A literature review of blockchain technology applications in supply chains: A comprehensive analysis of themes, methodologies and industries

Lim, M., Li, Y., Wang, C. & Tseng, M-L.

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Abstract: In the past few years, blockchain, the underlying technology of Bitcoin, has received considerable attention from academia and industry. It is widely accepted that blockchain technology causes disruptive changes in supply chain operations that can overcome supply chain difficulties encountered in realizing information sharing, maintaining traceability in the entire process and improving operational efficiency. However, the application of blockchain technology in the supply chain field is still in its infancy, which limits an understanding of its potential. This article uses descriptive and content analysis to review publications related to blockchain-based supply chains between 2017 and 2020 inclusive. To fully explore research on blockchain-based supply chains, four well-designed questions are proposed and addressed, namely, the value of blockchain in supply chains, the attraction of scholars to particular supply chain themes, the development of research methodologies and illustration types in adopting blockchain in supply chains, and the types of industries involved in blockchain-based supply chains. The results reveal that there is growing interest in applying blockchain technology to supply chain operations. A detailed analysis of findings is provided to identify the future opportunities of blockchain-based supply chains, including prospects for tertiary industries and concerted efforts that are necessary to explore sustainability themes. This article provides valuable information to help scholars and practitioners better determine the relevant research topics to accelerate the development of blockchain-based supply chains.

Keywords: Supply chain; Blockchain; Descriptive and content analysis; Literature review

1. Introduction

In 2008, Satoshi Nakamoto published his study on "Bitcoin: A Peer-to-Peer Electronic Cash System", in which a peer-to-peer (P2P) electronic cash system was proposed (Nakamoto, 2008). This system allowed payments to be directly initiated by one party and sent to the other without a third-party financial institution (Rana et al., 2019). In recent years, with increasing attention to digital cryptocurrencies such as Bitcoin, scholars have gradually realized the important role of blockchain, which is a crucial underlying technology of Bitcoin (Kumar et al., 2020; Nawari & Ravindran, 2019). Blockchain technology is a distribution database in which the use of cryptography technology guarantees that the distributed ledger cannot be changed, and smart contracts composed of script code enable transactions to be automatically executed (Juma et al., 2019; Kshetri, 2018). Currently, the application of blockchain technology is mainly concentrated in the financial field, but it also leads to disruptive changes in non-financial fields, such as e-commerce, e-government, credit evaluation and supply chains (Allen et al., 2019; Hald & Kinra, 2019; Juma et al., 2019).

Supply chain management is a comprehensive management problem involving information flow, capital flow, logistics and business flow that establishes a dynamic collaborative relationship between suppliers, manufacturers, retailers and end users (Mou et al., 2018). There are several problems with current supply chain management. First, supply chain information is isolated within an enterprise, which leads to information silos (Jiang & Ke, 2019). Upstream and downstream enterprises expand the information, causing a bullwhip effect (Jeong & Hong, 2019). Second, the opacity of information in the supply chain reduces the trust between parties and hinders the exchange of real information (Jia et al., 2020). Third, product tracking is difficult, and particular difficulties arise in finding the source of the problem when counterfeit and inferior products appear (Zhang & Guin, 2020). Blockchain technology is very suitable for solving these challenges faced by the supply chain since it can ensure the authenticity and traceability of information during transmission and the security of transactions in a distrusted environment (Helo & Hao, 2019; Tijan et al., 2019). These characteristics have a substantial impact on supply chain management and affect the design, organization, and operations of the supply chain (Hald & Kinra, 2019; S. Kamble et al., 2019).

Some scholars conducted studies on the blockchain-based supply chain to explore the potential of blockchain. For example, Y. L. Wang et al. (2019) conducted a literature review to determine the value of blockchain for supply chain management in four areas that encompassed: extended visibility and traceability, supply chain digitalization and disintermediation, improved data security and smart contracts. Philipp et al. (2019) identified potential applications of smart contracts in multinational and multi-mode supply chains through expert interviews and case studies. Even if there are some related studies, it should be clearly recognized that these types of studies are still in the early stages, and related academic articles are not fruitful (Pournader et al., 2020). In addition to academic publications, industry is also exploring the application of blockchain in supply chains. In the food industry, Wal-Mart has established a traceability system for mangoes that improves food traceability and shortens the traceability time of mangoes from farm to store from the original seven days to the current two seconds (Wong et al., 2020). In the trade industry, Maersk and IBM cooperated to use blockchain technology to solve problems in cross-border supply chains because it increases information transparency and realizes information sharing among trading partners (Y. L. Chang et al., 2020). Despite the aforementioned academic and practical concerns, the understanding of the impact of blockchain technology on supply chains is still limited. To better understand the value of blockchain, identify the current research content, and determine a research agenda for the future, this article reviews publications related to blockchain-based supply chains.

Some articles have carried out literature reviews about blockchain-based supply chains, and the articles reviewed here are presented in Table 1: five articles focused on food supply chains (Antonucci et al., 2019; S. Chen et al., 2020; Duan et al., 2020; H. H. Feng et al., 2020; Zhao et al., 2019), two articles reviewed the transportation field (Astarita et al., 2020; Pournader et al., 2020), and the remaining four articles did not have a specific application background (Gurtu & Johny, 2019; Queiroz et al., 2019; Wamba & Queiroz, 2020; Y. L. Wang et al., 2019). These articles analyzed the value, current trends and future opportunities from the perspective of the impact of blockchain on supply chains. To the best of our knowledge, no literature review has been carried out that considers the four aspects proposed in this article, including supply chain themes, research methodologies, illustration types and industries addressed. In addition, this article also discusses the value that blockchain will bring to the supply chains through the content of the existing research works, which has great significance for the technology at its early stage of development. This article aims to answer the following questions to provide research insights for scholars and practitioners.

RQ1: What is the value of blockchain for supply chains? The answer to this question will be given in Section 2.

RQ2: What supply chain theme has attracted the most attention of scholars? The answer to this question will be given in Section 4.2.

RQ3: What research methodologies and illustration types are developed in adopting blockchain in supply chains? The answer to this question will be given in Section 4.3 and 4.4.

RQ4: Which industries are involved in blockchain-based supply chains? The answer to this question will be given in Section 4.5.

The rest of this article is as follows. The value of blockchain is explored in Section 2. Section 3 introduces the research methodology. The descriptive analysis and content analysis of the reviewed articles are described in Section 4. Section 5 explores future research opportunities. Finally, Section 6 presents the conclusion.

Table 1. Review of the previously published literature.

Article	Time	N	Research questions/Aims	Key findings
Antonucci et al. (2019)	2008-2018	34	-To analyze the research of blockchain-based agricultural supply chain.	-A great number of researches in food traceability used the radio-frequency identification (RFID) technology, and it can be used to collect information of the whole production chain. -The RFID and blockchain technology were integrated to ensure the authenticity of the food safety and quality due the characteristics of blockchain. - Supervision inspection centres, such as government departments and third-party regulators, could implement emergency measures through the blockchain platform to prevent the danger spreading.
			-To explore the commercial application field of blockchain in the agricultural supply chain.	-Coffee, fish, beef, beer, fresh food, milk, pasta and wood.

