IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received March 4, 2020, accepted March 23, 2020, date of publication March 26, 2020, date of current version April 14, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2983601

When Blockchain Meets Supply Chain: A Systematic Literature Review on Current Development and Potential Applications

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This work was supported by the Ministry of Science and Technology, Taiwan, under Contract MOST-106-2221-E-005-053-MY3.

ABSTRACT This study aims to explore the current status, potential applications, and future directions of blockchain technology in supply chain management. A literature survey, along with an analytical review, of blockchain-based supply chain research was conducted to better understand the trajectory of related research and shed light on the benefits, issues, and challenges in the blockchain-supply-chain paradigm. A selected corpus comprising 106 review articles was analyzed to provide an overview of the use of blockchain and smart contracts in supply chain management. The diverse industrial applications of these technologies in various sectors have increasingly received attention by researchers, engineers, and practitioners. Four major issues: traceability and transparency, stakeholder involvement and collaboration, supply chain integration and digitalization, and common frameworks on blockchain-based platforms, are critical for future orientation. Traditional supply chain activities involve several intermediaries, trust, and performance issues. The potential of blockchain can be leveraged to disrupt supply chain operations for better performance, distributed governance, and process automation. This study contributes to the comprehension of blockchain applications in supply chain management and provides a blueprint for these applications from the perspective of literature analysis. Future efforts regarding technical adoption/diffusion, block-supply chain integration, and their social impacts were highlighted to enrich the research scope.

INDEX TERMS Blockchain, digital ledger, distributed ledger technology, logistics, shared ledger, smart contract, supply chain management, systematic literature review, value chain.

I. INTRODUCTION

In recent years, a proliferation of research, projects, and discussions regarding distributed ledger technology (DLT) has increasingly attracted the attention of researchers and practitioners. The reason lies in the characteristics that DLT may deliver promising disruption to the current model of trust, which has long created operational pain points of centralized systems. Traditional business operations rely heavily on a centralized authority or third parties, such as banks, to promote trust among participants [1], [2]. However, they have often been the targets of malicious attacks, malfunction and artificial alterations. The emergence of blockchain technology may bring about a rethinking of the design of business operations by virtue of its distributed and decentralized characteristics [3].

The associate editor coordinating the review of this manuscript and approving it for publication was Xiang Zhao.

Blockchain, a DLT, refers to a consecutive list of time-stamped records (usually digital transaction data) sequentially linked using cryptography. A peer-to-peer network of participating nodes contribute to the formation and validation of blockchain and manages distributed consensus by network majority. This makes blockchain an immutable, secure, and trustless model where transactions among parties are concerned. Blockchain technology has the potential to rebuild the way businesses conduct their operations [1], [4]. Several use cases have been investigated using the concept of blockchain, which could function as a distributed database without third parties. Several research endeavors regarding trade finance [5], medical record management [6], voting [7], and insurance industries [8] have improved the visibility of blockchain. Supply chain management (SCM) is one of these potential applications [9]–[13].

Growing efforts have been devoted to the study of blockchain technology and its applications across various

sectors [9]. The scope of this research ranges from technical discussion [14], [15], application feasibility [16], business operations [4], to even legal issues [17] and user acceptance [18]. Gathering information from 106 articles, including journal and conference papers published in a variety of sources during the period 2016 to early 2020, this study presents illustrative topics related to blockchain evolution in the recent decade. The major research methods adopted in these studies have also been reported to outline the relationship between the main topics and methodologies.

