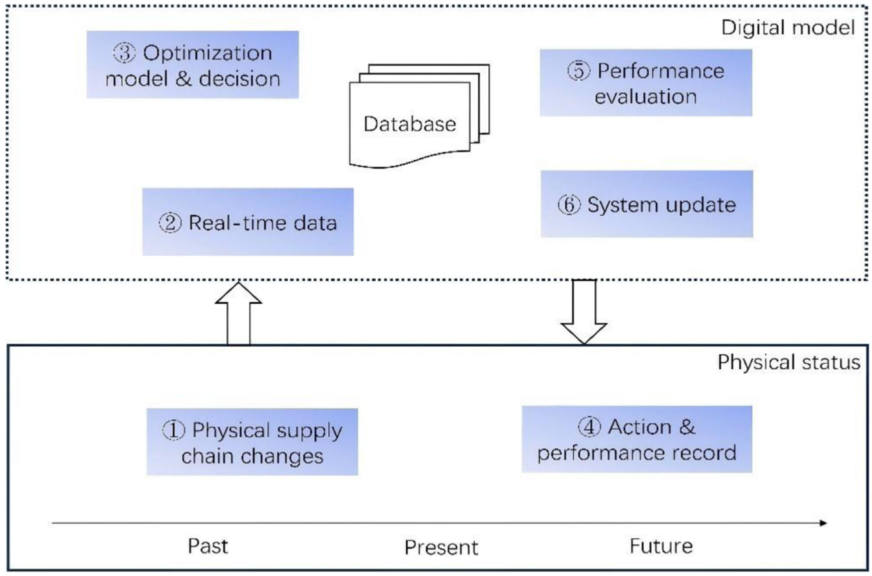

Fig. 4. Basic real-time decision scheme in a DTSC.

level instantaneous optimization of available information (Olsen and Tomlin, 2020). A basic decision scheme in a DTSC is shown as Figure 4.

3.6.2 Application of DT

DT can be used in sectors including circular supply chains, food supply chains, and international port management, etc. The most notable application for DT is production planning and control. Others include shop floor management, vehicle scheduling, warehouse management, freight load planning, etc. [93]. This section mainly reviews the DT-related literature in food supply chain and the pharmaceutical SC.

Sharma et al. [94] created DT for robotic work cells which utilize a robotic drive system and robot simulation software tools, for food retail supply chain during the epidemic. Binsfeld and Gerlach [95] developed a quantitative technique to evaluate the benefits of DTs and assess the impact of DT on supply chain management and logistics performance in multi-echelon inventory management of an organic food SC.

In pharmaceutical SC, Spindler et al. [96] investigated the benefits of a simulation-based model and evaluated the potential for the adoption in a scalable Digital Twins system. Park et al. [97] suggested a distributed DT simulation-based cyber physical production systems to reduce the differences among assets and develop a production plan based on the results of DT simulation.

3.6.3 Future trends and problems faced by DT in DSC

The supply chain sector is thriving with the digital twins, but there still lack of a common understanding of the word and literature to explore its potential application areas [98]. Future research is necessary to address the fact that DT and digital supply chain twins are not consistently defined academically. DT is rarely employed in service sectors of SC, such as purchasing, logistics, distribution, and retail, even though existing DT is predominantly used in manufacturing [99]. Additionally, since DT will affect multistructural composition of the supply chain network, such as changes in organizational structure, financial situation, and information flow [100], logistics executives are hesitant to implement DT because it is difficult to compare the effects of use in a reasonable cost-benefit manner. Table 6 lists the DT-related literature.

3.7 Intelligent autonomous vehicles

3.7.1 Overview

Intelligent autonomous vehicles (IAVs), also known as Internet of Vehicles (or Vehicles of Tomorrow), are completely computer-controlled depending on their surroundings and decision-making, and can run independently without human supervision [101,102]. As Figure 5, the intelligent automated guidance can be achieved by: first, awareness of surrounding context, through radars, cameras or other embedded sensors; second, interpretation of the sensory data retrieved into potential manoeuvres, through analysing and compiling a list of possible actions [104]. Compared with manual or traditional vehicles, IAVs provide intrinsic value to flexible supply chains and have advantages of enhanced safety, faster delivery times, less traffic congestion overall, and lower CO_2 emissions [105]. As a result, this will break restrictions on staff workers availability and work schedule control [106]).

3.7.2 Application of IAVs

IAVs can be well integrated with digital supply chains and incorporated into all aspects of the supply chain, such as flexible and sustainable supply chains. According to Tsolakis et al. [107], simulation tools and real IAV test beds are preferred for validating the design of digital supply chains.

Table 6. Problem description in IAVs literature.