Zhao et al. (2019)	2008-2018	62	-What are the main applications of blockchain in agri-food value chain management? -What are the key challenges of applying blockchain in agri-food value chain management? -What are the research gaps and future research directions of blockchain-based agri-food value chain management?	-Traceability, information security, manufacturing and sustainable water management. -Storage capacity and scalability, privacy leakage, high cost and regulation problem, throughput and latency issue, and lack of skills. -Apply the blockchain technology and edge computing in different agri-food manufacturers using empirical and analytical tools to assess its effect on agri-food manufacturing.
S. Chen et al. (2020)	2009-2019	2710	-To investigate the processes, benefits, and challenges of adopting blockchain technologies in food supply chains.	-Processes: Information collection on food supply chain, and chain-style storage mechanisms on the supply chain. -Benefits: Enhance efficiency of the supply chain, quick and accurate traceability, reliability and transparency, and improve food quality management. -Challenges: Complexity of integration, immature application of blockchain technology, blockchain technology characteristics, high investment in blockchain-based systems, and absence of regulations, legislation, and global standard.
Duan et al. (2020)	2008-2019	26	-What research has been carried out on blockchain adoption in food supply chain management? -What benefits can blockchain bring to the food supply chain? -What are the challenges of blockchain adoption in food supply chain management?	-Conceptual framework, pilot cases, theory papers, survey and systematic literature analysis. -Blockchain improves food traceability, food supply chain transparency and the efficiency of food recall, and blockchain can be combined with internet of things devices. -Lack of deep understanding and knowledge of the blockchain technology by companies -Technology scalability issue -Possibilities of raw data manipulation before uploading to blockchain.
H. H. Feng et al. (2020)	2005-2019	None	-How can blockchain technology provide better solutions to address the food traceability concerns in terms of full information transparency and security in food supply chains - How can blockchain-based Internet of Things traceability system be implemented for food traceability management?	-The characteristics of the blockchain technology ensure the information transparency and security, including decentralized and trustless network, smart contracts in traceability business process, consensus mechanism, transaction transparency and anonymity of the traceability chain, and data tamper-proof and traceable -Traceability information includes quality information, processing data, assets, logistic and transaction information. Data is recorded with

				connected devices (such as identity chips, RFID, and barcode technology). Various sensors will be used to collect and transmit automatically and continuously the ambient information about temperature, humidity, O2, CO2, etc. These connected devices are able to communicate with ledgers in blockchain.
			-What are the benefits and challenges in implementing blockchain technology in food traceability?	-Benefits: informational security, technological advantages, improvement of supply chain collaboration and trust, reducing economic loss and product waste, sustainability and transparency of traceability management. -Challenges: technical challenges, blockchain infrastructure, interoperability and standardization, social and institutional challenges, and system performance.
Pournader et al. (2020)	2008-2018	48	-To identify the main themes appearing in the field of blockchain and supply chains, transport and logistics.	-Traceability/transparency, technology, trust and trade.
			-To systematise the future research agenda in supply chain, logistics and transport management.	-Case study research is recommended to investigate the integration of hardware and software technologies into supply chain, logistics and transport operations.
Astarita et al. (2020)	2015-2019	371	-To explore the current research trends of blockchain-based systems in transportation.	-The first cluster is strongly focused on the use of blockchain technology, with the aim of ensuring product traceability in food chains -The second cluster refers to the intelligent transportation systems and interconnected smart vehicles.
			-To highlight the possible future research in the field of blockchain-based transportation.	-The need to have real case studies in the food supply chains, because the simulations approaches found in the literature are not suffice to demonstrate the feasibility of blockchain. -The right match between energy demand and supply in the field of electric vehicle.
Gurtu and Johny (2019)	2008-2018	299	-To identify the value of blockchain technology brings to the supply chain managements.	-Make supply chains more efficient, reduce the cost of the verification/audit processes, create a secure network and improve supply chain transparency.
Queiroz et al. (2019)	2008-2018	27	-What are the main current blockchain applications in supply chains management?	-Transportation, the electric power industry, security improvement, traditional supply chains management (distribution), education, smart-contract

				transactions, governance, emissions trading, healthcare systems and business information.
			-What are the main disruptions and challenges in supply chains management because of blockchain adoption?	-Smart contracts will contribute to several supply chain management improvement measures such as improved responsiveness, lead-time reduction, transaction costs reduction, increased visibility and more trust, security and transparency in the network. -Innovative changes in goods traceability will improve network transparency, dramatically reducing the costs of monitoring processes.
			-What is the future of blockchain in supply chains management?	-Future blockchain–supply chains management integration will transform relationships not only in business-to-business contexts, but also in business-to-customer and customer-to-customer contexts.
Y. L. Wang et al. (2019)	2017-2018	29	-To identify the drivers of blockchain deployment in supply chains.	-Trust, public safety and security.
			-To identify areas where blockchain provides the most value for supply chain management.	-Extended visibility and product traceability, supply chain digitalisation and disintermediation, improved data security for information sharing, and smart contracts
			-To investigate the challenges/barriers of further diffusion within the supply chain	-Organizational and user-related challenges, technological challenges and operational challenges.
			-To develop the elements of future research agenda for blockchain within the supply chains.	-Cryptocurrency and supply chain finance, disintermediation and reintermediation, digital trust and supply chain relationship management, blockchain, inequality and supply chain sustainability, and the dark side of blockchain.
Wamba and Queiroz (2020)	2008-2019	3507	-To present the themes and trends in blockchain research.	-Bitcoin, blockchain and smart contracts with their applications, and challenges, vulnerabilities, limitations related to the bitcoin and blockchain protocols.
			-To explore the future research directions of blockchain-based supply chains.	-How can blockchain leverage the traceability of food supply chains in a global perspective? -What is the role of blockchain in health care systems?

Note: The second column indicates the time horizon of review articles, and the third column "N" represents the word "Number", which indicates the number of review articles. "None" means no mention of the number of articles reviewed.

2. Value of blockchain

This section illustrates the value of blockchain for supply chains, that is, the benefits that blockchain brings to supply chains. The definition and attributes of blockchain technology are introduced in Section 2.1. A review of the functions of basic blockchain technologies provides further insights to explore the relationship of blockchain and supply chains in Section 2.2.

2.1 Blockchain technology

In technical terms, blockchain refers to a distributed ledger composed of a series of data blocks that are linked through cryptographic methods (Zachariadis et al., 2019). Each block records a batch of network transaction information; the structure of a block is shown in Fig. 1. A block consists of a block header and a block body (Z. Y. Liu & Li, 2020). The block header holds information used to connect to the previous block and information used for verification, including the version number, the hash value of the previous block, the timestamp of the current block writing time, the nonce and difficulty target used to prove the difficulty of the workload, and a total hash of Merkle tree root for verifying the block body transaction (Azzi et al., 2019). The block body contains transaction information and the Merkle trees of all the transaction information (Pandey & Litoriya, 2020). In Fig. 1, "T" is used to represent "transaction".