Among extant literature, research regarding the application of blockchain technology in supply chains is rather fragmented and diverse in topics [19], [20]. This phenomenon indicates a promising research interest but less-organized comprehension among the literature distribution. While researchers presented their early efforts regarding blockchain-based supply chain literature, there was a lack of qualified peer-reviewed articles that could be aggregated and analyzed in the current research's limited time frame. In [19], the first blockchain-related supply chain literature survey was conducted prior to January 2018 under scientific rigor with a peer-reviewed process. The authors also collected several blockchain trial pilots to demonstrate their contributions, and suggested second-round surveys to capture the rapid development of blockchain technology in the realm of SCM. Similarly, another study in the same-period [20] highlighted examples of blockchain-SCM integration while reporting the scarcity of related studies in leading journals and databases. In this study, the researchers highlighted the early adoption of blockchain in the electric power industry with a relatively mature understanding of blockchain-SCM integration. Both these papers reviewed only a few studies before 2018, i.e., 29 and 27 papers, respectively. These initial literature reviews are not adequate for providing a general overview, and a literature update is required due to the rapid proliferation of blockchain-based supply chain research from year 2018 to early 2020. Unlike the aforementioned review articles, this current work aims to provide a more holistic analysis of scenarios of blockchain use in supply chains by supplementing academic research for the past two years. Since blockchain with its unique features allows more streamlined business processes [21], [22], and enhanced transparency and trust among stakeholders, exploring its applications in supply chains is important for both academics and practitioners. We also realize the need for reporting the current status and potential of blockchain and its emerging applications across different industries in the SCM context. In this regard, we proposed certain questions to develop the logical connection between relevant extant articles and the potential for further research.

The research questions in this study are as follows:

RQ1: What are the main topics and subjects of interest in supply chain studies that utilize blockchain technology; how do they address its core issues; and how have these topics evolved over time?

RQ2: What are the main research methodologies employed in blockchain-based supply chain literature and how are they related to the main topics?

RQ3: Which blockchain-supply-chain papers were most instrumental in driving the development of literature thus far?

To answer these questions, we adopted a systematic literature review (SLR) to gain insights regarding correlated issues. The aim of using SLR was to present a general overview of recent research by conducting a systematic analysis of extant literature. Thus, we outline the understanding regarding the research path based on our comprehension of related research interests and topic distributions. This paper contributes to the understanding of blockchain applications in the field of SCM by exploring various research topics and directions for future research. The literature analysis highlighted several potential research areas that may point out certain research gaps for future study. The remainder of this paper is organized as follows. Section II describes the basic knowledge regarding blockchain and smart contracts. Section III presents the methodology and procedural steps utilized in this review and Section IV reports findings from the analysis of literature. Section V identifies the main research issues, challenges, and implications, before the final conclusion is presented in Section VI.

II. PRELIMINARIES

A. BLOCKCHAIN

Nakamoto [23] proposed the concept of a decentralized digital currency, Bitcoin, supported by a decentralized payment system. Decentralization refers to an operating mechanism that allows peer-to-peer (P2P) exchange or transactions without centralized authorities. This disruptive innovation eliminates the heavy reliance on powerful third parties. Blockchain is the technology underpinning the Bitcoin cryptocurrency, which is a consecutive growing list of blocks, wherein each block records encrypted transactional data and may have further potential for other decentralization purposes [24]. The operating nodes in this kind of collaborative network have a duplicate record of transactional information, known as a ''ledger.'' Inherently shared by participating nodes, DLT provides the opportunities for a trustless operating environment without traditional trusted authorities such as banks and clearing houses. P2P exchange facilitates trust building among participating nodes and the shared ledger is maintained by nodes in the network.

Computer nodes comply with an encrypted protocol to verify updated data in the shared ledger. This kind of distributed ledger system harvests the benefits of decentralized governance which may solve the issue of information exposure and accountability [25]. This inherent attribute favors the interactions between counterparties in the context of business operations [26]. Critical information could be maintained without checking the consistency of individual data and every single node possesses a duplicate of transactional data,

thereby enhancing the transparency and visibility of business activities.

In a supply chain context, this kind of system and operational scheme may provide a better foundation of trust as well as benefits resulting from the absence of a centralized authority and intermediation [12]. Accordingly, blockchain could further be utilized to record the ownership of assets [27], permissions, and activity logs. This improves the traceability of information, cash, and process flows, and thus provides timely tracking of products and services. The different types of blockchain are public, private, and consortium (or federated) blockchains, each of which could be applied in certain scenarios to gain better advantages and for effectiveness.