Authors	Year	Research object	Problem description
Tyagi et al.	2021	Application	Stability needs to be confirmed Multiple parties are needed, including customers, industry experts and government Complex network issues and legal issues
Ahn et al. [124]	2021	Business	Legislation and infrastructure that brings new foundations Charging infrastructure requires self-driving vehicles likely to be charged to support automatic charging
Tsolakis et al.	2019	Application	Needs to test IAVs industrial warehouses in realistic environments Low modelling capabilities Time-consuming and expensive Needs to improve consistent simulation models and corresponding real-world systems for distribution operations
Walter et al.	2017	FAP supply chain	A clear law needs to be provided
Cronina et al.	2020	Flexible Manufacturing	Requires supply chain with hardware and software Needs to determine stability in complex environments
Bechtsis et al.	2018	Sustainable value networks	Lack of quantification of economic or social factors Needs for more diverse analysis beyond warehouse management

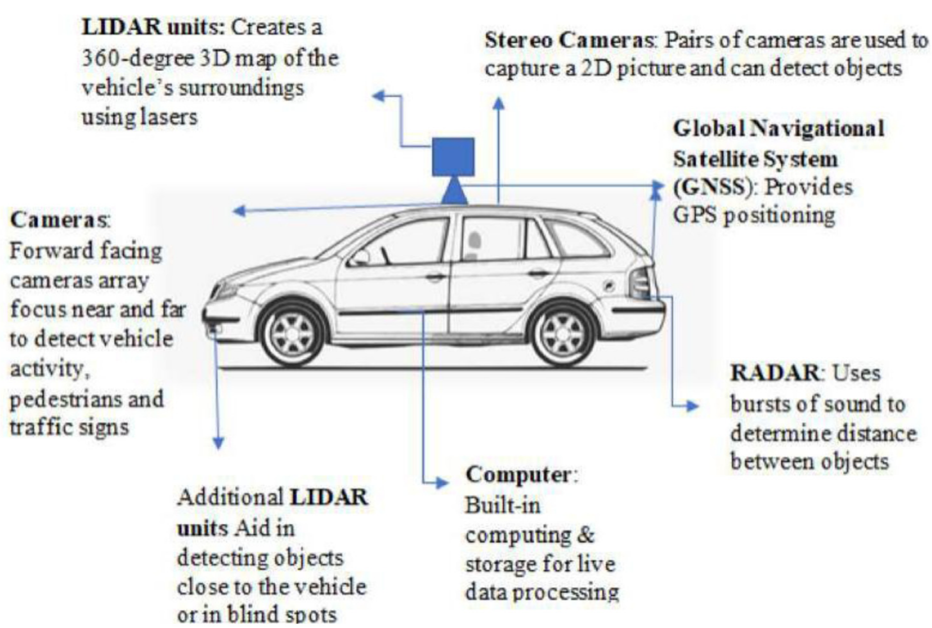

Fig. 5. . High-Level Functional Parts of a standard IAV System (Tyagi & Aswathy, 2021)

Flexible supply chains are playing an increasingly significant role in the manufacturing sector. IAVs are seen as a good solution for flexible manufacturing systems (FMSs) to reduce the repetitive and labor-intensive manual handling operations in manufacturing processes [108]. This performance is widely used by fresh agricultural products (FAP) supply chain to demonstrate great agricultural achievements such as intelligent farming, mechanical weeding, fertilization and fruit and vegetable harvesting [109]. Cronin et al. [110] suggested a plan for an integrated AIVs material handling system based on user requirement specifications and function requirement specifications. This system demonstrated the potential opportunity for AIVs applications in the supply chain to enable low-cost, autonomous material handling processes.

In addition, IAVs can be used in connection with sustainable supply chain networks, as they can improve the economic, environmental, and societal sustainability aspects of supply chain systems [111]. By matching the vehicle characteristics with a software framework that establishes vehicle characteristics as membership variables in the simulation model, business managers and academics

Table 7. Problem description in DT literature.

Authors	Year	Research object	Problem description
Binsfeld et al.	2022	Quantifying Benefits	More data linked to real-world logistics systems should be added Storage capacity of distribution centers and hubs are neglected Implementation costs are largely ignored
Park et al.	2021	Make-to-order (MTO) environment	Additional research is needed on personalized production. Does not extend the technical capabilities associated with demand forecasting and inventory management in a manufacturing-to-stock (MTS) environment The current 3D model of RAMI 4.0 does not include the supply chain at the hierarchical level
Kim et al.	2022	Implementation	Provides planning and control capabilities at the operational level Rarely used for different supply chain functions Ignores real-world systems such as farms, fields, animals, etc.

can incorporate commercial IAVs into the supply chain ecosystem. Vehicle navigation, planning, and scheduling tasks can be further implemented at the control level, enabling an improved sustainable performance [101].