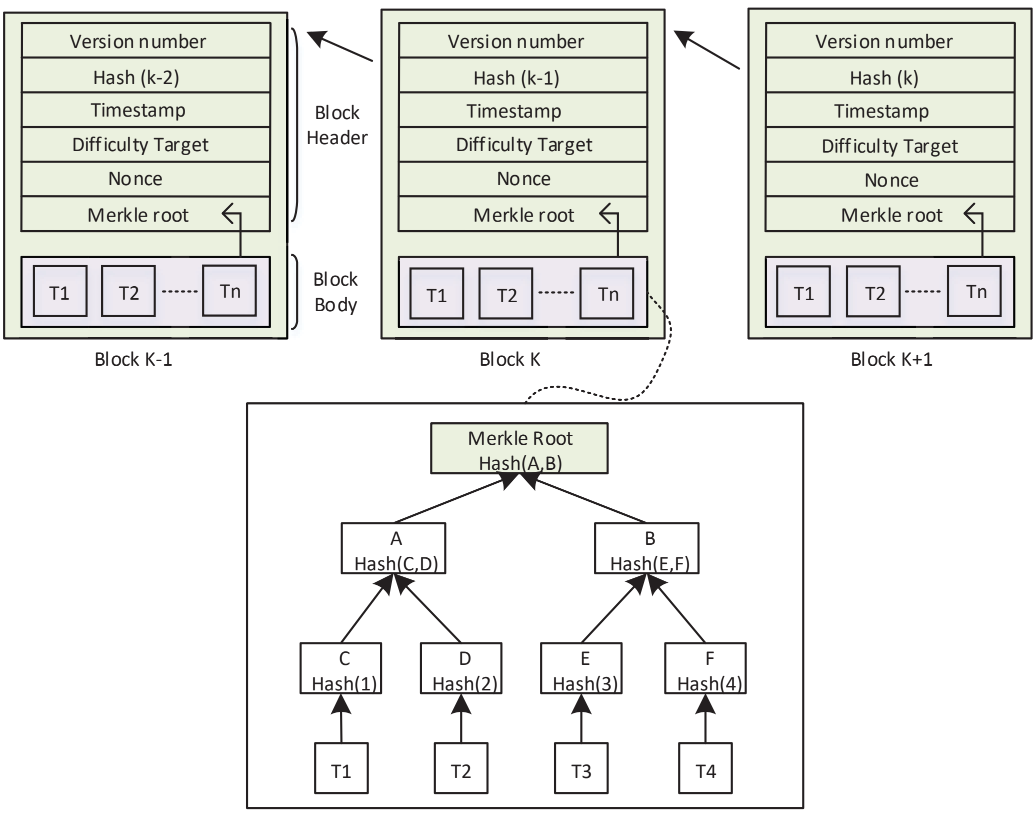

Fig. 1 Blockchain structure.

In a blockchain network, any two nodes can conduct transactions, and each transaction is broadcast by a single node to all nodes on the entire network (Frizzo-Barker et al., 2020). Transaction information is linked in the blockchain when all nodes confirm that the records are correct, and this process relies on the consensus mechanism of the blockchain network (J. Feng et al., 2020). The distributed structure enables each node to record all transaction information, and each node updates and stores all the information of the entire network in real time (Hughes et al., 2019). Blockchain technology involves three technological innovations, namely, cryptography, consensus mechanisms and smart contracts.

(1) Cryptography technologies, including the hash function and public key cryptography, are the basic technologies used to ensure the security of the blockchain system and are used in data structures, verification methods, communication protocols, and information storage (L. C. Wang et al., 2019). The hash function guarantees the integrity, authenticity and immutability of the distributed ledger data through the hash value and hash pointer, and it can convert the input data into a fixed-length digest through a hash algorithm, whose process is irreversible (Maesa & Mori, 2020). Public key cryptography is an asymmetric encryption algorithm that is used to provide identity verification to the blockchain network (Lopez & Farooq, 2020). Public key cryptography effectively solves the problem of key distribution and exchange in network communications, which ensures the security of information transmission (Ali et al., 2019).

(2) The consensus mechanism proves the ownership and accuracy of the bookkeeping nodes through a consensus algorithm that solves consistency problems. This mechanism establishes trust between different nodes in the blockchain system and guarantees that each transaction remains consistent for all nodes (J. Feng et al., 2020). With the development of blockchain technology, many consensus algorithms have been developed, such as proof of work (POW), proof of stake (POS), and practical byzantine fault tolerance (PBFT).

(3) A smart contract is a set of promises defined in digital form; the contract content is fixed in the blockchain in the form of code, and eventually, an automatically executed script is generated (Tanwar et al., 2020). Each transaction is processed by a smart contract, and the corresponding contract terms can be executed automatically once a predefined condition is

triggered (Abdullah et al., 2020). This process does not require a third party, which has an enormous impact on the design of business models (Zhu et al., 2020). A smart contract can be used to model various types of businesses, organizational behaviours and rules in the real world and affects interactions among various entities, including the transfer of asset ownership, payments of digital assets and currency transactions (X. Wang et al., 2019).

2.2 Blockchain and supply chain relationship

The three major aspects of blockchain technologies that create value, namely, shareable, secure and smart attributes, are summarized according to the analysis of the aforementioned blockchain technology, namely, cryptography, consensus mechanism and smart contracts.

2.2.1 Shareability

Blockchain uses a P2P network model, which means that the resources and services are distributed across all nodes, allowing each node to obtain a copy of the same distributed ledger achieving the data sharing (Drljevic et al., 2020; Savelyev, 2018). This mechanism guarantees that a transaction conducted by any node requires all nodes to jointly verify the transaction, thus ensuring the integrity of the data in the entire network. At the same time, this distributed system can better prevent hackers from attacking, and it does not affect the operation of the entire system even if individual nodes are attacked.

Azzi et al. (2019) pointed out that blockchain technology can prevent data fraud caused by data centralization in a traditional supply chain because it uses a distributed system that eliminates intermediaries. This process also occurs for supply chain finance, which allows parties in supply chains to directly carry out activities, such as transfers, payments and stock transactions in a secure manner without financial service providers (T. Chen & Wang, 2020). Furthermore, Toennissen and Teuteberg (2020) claimed that the elimination of intermediaries reduces the time and cost of transactions. In a traditional supply chain, another issue that needs attention is information fragmentation between participants, and blockchain is regarded as a promising technology that can solve this problem (Gonczol et al., 2020; Y. Wang et al., 2019). Longo et al. (2019) concluded that data sharing through blockchain technology helped upstream enterprises gain a deeper understanding of the needs of downstream customers, which helped enterprises make better decisions. At the same time, the ability to obtain timely data can improve procurement management, production management, transportation management, inventory management and many other links in a supply chain, thereby improving the overall level of supply chain management (Cole et al., 2019). In addition, the mode of common recording across the entire network allows each permitted modification to be observed in real time, which shortens the response time (Nayak & Dhaigude, 2019).

Blockchain technology makes intermediaries unnecessary and allows for data sharing, making it suitable for large and complex supply chain networks, such as those used for international trade, in which a large number of stakeholders are involved (Bai & Sarkis, 2020; Cole et al., 2019). According to Y. L. Chang et al. (2020), there are two problems related to traditional international trade that need to be urgently solved. The first is that the processing platforms used for international trade are mostly centralized, which limits transactions. The second is that hard copies are required for all documents required for cross-border transportations, so there may be delays, losses, and misplacement, which affect the operational efficiency. Z. Y. Liu and Li (2020) considered that the application of blockchain can be used to develop digital solutions and could enhance the ability to share transaction records in real time across the network to improve operational efficiency.

2.2.2 Security

The security of the blockchain system is protected at three levels. First, decentralization eliminates the possibility of data tampering (Schmidt & Wagner, 2019). Second, the use of cryptographic technology guarantees data security and ensures that information cannot be modified without authorization (Lu, 2018). Finally, the consensus mechanism provides protection for the entire network by requiring all nodes on the network to adhere to consistent protocols (M. Singh & Kim, 2018).

Behnke and Janssen (2020) claimed that information and product security are improved through blockchain-based supply chain management. From the perspective of information security, trust among participants is not high due to the lack of transparency in traditional supply chains (H. H. Feng et al., 2020; Mao et al., 2018). Di Vaio and Varriale (2020) pointed out that blockchain technology prevents information from being changed, which reduces the risk of the supply chain and thus improves trust between the supply chain participants. Blockchain guarantees data integrity by ensuring fixed information (on raw materials, processes and operators), item flow information (changes in different locations) and changes in ownership information (Lambourdiere & Corbin, 2020). Other types of information can be collected according to actual needs.