B. SMART CONTRACTS

Smart contracts are programmable protocols that allow the execution of contract terms and agreements. The concept was first proposed by Szabo [28], who defined a smart contract as ''a computerized transaction protocol that executes the terms of a contract.'' Thus, smart contracts can be deployed to a blockchain database and users can develop computer codes based on contractual clauses [29]. Contracts are executed when certain preset conditions are met. Smart contracts may outperform traditional contracts due to advantages such as allowing the mitigation of intermediaries among transacting counterparties and the facilitation of transaction flows without malicious alterations and tampering [30]. Smart contracts can be deployed on blockchain platforms in terms of scripts and stored with specific addresses for functional calls similar to those performed in other programmable computer languages [31]. They may facilitate data-driven interactions in the blockchain network and further allow applications to meet supply chain objectives.

Smart contracts are essential in the use of blockchain applications. A potential use case for smart contracts is in SCM. For example, a comprehensive paper-based process of administrative auditing may hinder the overall performance of a supply chain. Regulated conditions and agreements can be coded in smart contracts to avoid fraud, theft or other managerial risks. When smart contracts are deployed in the blockchain network, they are transferred to each connected node. Latest changes recorded in the local database may in turn trigger the conditions prescribed in computer codes to execute related process flows or notifications [32]. This is referred to as an event-driven mechanism, which can be facilitated without interference from a single entity. Typical use cases include conditioned payment transactions [33], [34], and asset and proprietary transfers [35].

With data updates and an event-driven mechanism, smart contracts may facilitate the manipulation of supply chain activities [36]. For example, commercial pilots, such as IBM and Maersk, recently announced their successful adoption of blockchain technology and smart contracts for shipment tracking and facilitating trade finance. Traditional paper-based procedures dealing with the collection and presentation of commercial documents could be significantly mitigated with the use of smart contracts [37]. This technology can reduce transaction costs and the number of involved intermediaries, and improve trade efficiency to achieve process automation.

Smart contracts on a blockchain-based platform can have applications in various fields; however, previous studies have reported certain unresolved issues with respect to technical and legal concerns [38]. For example, contract vulnerabilities with regard to transaction-ordering and timestamp dependence, mishandled exceptions, re-entrance, and callstack issues [39]. To pursue a wider spectrum of applications, more research endeavors must focus on solving validation/verification issues [40], enhancing security and privacy, and contract-based integration with other technologies [41]–[43]. Smart contracts may facilitate obligation execution and process automation among parties based on technical openness, however, its long-term development still requires a cross-disciplinary approach, combining technological, economic, and legitimation practices.

III. METHODS

To answer the research questions, we conducted an SLR to gain further insights into the relationship, integration, and development of blockchain technology in the realm of SCM. SLR is a kind of review genre that places strong emphasis on utilizing a series of standard processes to search, screen, analyze, and review literature, along with providing comments or suggestions. Since blockchain and its affiliated technology, i.e., smart contracts, have only emerged in the past decade, related works, technological standards, and innovative applications are still in their nascent stages. We selected the latest four years, 2016∼2019 (extended to early 2020), as the time span of this literature survey to capture the most updated usage of these technologies in SCM. This study followed previous research guidelines to construct a robust and replicable study [44]–[46]. Additionally, to explore and analyze as many extant studies related to blockchain and supply chain as possible, we searched the IEEE Xplore, ACM, Google Scholar, and other major digital libraries from various academic publishers, using the following search string shown in Fig. 1. In this study, literature search and screening involved the following steps (Fig. 1).

A. STEP 1: INCLUSION/EXCLUSION CRITERIA

Article selection was conducted by setting inclusion and exclusion criteria prior to analysis to extract highly-relevant literature. In this research, we focused on keywords related to the emerging blockchain technology and its extended concept, smart contracts, in the field of SCM to identify relevant articles. Considering the essence of blockchain, more general synonyms or terminologies, such as DLT and ''decentralized ledger system'' (DLS), were included. After employing these procedures, we obtained a total of 433 articles. Meanwhile, exclusion criteria were set to exclude ambiguous articles not highly correlated to the key topics. In this research, we included some conference articles and proceedings to extend