3.7.3 Future trends and problems faced by IAVs in DSC

The desire to boost pertinent accuracy and efficiency is still a major driving force behind the expanding trend of IAVs supply chain adoption [112]. Due to the advantages of IAVs, they have received much attention from the manufacturing industry. However, IAVs are not used on a large scale because there are still some problems to be solved. First, since the majority of the models have only undergone laboratory testing, it is still necessary to verify their stability in complex environments. Second, the construction of infrastructure needs to be improved. For instance, there may not be enough charging piles in some impoverished regions, which could cause management challenges subsequently. In addition, the high cost is also a barrier for enterprises to use IAVs, such as hardware, software installation, and staff training. Businesses need to closely follow regulations regarding IAVs and upgrade their computer programs. All the problems with intelligent autonomous vehicles in the supply chain are listed in Table 7.

4 Findings and discussion

In this section, we provide a number of observations regarding the application of seven technologies in digital supply chain management and identify the gaps in the literature with respect to the potential of the technologies in helping address supply chain management challenges.

One of the major concerns in digitizing the supply chain with the technologies is the high costs that include database, staff training, hardware, software installation, and supporting infrastructure, etc. In the usage process, there are system maintenance and upgrading costs, which are not negligible. Attracting and retaining the proper personnel is key to maximize the company's technology investments. However, budget constraints and staff turnover are the barriers to adopt the digital technologies for the supply chain.

Another concern in supply chain digitization is standardization. The lack of standardization for global digital transformation has severely restricted the digital transformation for the enterprise in supply chains, which has pushed the governments and relevant international organizations to further establish a clear reference framework and guidelines for enterprises to digitalize their supply chain [113]. Through standardization, information interoperability and data exchange and sharing can be achieved. A unified standard can link the systems of one company with other systems when collaboration with other parties is required to reach the highest level of efficiency within the supply chain. The establishment of a standardized DSC management platform for different digital technologies is also one of the future trends.

The large amount of data sharing and exchange in digital supply chain applications brings security and privacy issues. Nevertheless, the industry is currently concentrated on using high-precision data analysis algorithms, and the application of data privacy protection algorithms is still in its infancy [114]. The problems of an untrustworthy transaction payment environment, easy data loss, and difficult traceability have largely restricted the further development and implement of digital supply chain technologies. Therefore, developing a privacy assurance system to guarantee the integrity and confidentiality of data is one of the key research directions in the future.

The application of digital technologies to the agri-food supply chain is another area of great interest to both academics and practitioners. From a management perspective, the agri-food supply chain presents enormous challenges since it deals with perishable goods, safety is an important concern, and there are many actors involved in the chain. This market niche for healthier products, especially fruits and vegetables, has increased amounts of agri-food surplus, waste, and loss (SWL) generated during production, shipping, storage, and processing [115]. It is estimated that approximately 33% of the food produced globally is lost or wasted annually, with agri-food SWL from fruits and vegetables accounting for about 22% of this loss [116]. Furthermore, agri-food supply chains are an essential component of all economies and cannot be offshored. Thus, preventing avoidable agri-food SWL throughout the supply chain is a compelling potential of the application of digital technologies and research in this area is expected to grow.

Moreover, scalability is the ability of a system or software to increase its capacity and maintain operational stability in response to user demand [117]. Rare literature in digital supply chains has focused on scalability. Scalable supply chain can leverage digital technologies to improve visibility, expedite decision-making processes, enhance real-time communication [118]. Additionally, majority of the research activities are in two of the supply chain processes in digitization, namely make and deliver and isolate digital technology. To extend the supply chain with more activities and digital technologies is the future trend.

5 Conclusion and future research directions

This paper reviews latest research articles in the application of digital technologies to areas of supply chain management and various supply chain processes. As such, we explored IoT & RFID, 5G, 3D Printing, BD, Blockchain, Digital Twins, and Intelligent autonomous vehicles in an SCM context, presented its main technology enablers and current status. We organized the seven digital technologies applications around key supply chain processes. We identified the gaps in the literature with respect to the potential of the seven technologies to help supply chain managers better understand the status, applications, benefits, and drawbacks of digital technologies. The aim is to provide an informative overview of the latest development in this emerging and growing area, which is of interest to both researchers and practitioners. We conclude this paper by pointing out several limitations for future research to address.

– Due to the rapid and mature development of emerging technologies in the last decade, this paper focuses primarily on the review of pertinent papers from the last decade and less on literature from a decade ago.
– Most of the papers in this literature review are based on mainstream academic journals in the field of supply chain and related technologies because the papers published in such journals are more authoritative, but this may lead to some other important types of research being neglected.
– Using input keywords, the aforementioned databases were searched to produce the findings of this review. Studies with marginally different inputs may have gone unnoticed because searches are so sensitive to these keywords.
– Augmented Reality, Cloud Computing, Nanotechnology, Omni Channel, and other technologies are not covered in this paper. Future research could make supplement of these literature to digital supply chain.

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Conflict of Interest

The authors declare that they have no competing interests.

Data availability statement

All data generated and analyzed during this study are included in this article.

Author contribution statement

Shuo Zhang, Qianhui Yu, Shuwei Wan, Hanyue Cao contributed to writing—original draft preparation; Yun Huang proposed the method and reviewed, revised; and acquired the funding.

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