Blockchain technology enhances product safety (Ding et al., 2020). Effective enterprises have realized that high product transparency enhances consumer trust, which is a competitive advantage (Y. Wang et al., 2019). S. S. Kamble et al. (2020) illustrated that transparency is essential to ensure product authenticity and improve product traceability. The increase in transparency in blockchain technology depends on two aspects. The first aspect is the timestamp in the block, which provides chronological proof of a series of transactions (Hyla & Pejas, 2020). The second aspect is the integration of modern sensors into blockchain, such as radio frequency identification (RFID) and a global positioning system (GPS) (Helo & Shamsuzzoha, 2020). Blockchain technology creates a block for each link of goods that follows processes from manufacturing to sales, and these blocks are connected to record information on the entire process (Azzi et al., 2019). Information cannot be changed once the blocks are formed, and this process ensures traceability and thus product safety (Galvez et al., 2018; O'Leary, 2017; Yong et al., 2020). With the deterioration of the environment, people are favouring low-carbon products more, but it is difficult to define them in traditional supply chain systems (Manupati et al., 2020). Blockchain technology can track the raw materials of products and the carbon emissions of the entire process of a product, which is conducive to customers' green consumption (Saberi et al., 2019). At present, IBM and the Energy Blockchain Lab have jointly developed a carbon asset platform using blockchain technology to help organizations measure their carbon footprint and facilitate the trading of carbon assets (IBM, 2018).

2.2.3 Smart capabilities

The smart capabilities of blockchain are reflected in smart contracts, which is considered a revolutionary application. A. Singh et al. (2020) introduced smart contracts embedded in a blockchain network; contract terms can be automatically executed to achieve internal interaction between participants when the execution conditions are triggered. Smart contracts are executed quickly, which improves operational efficiency, and the rights and interests of the participants are protected through the contract terms (Macrinici et al., 2018). Z. Y. Liu and Li (2020) proposed that smart contracts reduce paperwork and labour by eliminating contract registration and monitoring processes, which reduce operating costs and improve the efficiency of supply chains.

The contract terms agreed upon by supply chain participants are fixed in the coding used for smart contracts, which define the statement obligations, benefits, and penalties, and the terms are enforced when the conditions for execution are met (Dolgui et al., 2020). For example, in a cash-on-delivery smart contract, the stakeholders realize automatic settlement when the goods are successfully stored in the warehouse. This high degree of automation makes blockchain technology particularly suitable for multi-tier supplier networks with complex relationships; in this context, it is difficult to track the status of the business and settle payments. Smart contracts can be used to organize the financial situation of the entire supply chain network and establish connections for transactions between different currencies so that each participant is paid (Pournader et al., 2020). At the same time, the use of smart contracts can prevent the risk of default and ensure that the trading parties fulfil their obligations (Min, 2019). Transactions are carried out within a safe and controllable range, as the clearing of the funds of both parties is solidified (Dolgui et al., 2020). Smart contracts should be established for the different links in a supply chain system and can be used for purchase contracts, transportation contracts, and storage contracts. Each contract has its own stated variables, and if any changes occur, information is automatically sent to the stakeholders of the contact. Any entity that needs other relevant information can obtain the corresponding power by registering events in the relevant contract. This approach also ensures information flow throughout the supply chain (Panescu & Manta, 2018).

3. Research methodology

This section describes the research methodology used for the literature review, which consists of article screening and article coding.

3.1 Article screening

Relevant high-quality articles were considered to provide reliable insights into the research questions. Web of Science (WoS), Scopus, and Google Scholar are the three most important citation databases. WoS is considered to be a more reliable international academic journal database than the other two sources and covers the most high-quality research articles (C. Wang et al., 2020). To further improve the quality and rigour of the search for articles, the types of articles reviewed were limited to those published in peer-reviewed academic journals and articles that focus only on technology, Bitcoin and finance were excluded to make the analysis effective. This study used “blockchain” and “supply chain” as the query string. To further expand the relevant research content, other query strings related to supply chains were identified after a consultation among the authors: "transport", "logistics", "cross-border trade" and "manufacturing". All articles with these query strings in theme were selected. The term blockchain can be traced back to 2008, but it was only used in the financial field in the beginning. In June 2017, the first academic journal article related to the combination of blockchain and supply chains was published. Hence, the range of the timeframe that was searched was set to June 2017 to March 2020.

Each article was independently reviewed by four authors in the article screening stage. The four authors exchanged opinions to determine the selected articles after completing the review. This method reduces individual subjective bias and makes the results more rigorous. Table 2 lists the three stages used to screen the articles: theme search, type screening and content screening. This table also lists the screening criteria. In the first stage, theme search, 421 articles were selected. After filtering by article type, 198 articles were identified. Finally, 106 valid articles remained after content screening.

Table 2. Criteria used to screen the articles.

Stage	Details
Theme search (421)	-Database：WoS core collection -Language: English -Time range: June 2017 to March 2020 -Query strings: “blockchain” AND【“supply chain” OR “transport” OR “logistics” OR “cross-border trade” OR “manufacturing”】 -Search space：Theme
Type screening	-According to the theme search, the articles in the WoS database are initially selected.

(198)	-Delete conference papers, books, comments and editing notes, only journal papers are retained.
Content screening (106)	-Read the title and abstracts to judge the relevance. -In addition, read the contents of the articles selected in the previous step to judge the relevance

3.2 Article coding

The coding method used in this study is based on the four-dimensional coding proposed by Ghadimi et al. (2019) including supply chain themes, research methodologies, illustration types and application industries. The selected 106 articles discussed in Section 3.1 were coded according to the above four dimensions to obtain the four angles of content analysis described in Section 4. In the coding process, a problem arises that deserves attention: defining the category to which the article belongs is a subjective process. Therefore, the guidelines proposed by C. Wang et al. (2019) to double-check the categories were adopted to ensure the rigour and objectivity of the classification process. The specific process used is as follows: The first author and the second author completed the coding. If there was any inconsistency in the coding, the third author participated in the coding and all the authors made the final decision together.

Here, Zheng et al. (2020) is used as an example to introduce the specific coding process. These scholars studied the risk decision-making problem in a spacecraft supply chain under decentralized, partially centralized and fully centralized situations using blockchain. (1) Supply chain themes. The study discussed the risk issues in supply chains, so it belongs to the risk category in terms of the specific impact of the blockchain. (2) Research methodologies. The study used the Stackelberg game model to explore the profit in three situations, so it belongs to the modelling category for mathematical models. (3) Illustration types. The use of mathematical models means the study used numerical experiments. (4) Industries addressed. The study analyzed a spacecraft production supply chain, which obviously belongs to the manufacturing industry category.

4. Findings and discussions

This section discusses the descriptive and content analysis of the 106 selected articles as described in Section 3.1, leading to the findings and discussion. Basic information on the articles, including publications per year, main journals and countries, is described in the descriptive analysis (Section 4.1). Moreover, content analysis is carried out to analyze the current research content based on the four coding dimensions proposed in Section 3.2: including supply chain themes (Section 4.2), research methodologies (Section 4.3), illustration types (Section 4.4) and industries addressed (Section 4.5).

4.1 Publications per year, main journals and countries

Table 3 shows the number of articles published in related fields since 2017, and the articles are divided into research articles and review articles. The overall trend indicates that the number of published articles increased year by year, showing that scholars' research interest has gradually increased. The timeframe considered in this study ends with 2020.03.31. The number of articles published reached 43 in the first quarter of 2020; therefore, the number of articles published throughout the year is expected to exceed 150. It can be seen that review articles have appeared since 2019. This is because research on the combination of blockchain and supply chain has just started, and the previous research results are not rich enough to support the completion of review articles. As the research deepens, the number of review articles will rapidly increase.

Table 3. Number of articles per year.