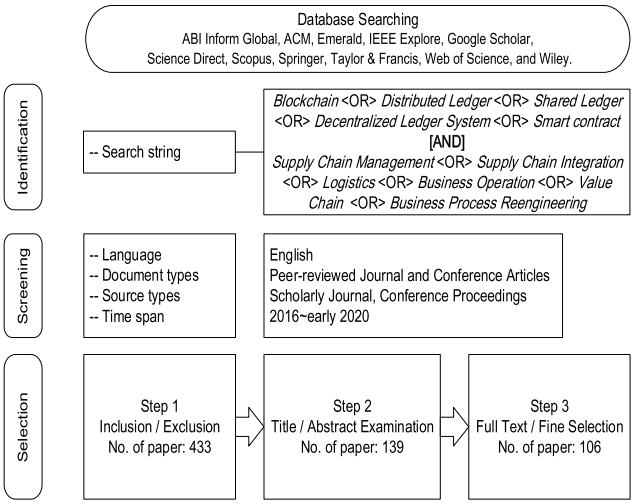

FIGURE 1. Procedural steps of the selection protocol.

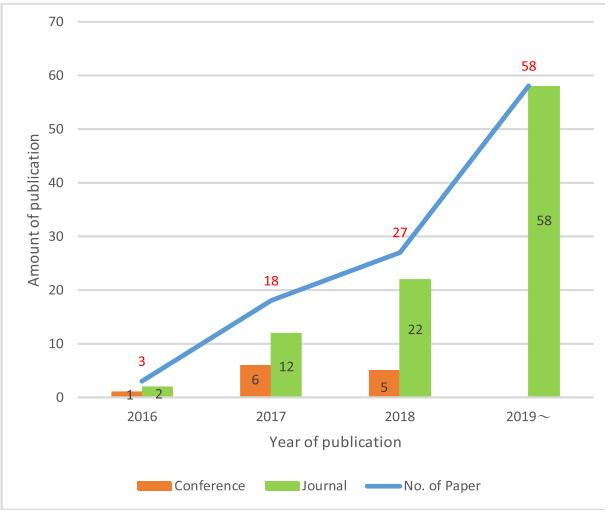

FIGURE 2. Paper distribution by year of publication.

the scope of literature. However, preliminary studies in the form of technical reports, comments, editorial, and consulting papers, were excluded to ensure quality, consistency, and academic rigor.

B. STEP 2: TITLE AND ABSTRACT EXAMINATION

Based on the results of keywords identification and screening procedures, we examined the title and abstract of each selected article by each author. To assure quality and academic rigor, content of abstracts with less focus on major topics or with less concrete findings/contributions to the body of knowledge were removed. We double-checked our process to maintain coherence in article selection. In this stage, we excluded 294 papers that focused mainly on the applications of other emerging technologies such as the internet of things (IoT), cloud computing, industry 4.0, machine to machine (M2M), and radio frequency identification (RFID), etc.

C. STEP 3: FULL TEXT READING AND FINER SELECTION

To better align the research questions with the contents of the selected papers, we conducted a full text reading and perform the procedure for finer selection of candidate papers. We removed 33 papers from the selection as they were less relevant to our main focus. In this final step, we obtained 106 papers for this study. Fig. 1 illustrates the procedural steps for paper selection and presents the selection criteria or main actions conducted to filter for the most related articles.

Additionally, to better comprehend of the selected corpus, we conducted a preliminary descriptive analysis to determine answers for the research questions. We classified the selected papers according to their topics and research methods to respond to RQ1 and RQ2. We also conducted a citation analysis to provide evidence for RQ3. A number of frequently-cited supply chain articles based on blockchain and smart contract technology were examined to obtain a better understanding of the research interest and its applications. The following sections provide explanations for the literature classification and related analyses.

IV. RESULT

A. DESCRIPTIVE ANALYSIS OF THE CORPUS

Fig. 2 displays the distribution of the sources of the selected review articles and illustrates the proliferation of blockchain research in the field of SCM in the last 3 years. This indicates the potential and opportunities for this emerging technology in various facets of supply-chain-related issues. Blockchain was coined and introduced around 2008, from then on, research has focused on cryptocurrencies, e.g., Bitcoin, along with their security and privacy issues. The development and evolution of such technologies have moved from their original financial applications to other areas in the following years. During the period 2008∼2015, due to the technical essence of blockchain, related publications were scattered in the form of technical forums, consulting reports, news reviews, or comments. Since 2016, blockchain and its applications have drawn the attention of engineers, scholars, and practitioners. For example, the special topic conference entitled ''The 2018 international conference on blockchain'' focused on the discussion of applications of blockchain technology and smart contracts in various sectors, including supply chains.