Types	2017	2018	2019	2020
Research	3	15	40	37
Review	0	0	5	6
Total	3	15	45	43

In addition, the sources of the articles are analyzed. The 106 articles considered in this study were published in 45 journals, covering areas including computer science, information science, environmental science, engineering, manufacturing, operations management, and business management. Fig. 2 lists the top ten journals, in which abbreviations ("Int." for International and "Trans." for Transportation) are used to represent the reported journals. The largest number of publications appeared in the *International Journal of Information Management* and *IEEE Access*, both of which published 12 articles. The impact factors of these two journals are 13.17 and 6.17, respectively, which means they are influential. Therefore, they are likely to become high-level journals in the field of blockchain-based supply chains attracting a large number of submissions in related fields. It is worth noting that a large number of articles have not been published in supply chain and logistics journals, such as *Supply Chain Management: An International Journal* and *Transportation Research Part E-Logistics and transportation review.* It is speculated that the number of studies on blockchain-based supply chains published in these two journals will grow rapidly.

The 106 articles considered in this study come from 31 countries, so the topic of blockchain-based supply chains has attracted the attention of scholars from various countries, and research has been carried out on a global scale. Table 4 shows the top eight countries with the total number of published articles. China published 23.58% of the total articles, ranking first in the world. This is because blockchain has risen to national strategic importance in China, and various departments, provinces and cities have also actively issued relevant documents to support the development of the blockchain industry (China Blockchain Technology and Industrial Development Forum, 2016). Therefore, scholars can actively carry out relevant research on blockchain. China is followed by the United States (16), Italy (9), the United Kingdom (7), India (7), France (5), Arabia (3), and South Korea (3). However, it should be noted that the average number of citations in the articles published in China is only 4.04, far lower than 15.75 in papers from the United States and 10.57 in papers from the United Kingdom.

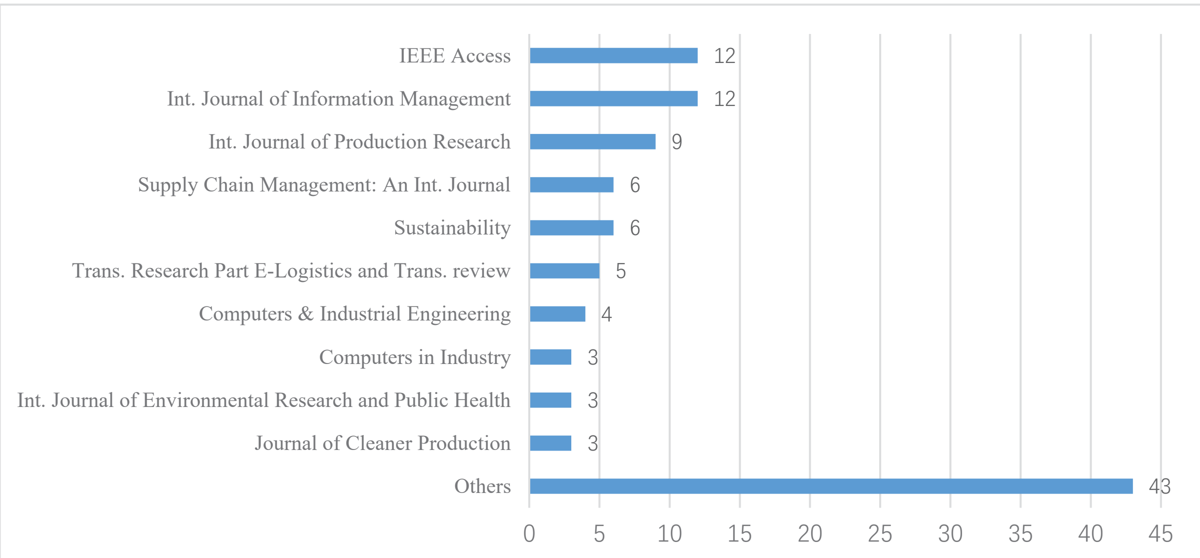

Fig. 2. Top ten journals with the number of articles.

Table 4. Top eight countries with the number of articles.

Rank	Country	Count	Citations	Average Citations
1	China	25	101	4.04
2	United States	16	252	15.75
3	Italy	9	33	3.67
4	United Kingdom	7	74	10.57
5	India	7	28	4.00
6	France	5	4	0.80
7	United Arab Emirates	3	5	1.67
8	South Korea	3	3	1.00

4.2 Supply chain themes

In terms of applying blockchain technology to supply chains, researchers and practitioners have discussed three themes, impact, function and configuration, which are expanded in Y. L. Wang et al. (2019). This study further subdivides these three themes into subthemes based on the characteristics of supply chain activities, which are shown in Table A1 in Appendix A. The 106 articles are classified according to these themes.

The first theme is “Impact”, with 36 articles, accounting for 34% of all the articles. Since research on blockchain-based supply chains has just started, it is necessary to define the impact of blockchain on supply chains to identify research opportunities. Most of these articles are still in the reasoning stage, meaning that conceptual means are used to explain the value, current status, challenges and opportunities of blockchain. For example, Queiroz and Wamba (2019) discussed the challenges of adopting blockchain in the supply chain through empirical research on the main driving forces in India and the United States. In their research, a model based on a slightly altered version of the classical unified theory of acceptance and use of technology was developed, and the results obtained revealed the existence of distinct adoption behaviours between India-based and USA-based professionals. For example, in response to the hypothesis that "social influence positively affects the behavioural intention to adopt blockchain", India supports this view, while the United States stands on the opposite side. Under the theme “Impact”, 25 articles have no specific application area (categorized in the sub-theme “Ordinary”), and 11 articles explore the impact of industry background including the agriculture (Antonucci et al., 2019; S. Chen et al., 2020; Duan et al., 2020; H. H. Feng et al., 2020; Kittipanya-ngam & Tan, 2020; Zhao et al., 2019) and service industries (Boulos et al., 2018; Y. L. Chang et al., 2020; Choi, Guo, et al., 2020; Juma et al., 2019; Yang, 2019). More industries that have applied blockchain are discussed in Section 4.5.

Most articles, 59.4%, focus on the second theme "Function". This theme is related to addressing the following problem: "Where will blockchain penetrate the supply chain?" These articles focus on the specific changes caused by blockchain in terms of a certain aspect, which is a deeper study of the value of blockchain in terms of "Impact". Through a review of 63 articles, it is found that blockchain has penetrated four aspects: product (35), process (11), operation (9), and sustainability (8). The sub-theme "Product" has attracted the most attention, in which most articles focus on "Traceability". For example, S. S. Kamble et al. (2020) identified thirteen enablers of blockchain application in the agriculture supply chain based on a combined interpretive structural modelling and decision-making trial and evaluation laboratory methodology, and the findings from the study suggest that, among the identified enablers, traceability was the most significant reason followed by auditability, immutability, and provenance. This phenomenon is consistent with the view that traceability is the greatest value of blockchain for supply chains. In contrast to the "Specific" theme with four subthemes, there are also many articles about "Information sharing" and the "Trust system". In terms of the supply chain process, these articles discuss the impact of blockchain on design (Rahmanzadeh et al., 2020), order management (Martinez et al., 2019), produce (Leng et al., 2018; Mandolla et al., 2019), workflow (S. E. Chang et al., 2019; Perboli et al., 2018; Philipp et al., 2019) and logistics (Dolgui et al., 2020; Hasan et al., 2019; Tijan et al., 2019; Toennissen & Teuteberg, 2020). For example, Martinez et al. (2019) studied blockchain-driven customer order management and carried out simulations for three scenarios: current with no blockchain, 1-year and 5-year blockchain use. The results showed that blockchain improved the efficiency of the process: it reduced the number of operations, the average time of orders in the system and the workload, showed order traceability, and improved visibility to various supply chain participants. The level of operation directly affects the overall performance. The existing research studied operations from the viewpoint of partnerships (Kim & Shin, 2019), coordination (Li et al., 2019), performance (Hald & Kinra, 2019), platforms (Choi, 2019) and risk management (Choi et al., 2019; Fu & Zhu, 2019; L. Liu et al., 2019; Min, 2019; Zheng et al., 2020).

The operation of the supply chain should focus on economic benefits and consider the environment and society, which collectively represent the well-known triple bottom line (TBL) principle. Saberi et al. (2019) proposed that blockchain technology may be a panacea for addressing the TBL, which is based on sustainability. To date, eight articles studied sustainability. Among them, two articles considered a single factor, environment (Kouhizadeh & Sarkis, 2018) and society (Venkatesh et al., 2020). Two factors were studied in three articles: environment and society (Castka et al., 2020), economy and society (Yadav & Singh, 2020), economy and environment (Manupati et al., 2020). Only three articles comprehensively considered all three factors (Di Vaio & Varriale, 2020; Nayak & Dhaigude, 2019; Saberi et al., 2019). Therefore, the study of blockchain-based sustainable supply chains considering the three dimensions of economy, society and environment is still insufficient, and agendas for future studies are proposed in Section 5.

Fewer studies, only 7, explore the theme “Configuration”. The articles focusing on this theme consider the simultaneous application of blockchain technology and emerging technologies such as big data, the Internet of Things, and artificial intelligence (Bencic et al., 2019; Fernandez-Carames et al., 2019; Lezoche et al., 2020; Mazzei et al., 2020; Mondal et al., 2019; Rejeb et al., 2019; A. Zhang et al., 2020). For example, Fernandez-Carames et al. (2019) designed a system in which blockchain and a distributed ledger are used to store the big data of a certain inventory collected by unmanned aerial vehicles. Different tests that were performed in a real industrial warehouse concluded that the system is able to rapidly obtain the inventory data compared with traditional manual tasks. Furthermore, the system is also capable of estimating item positions from a hovering vantage point that leverages their tag’s signal strength.

4.3 Research methodologies

This section analyzes the research methodologies used to study blockchain-based supply chains. Four research method categories are identified through a review of 106 articles:

conceptual, empirical, modelling and technical. Table A2 in Appendix A shows the 106 articles grouped in the proposed four method categories, and it can be seen that the number of articles aligning with each of the four methodologies are not much different. This result illustrates that research opportunities still exist, as research in related fields is still in the exploration stage.

There are 31 articles, the largest number, falling into the “Conceptual” category, and this is consistent with the development of an emerging research field. A general description, literature reviews and theory are developed to address the proposed problem and are categorized in the "Conceptual" category, in which most studies were a general description. For example, Schmidt and Wagner (2019) utilized transaction cost theory to create a better understanding of how blockchain might influence supply chain relations, specifically in terms of transaction costs and governance decisions. The results revealed blockchain might significantly reduce transaction and governance costs of supply chain transactions, especially in reducing search and information cost.

“Empirical” is the second largest research methodology category, with a total of 28 articles, including 19 qualitative articles and 9 quantitative articles. In qualitative research, different methods, such as seminars, implementation experience, expert interviews, and case studies are adopted to gain research insights. For example, van Hoek (2019b) explored lessons learned by early adopters of blockchain technology in the supply chain through three case studies from different industries (logistics services, consumer products and retail), supply chain positions (manufacturer, carrier, and retailer) and geographies (Europe and USA). Based on the insights from the case studies, lessons learned include the value in scoping pilots in a targeted manner, including the use of existing technology in the pilot, and the ability to rapidly when provided with executive and stakeholder engagement. In addition to the qualitative analysis mentioned above, some studies carried out “Empirical” quantitative research, which refers to developing and testing hypotheses, collecting data, and verifying hypotheses. For example, Wong et al. (2020) discussed the impact of top management support, cost, market dynamics, competitive pressure, and regulatory support on supply chain management based on empirical data from 194 small-medium enterprises in Malaysia. The results showed competitive pressure, complexity, cost and regulatory support have significant effects on behavioural intention. In contrast, market dynamics, regulatory support and upper management support were insignificant predictors.

A total of 22.6% of the articles used modelling methods to solve research problems. More specifically, 12.3% of the articles adopted mathematical modelling, which consists of nonlinear programming, game theory and mean-variance approaches. These approaches attempt to solve problems through the results of mathematical operations. For example, Manupati et al. (2020) studied the use of blockchain for production allocation problems in a multi-echelon supply chain, and the results showed that the blockchain approach minimizes both total cost and carbon emissions. Furthermore, 6 articles used simulation modelling, and the purpose of this method is to imitate the implementation of blockchain. For example, Leng et al. (2018) designed an agricultural supply chain system based on blockchain technology, and the results illustrated that the proposed system improved the openness and security of transaction information. In addition, 5 articles applied multicriteria decision modelling methodologies, including fuzzy decision making (FDM) and fuzzy analytic hierarchy process (FAHP). The barriers (Ozturk & Yildizbasi, 2020), evaluation and selection criteria (Bai & Sarkis, 2020) and success factors (S. S. Kamble et al., 2020; Nayak & Dhaigude, 2019; Yadav & Singh, 2020) were determined using the multicriteria decision method.

The smallest number of articles, 23, focused on system implementation, and current research focuses on the framework (52.2%) and system (47.8%). This series of articles attempted to determine how to deploy blockchain in supply chains. Technical and business solutions were provided in the "Technical" articles. Some scholars proposed technical frameworks, for example, Wu et al. (2017) introduced a delivery framework composed of a set of private distributed ledgers and a blockchain public ledger. Studies also focused on the implementation of a system. Helo and Hao (2019) established a blockchain-based logistics monitoring system that was designed and tested based on Ethereum. In general, most systems were implemented through Ethereum (Fernandez-Carames et al., 2019; Hasan et al., 2019; Helo & Hao, 2019; Toyoda et al., 2017; Yoo & Won, 2018) and Hyperledger Fabric (Cui et al., 2019; Z. Wang et al., 2020; X. Zhang et al., 2020).

4.4 Illustration types

This study designed three illustration types to narrow the various gaps in the research methodologies discussed in Section 4.3 and to identify the theoretical gaps and empirical opinions of different authors. Three categories were developed, "Application", "Theoretical approach" and "Numerical examples", as shown in Table A3 of Appendix A. This table shows that 38 articles, the largest number, study and verify the proposed theories by analysing case studies or applications of blockchain, which is consistent with the view that industry leads academia in the study of practical technology. For example, Kshetri (2018) discussed case studies of blockchain projects at various stages of development for different purposes to analyze how it affects key supply chain management objectives. The results showed that blockchain affects cost, quality, speed, reliability, risk reduction, sustainability and flexibility.

Thirty-five articles (33%) used a "theoretical approach"; these studies discussed the theoretical gap by using some methodologies or empirical approaches. Only qualitative empirical approaches fall under this theme. The quantitative empirical approaches are classified as "Numerical examples" due to the use of empirical data. For example, the study of Y. Wang et al. (2019) falls into the "theoretical approach" category because these scholars determine how blockchain technology has transformed the supply chain through in-depth interviews with 14 supply chain experts. However, Yang (2019) studied the driving factors of the successful application of blockchain in a maritime supply chain through empirical data from top management, members of boards of directors and planning staff. Hence, their research is classified into the "Numerical example" category.

Thirty-three articles used "Numerical examples" to prove the effectiveness of the developed methods; this is regarded as an appropriate approach for verifying the theories of the study, but it should also be noted that the limitations of this approach cannot be fully fitted unless it is applied in practical applications. Longo et al. (2019) simulated the operation process of a blockchain-based supply chain to quantitatively evaluate the benefits that companies can obtain under this context, and the results showed that blockchain technology is a convenient tool for supply chain collaboration, trust and overall performance. More discussions about the theory and practice are provided in Section 5.3.