Assorted but fragmented peer-reviewed journals contributed around 89% of the selected articles, while IEEE, ACM and other topic-related conferences accounted for the rest. Fig. 3 presents the popular journals for blockchain-related publications, which include *IEEE Access, International Journal of Information Management, Future Generation Computer Systems, Supply Chain Management: An International Journal, International Journal of Production Research, Sustainability, Computers & Industrial Engineering*, etc. Originally designed for solving the double spending issue of digital currency, blockchain applications

TABLE 1. Article topics classification.

Topics	Description	Papers
General Influence / Overview	Influence on SCM, collaborative organizations and discussion on blockchain feasibility / applicability.	1, 19, 20, 26, 47, 63, 68, 73, 97, 98, 100, 107, 112, 116, 117, 131, 132, 135
Distributed Ledger Technology & Smart Contract	These topics include the discussion, application and evaluation of distributed ledger technology and smart contract.	30, 36, 82, 89, 91, 93, 95, 102, 111, 116
Business Process Management and Quality Management	This category emphasizes the implementation, monitoring and execution of business process in real practice.	3, 16, 21, 22, 32, 37, 40, 50, 74
Ownership Management	Focus mainly on identity, asset or ownership transfer during business transactions.	27, 67
Information Sharing	This area includes how data, such as shipping, accounting or financial information is shared in business operations.	16, 37, 62, 74, 111, 113, 114, 116, 126
Security and Privacy	This topic includes issues on counterfeit prevention, tamper-proof and privacy-keeping mechanism.	55, 62, 87, 90, 91, 92, 114, 116
Business Model and Operation	Business model describes the rationale of how organization create, deliver, and capture value, in economic, social, cultural contexts (Wikipedia). Business operation deals with work flow and coordination of processes.	1, 4, 73, 78, 105, 107, 117
Acceptance and Adoption	This issue deals with the extent of the act taken or received by using blockchain technology in supply chain activities.	10, 18, 77, 78, 79, 80, 128, 129, 133 134
Supply Chain Integration	Supply chain integration refers to the alignment and coordination within a supply chain. Focus is mainly stressed on the shared information system.	20, 115
Purchasing and Supply	The process business participants go through to fulfill their demand on raw material, product and even service.	122
Manufacturing	A process to produce merchandise for use or sale.	53, 54, 64, 66
Physical Distribution and Logistics	Major concerns on the practical involvement of commodity transportation, shipping and distribution.	48, 52, 65, 72, 73, 74, 81, 82, 93, 101, 104, 105, 116, 123, 128, 130
Transaction Processing	This topic deals with the operation of blockchain-based transaction processing.	33, 96, 123
Financing, Accounting and Payment	A distributed and disintermediated method to process accounting, financing and payment.	33, 34, 37, 66, 130
Governance	Business governance depicts a working mechanism which comprise of policies, methods and business processes for an organization's operation.	95, 96
Credit Evaluation	A process businesses or lenders usually undertake when evaluating a request for credit.	94
Blockchain with Other Technology	Internet of Things (IoTs) integration, Radio Frequency Identification (RFID), Industry 4.0, Machine to Machine (M2M), Near Field Communication (NFC)	55, 60, 68, 69, 70, 71, 84, 85, 92, 97, 104, 122, 127
Traceability & Transparency	Traceability refers to the extent business participants could monitor or get full control of entity status. Transparency is about to the visibility of information and process flow.	16,18,30,47,49,51,50,52,54,57,58,59,67, 70,72,82,84,85,87,88,89,94,96,103,106, 110,116,123,124,125,126,127,132
Agricultural & Food Applications	This topic deals with blockchain application in the agricultural and food industry.	50, 51, 59, 69, 84, 85, 86, 87, 88, 94, 106, 109, 110
Other Industry Applications	Blockchain applications in drug, chemical, medical, construction, or other industry.	49,55,56,57,60,61,62,63,64,67,80,96, 100,108,120
Tactical Planning / Risk Analysis	Business strategy with tactical thinking. Consideration, classification and identification about risks.	75, 76, 118, 120

Note: Each paper may refer to more than one topic. Paper number refers to that in Reference section.

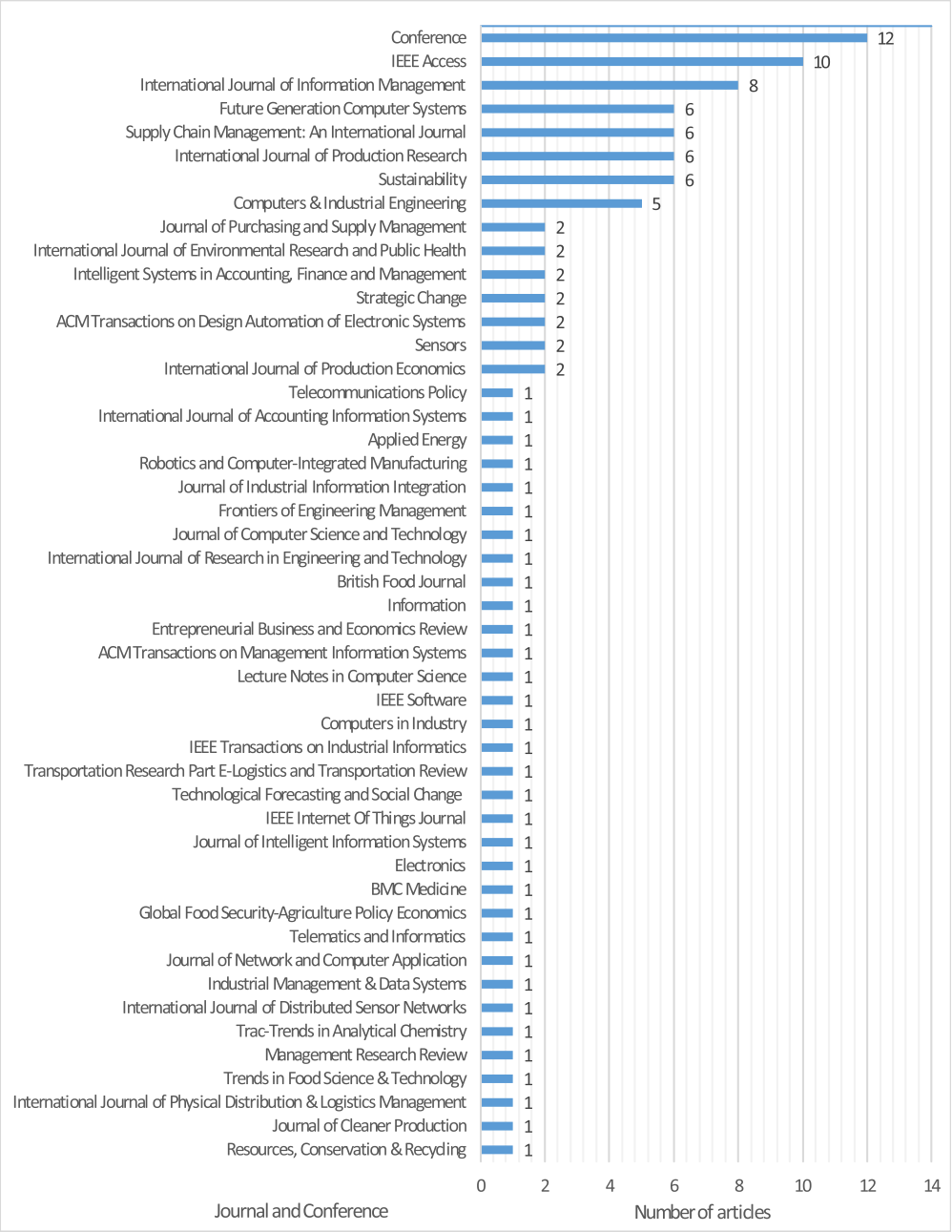

FIGURE 3. Journal/conference publications and number of papers published.

were first used mainly in the financial sectors rather than others, such as supply chain, medical records, and information systems. Additionally, we discovered a growing demand for papers in 2018 and expect double or triple the amount of publications in 2019 and 2020. The growing numbers of conferences and special sections regarding blockchain-related supply chain publications in recent years have resulted in an increasing research interest in this field. Due to the proliferation of blockchain-related conferences held in recent years, we excluded conference papers from the year 2019, but selected a few frequently-cited conference papers for the literature analysis.