4.5 Industries addressed

Research on the combination of blockchain and supply chains focuses on different industrial sectors. The review articles are classified into primary, secondary and tertiary industries according to the North American Industry Classification System (C. Wang et al., 2019). Primary industries refer to agriculture, forestry, fishing, and animal husbandry, and secondary industries include manufacturing, light industry, construction, mining and so on. Trade, logistics, transportation, retail, etc., are all tertiary industries. Table A4 in Appendix A shows that 36 out of 106 articles did not focus on a specific industry application, which is indicated under the category "None". These studies tried to explain common problems, which is the current research focus. In the articles focusing on a specific industry, the primary, secondary, and tertiary industries accounted for 21.7%, 18, 9%, and 17.9%, respectively.

Most research mainly focused on primary industries, and agriculture has attracted the most attention, with studies on pork (George et al., 2019; Sander et al., 2018), soybeans (Salah et al., 2019), wine (Bencic et al., 2019), fresh food (Perboli et al., 2018), eggs (Bumblauskas et al., 2020), cereals (X. Zhang et al., 2020) and so on. The agricultural field attracted the most attention. There are two reasons to show that the concern for the agricultural field is reasonable. The first reason is that consumers need detailed product information from the farm to the table, and blockchain technology improves the traceability of agricultural products (H. H. Feng et al., 2020). At the same time, blockchain technology can realize real-time temperature monitoring for fresh foods with strict temperature requirements such as eggs and pork, during circulation (Leng et al., 2018). The second reason is due to concerns about food safety. Blockchain technology can quickly and accurately locate problematic products to improve the recall rate of food and be used to build a complete recall system to respond to public health emergencies (Zhao et al., 2019).

The second largest group of articles focuses on three types of secondary industries: manufacturing (Ko et al., 2018; Mandolla et al., 2019; Xu et al., 2019), light industry (Sylim et al., 2018; Tseng et al., 2018; Yong et al., 2020), and construction (Z. Wang et al., 2020; Xiong et al., 2019). For example, Mandolla et al. (2019) focus on the phases characterizing the metal additive manufacturing process for producing components for the aircraft industry and propose a digital twin for additive manufacturing in the aircraft industry through the exploitation of blockchain solutions, ultimately providing a conceptual answer to securing and organizing the data generated through an end-to-end additive manufacturing process in the aircraft industry. Most of the research focused on manufacturing because the bullwhip effect arises if an upstream enterprise cannot obtain the demand of the downstream enterprise in a timely and accurate manner. Blockchain technology improves information incompleteness and asymmetry in the manufacturing process and can be used to achieve real-time information sharing (Fu & Zhu, 2019).

Finally, the third group of articles studied the field of tertiary industry, which consists of trading (Allen et al., 2019), transportation (Yanovich et al., 2018), retail (Choi & Luo, 2019) and health (Boulos et al., 2018). The application of blockchain technology in the trade field can bring some benefits, such as reducing intermediaries, reducing costs and increasing efficiency (Z. Y. Liu & Li, 2020). In addition to the specific industry sector, some scholars have also conducted research in multiple industrial sectors (meaning an article contains two or more application scenarios), which are shown under the category "Multi-industry" (Astarita et al., 2020; Azzi et al., 2019; Y. L. Chang et al., 2020; Gurtu & Johny, 2019; Karamchandani et al., 2020; Toennissen & Teuteberg, 2020; van Hoek, 2020; Wamba & Queiroz, 2020), which makes the conclusions more universal and applicable to providing industry insights. For example, Toennissen and Teuteberg (2020) investigated ten blockchain-based industries, including ocean freight, agri-food, animal products, etc., and the results showed that there is no disintermediation. Y. L. Chang et al. (2020) summarized the key challenges for blockchain implementation through the analysis of blockchain applications in the maritime industry, transportation industry, food, pharmaceuticals and manufacturing supply chains.

5. Future opportunities in the field of blockchain-based supply chain

The findings and discussions in Section 4 help to determine the research gaps and identify future research opportunities. Based on Sections 4.2-4.5, research gaps and opportunities are found in terms of the following four directions: (1) ignored themes in supply chains, (2) applied methodologies in the research, (3) academic theory and industrial practice and (4) practice in different industrial sectors.

5.1 Ignored themes in supply chains

The research of configuration receives less attention in comparison with the themes of impact and function. This situation may be due to the following three reasons (Duan et al., 2020). The first is described as the amount of data increases exponentially with the widespread use of the the Internet of Things (IoT) devices, which brings great difficulties to data storage. The second is the delay in the transmission process. The consistency of the entire blockchain network is ensured through delay, but the delay is unacceptable for many IoT-based applications. The third is the security issue; the blockchain network security and the privacy of the participants are both worthy of attention due to the vulnerability of the IoT. A. Zhang et al. (2020) proposed that the integration of blockchain and IoT, artificial intelligence, big data, machine learning and other emerging technologies can achieve excellent operation of the supply chain. Therefore, carrying out related research in this field, especially regarding data storage, information transmission, and blockchain network security, is a promising avenue.

The discussion on sustainability seems to be limited compared with other subthemes. The following limitations are discovered by analysing eight articles related to the theme of sustainability: (1) Social dimension attention is insufficient. Social-level standards should all be considered in the sustainable supply chain, including working conditions, work health and safety, human rights and product safety. However, product safety is the focus of most articles, and only one article considers other dimensions in addition to product safety (Venkatesh et al., 2020). Therefore, relevant research is needed to improve the indicators of the social dimension in the blockchain-based supply chain. (2) Environmental concern is not comprehensive. The environmental issues considered in supply chains should include waste management, energy efficiency, greenhouse gas emissions and so on. Most of the current research focuses on the discussion of "Green", that is, reducing carbon emissions (Manupati et al., 2020). A few articles mention waste management (Kouhizadeh & Sarkis, 2018; Saberi et al., 2019), and there is no relevant research on energy efficiency. Therefore, more comprehensive environmental issues need to be studied to better emphasize the role of blockchain in promoting environmental management. (3) Lack of quantitative research. Since conceptual methods were used in most articles, the quantitative studies are deemed inadequate. At present, there is no research that can systematically propose a sustainable supply chain performance model under the blockchain environment.

More research should be carried out under the theme of coordination, performance and order management. From Table A1, it can be seen that the top five specific articles are traceability (20), information sharing (9), economy, society and environment (8), trust system (6), and risk (5). This phenomenon is consistent with the value of the blockchain for supply chains analyzed in Section 2. The other topics listed in Table A1 have not received much attention, such as coordination, performance and order management, which are crucial for supply chains management (Hald & Kinre, 2019; Li et al., 2019; Martinez et al., 2019). Therefore, the research related to these topics should also be conducted to meet the challenges of blockchain-based supply chains.

5.2 Applied methodologies in the research

Four methodologies are developed to carry out the research, including conceptual, empirical, modelling and technical. This section explores the research opportunities from the above four methodologies. First, literature reviews have gradually become the focus of research under the conceptual category with the increase in the number of related studies. However, the existing literature review can be divided into two categories: research in which there is no specific industry background focus, and research that has an agricultural background focus. Hence, there is a lack of literature reviews about the application of blockchain in manufacturing, trade and other specific fields. Second, current research uses empirical qualitative methods. As this research deepens, case studies and quantitative research should occupy a dominant position to guide the configuration of blockchain in supply chains. Since blockchain technology is in the early stages of development, conceptual and empirical methodologies can be used to strengthen the relationship between blockchain and supply chains and propose related theories. As the research continues, it is necessary to use modelling methods to verify newly developed theories.

Currently, there are many research opportunities in mathematical modelling, simulation modelling and multicriteria decisions, which fall in the modelling category. There is a lack of studies using mathematical modelling for the direct application of blockchain. At present, research content focuses on the blockchain environment and determining the factors affected by blockchain as well as their impact on the results. For example, Ko et al. (2018) compared the impact of blockchain technology on the profits of manufacturing companies, and the results showed that blockchain technology improves the profitability and competitiveness of manufacturing firms. Choi et al. (2019) discussed aviation logistics risks in the era of blockchain, focusing on “air-logistics related operations”, “demand management”, “supply management”, and “supply-demand coordination”. Therefore, research using mathematical modelling to analyze blockchain technology is urgently needed to address this research gap.

The articles using simulation modelling connect theory and practice and narrow the gap between them. There are six articles in the category for this theme, but only one article simulates the entire supply chain operation (Longo et al., 2019). Therefore, future simulation research should consider goods, information, capital flow, organization, production, and delivery processes (purchasing, inventory management, logistics management, etc.) with suppliers, wholesalers, retailers, and carriers. Five articles use multicriteria decision-making models to determine the successful factors of implementation (S. S. Kamble et al., 2020; Nayak & Dhaigude, 2019; Yadav & Singh, 2020), obstacles to implementation (Ozturk & Yildizbasi, 2020) and blockchain selection and evaluation (Bai & Sarkis, 2020). There are gaps in some of the studies determining the factors of and obstacles to successful implementation, so the general conclusion needs to be applied to blockchain practice. It is also necessary to establish a connection between these factors through mathematical modelling or simulation modelling and identify new research gaps.

Finally, research on technology should be strengthened. The review of the technology studies indicates that the following two aspects are not well studied. First, each company currently has its own management system, so studies should pay more attention to existing systems that can be integrated with blockchain technology. Second, many enterprises have developed their own unique blockchain platforms. If an enterprise participates in multiple groups, it needs to use multiple platforms, which will increase the burden of the participants and consume too many resources. Therefore, unified technical standards are needed to ensure system compatibility.

5.3 Academic theory and industrial practice

Theoretical gaps and empirical claims are verified in three types of articles, namely, those that fall into the application, theoretical approach and numerical examples categories, as shown in Table A3. Thirty-eight articles validated their theories through "Applications". This method is generally accepted by the related research community, and the research results provide opinions for current academic and practical research. To better explore the relationship between academic theory and industrial practice, scholars should consider the following research opportunities.

Blockchain technology has not attracted the attention of small and medium-sized enterprises (SMEs). Through the analysis of 13 case studies in the “Application” category, it is found that most cases are concerned with the implementation of blockchain projects of some large enterprises, such as Wal-Mart, IBM and Maersk, and only two of them focus on SMEs (Y. L. Chang et al., 2020; Perboli et al., 2018). It is normal for this phenomenon to occur, and the development of SMEs is lagging behind that of large enterprises in emerging technologies due to the difference in cognitive level and infrastructure. However, blockchain technology can solve current dilemmas of SMEs, including limited resources and the difficulty in finding investors and expanding the business scale. Therefore, blockchain technology presents both opportunities and challenges for SMEs. At the same time, SMEs should also recognize their own advantages. Having a concise organizational structure makes the deployment of blockchain easier and the initial cost lower. As noted above, relevant research on SMEs is in-depth. Since research on SMEs has just started, there are many topics that can be considered: (1) What value does blockchain technology have for SMEs, and how does this value differ from that for large enterprises? (2) What are the obstacles to successful blockchain implementation in SMEs? What are the similarities and differences concerning those found in large enterprises?

The voices of different groups should be investigated when academic research is conducted. There are 35 articles using the "Theoretical approach" method, so a question arises:

Can theory be used to guide practice? Pagell and Shevchenko (2014) claimed that academic research involving practice managers can better guide practical activities. Therefore, some research involves the intersection of theoretical methods and numerical experiments due to the use of statistics. To carry out research on industrial practice, seminars, questionnaire surveys and expert interviews are designed to obtain data. The interviewees are supply chain experts (Hackius & Petersen, 2020; Kim & Shin, 2019; Philipp et al., 2019; Y. Wang et al., 2019), supply chain industry managers (Dubey et al., 2020; Sander et al., 2018; van Hoek, 2019a, 2019b), and supply chain practitioners (Behnke & Janssen, 2020; S. Kamble et al., 2019; Karamchandani et al., 2020; Queiroz & Wamba, 2019; Sheel & Nath, 2019; van Hoek, 2020; Wong et al., 2020; Yang, 2019), with different perspectives from academia and industry. Future research needs to include other groups, such as individuals representing the government, different industries, and different countries, to obtain a more general view. The articles using numerical experiments operate somewhere in the middle of "theoretical method" and "real-world application", which connects theory and practice.

The sustainability theme deserves more attention. In the numerical example category, there are 12 articles that considered cost or profit when the objective function was established (Choi, 2019; Choi, Feng, et al., 2020; Choi & Luo, 2019; Choi et al., 2019; Hayrutdinov et al., 2020; Ko et al., 2018; Li et al., 2019; L. Liu et al., 2019; Longo et al., 2019; Manupati et al., 2020; Rahmanzadeh et al., 2020; Zheng et al., 2020); these two aspects have attracted great attention and will be the focus of future research. However, only one of these articles in the sustainability theme category considered environmental factors (Manupati et al., 2020), which means that relevant research on theory and practice of the sustainability theme is insufficient.

5.4 Practice in different industrial sectors

Tertiary industry presents prospects for the future of blockchain-based supply chains. According to the survey results presented in Table A4, research on blockchain-based supply chains considers primary, secondary and tertiary industries, indicating that blockchain has good applicability in all industries. In addition, the proportion of studies on various industries is not very different. This result indicates that there are still research opportunities for studying blockchain technology in various industries. However, in recent decades, the economy has developed rapidly and there is a great focus on tertiary industries rather than secondary industries. Therefore, more relevant research will be carried out in tertiary industries to determine the value of blockchain.

More industrial sectors should be studied. In terms of the industries subcategory, the agriculture, manufacturing, and trade sectors have received the most attention. That is, the shareability, security, and smart capabilities of blockchain technology are helpful for solving problems in these industry sectors. There are few studies focusing on forests and fisheries (Figorilli et al., 2018; Howson, 2020), and some industries have also been overlooked, such as animal husbandry in the primary industry, mining and energy in the secondary industry, and cultural entertainment in the tertiary industry. These industries also represent future research opportunities.

6. Conclusions

This study included a review of existing research on blockchain technology in supply chains. Overall, 106 publications were identified through an article theme search, type screening and content screening. Then, through descriptive analysis and content analysis, five themes were identified in the 106 publications, including (1) publications per year, main journals and countries, (2) supply chain themes, (3) research methodologies, (4) illustration types and (5) industries addressed. The results and findings of this study prove that research on blockchain-based supply chains is an emerging field that is receiving strong attention. Specific findings and discussions are addressed in Section 4, and future research opportunities are presented in Section 5; these are identified based on the discussion in Section 4 and our academic experience.

To our knowledge, this study is the first literature review that considers the supply chain themes, research methodologies, illustration types and industries addressed. This review of research of blockchain-based supply chains is timely because it provides a solid foundation for related studies. The contribution of this research is twofold. For academia, this study explains the value of blockchain technology for supply chains, and insights for future agendas are provided for scholars. In terms of industry and individuals focused on practice, this study helps managers worry less about applying blockchain and implementing blockchain plans. Finally, although a detailed search was conducted, we acknowledge that some related articles were missed. This study considered only peer-reviewed journal papers; conference papers, books, newspapers, reviews and other documents are not included. Therefore, a literature review that overcomes the above limitations should be conducted in the future.

Appendix A. supplementary data

Table A1 shows the classification of the different supply chain themes. The detailed categorization of the research methodologies is provided in Table A2. Table A3 lists the validation approaches used in the reviewed articles. Finally, the classification for industries addressed is presented in Table A4.

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