B. CLASSIFICATION OF SELECTED PAPERS

To answer RQ1 and determine corresponding research methods for RQ2, we classified the selected papers in terms of supply-chain-centric topics to identify the research foci and examine the potential influence of and emphasis on blockchain in supply chain applications [47]. The classification of selected paper is presented in Table 1 with a brief description of related topics. A considerable number of papers covered traceability/transparency issues and the influence of blockchain technology in the supply chain context. Similar efforts highlighted the potential of blockchain-based supply chain applications in diverse sectors, prototype system

TABLE 2. Topic classification in various industries.

Topic assorted by application sectors	Papers
Physical Distribution and Logistics	48, 52, 65, 72, 73, 74, 81, 82, 93, 101, 104, 105, 116, 123, 128, 130
Agricultural & Food Applications	18, 50, 51, 52, 59, 69, 84, 85, 86, 87, 88, 109, 110
Manufacturing	53, 54, 64, 66
Drug and Pharmaceuticals	55, 56, 57, 96
Airline	63,64
Chemical industry	60
Construction	61
Other industry application	49, 67, 80, 100, 108, 120

Note: Paper number refers to that in Reference section.

design [48]–[50], and a combination of other emerging technologies. We noticed that each paper may have referred to more than one topic to better respond to the scope of the selected papers.

For better objectivity, we conducted a two-stage review for paper classification. We independently classified the selected papers into a grouping list. Next, we performed a cross examination to extract common opinions regarding research topics, finely adjusting for topic headings after the discussion. Subsequently, we conducted a random check using the previous classification to ensure less disagreement and to present more stable final decisions.

Table 2 presents potential blockchain applications across different industries showing that early applications were mainly in the fields such as food provenance [51], physical distribution and logistics [52], manufacturing [53], [54], and drug/pharmaceuticals supplies [55]–[57]. Traceability [58] and transparency [59] issues are increasingly drawing more attention, and this phenomenon explains the penetration point where blockchain could be applied in SCM. We also found early evidence that these applications may cover various sectors such as the chemical [60], construction [61], [62], airline [63]–[65], and manufacturing [66], [67].

The most addressed topics were divided into four categories: (1) traceability and transparency, (2) general influence/overview, (3) blockchain applications in agriculture or other industries, and (4) physical distribution and logistics (Fig. 4). The results of our topical discussion were reasonable since the major focus of the research interest and proposed solutions began with the pursuit of major supply chain objectives. We also found complementary interactions with emerging technologies such as IoT [68], RFID [69], [70], [71], NFC, etc., which are considered critical to streamlining supply chain flows/activities and real-time response.

C. ANALYSIS OF THE RELEVANCE OF THE TOPICS OVER TIME

Blockchain-related studies can be chronically divided into four-year intervals to examine the evolution in research topics. In this sense, we could further illustrate the relevance of research topics through an evolutional timeline. Before 2016, blockchain discussions mainly focused on Bitcoin or other digital currencies. Therefore, technical applications of blockchain in SCM were not significantly investigated. Fig. 5 illustrates topic relevance over time with the gray area denoting new topics. In the first period (year 2016), only few papers were published, and as expected, supply chain traceability and transparency were the first topics discussed. A few applications focusing on agricultural products were presented as templates. In the second stage (year 2017), it was apparent that growing attention had been granted to the discussion of blockchain integration with other emerging technologies, general influence of blockchain, the essence/design of the ledger system and smart contracts, and security/privacy issues. Simultaneously, the focus on the previous stage's research topics increased both in amount and in depth. More publications that explored traceability and transparency were presented and there was also a growing interest in practical applications among various industries.

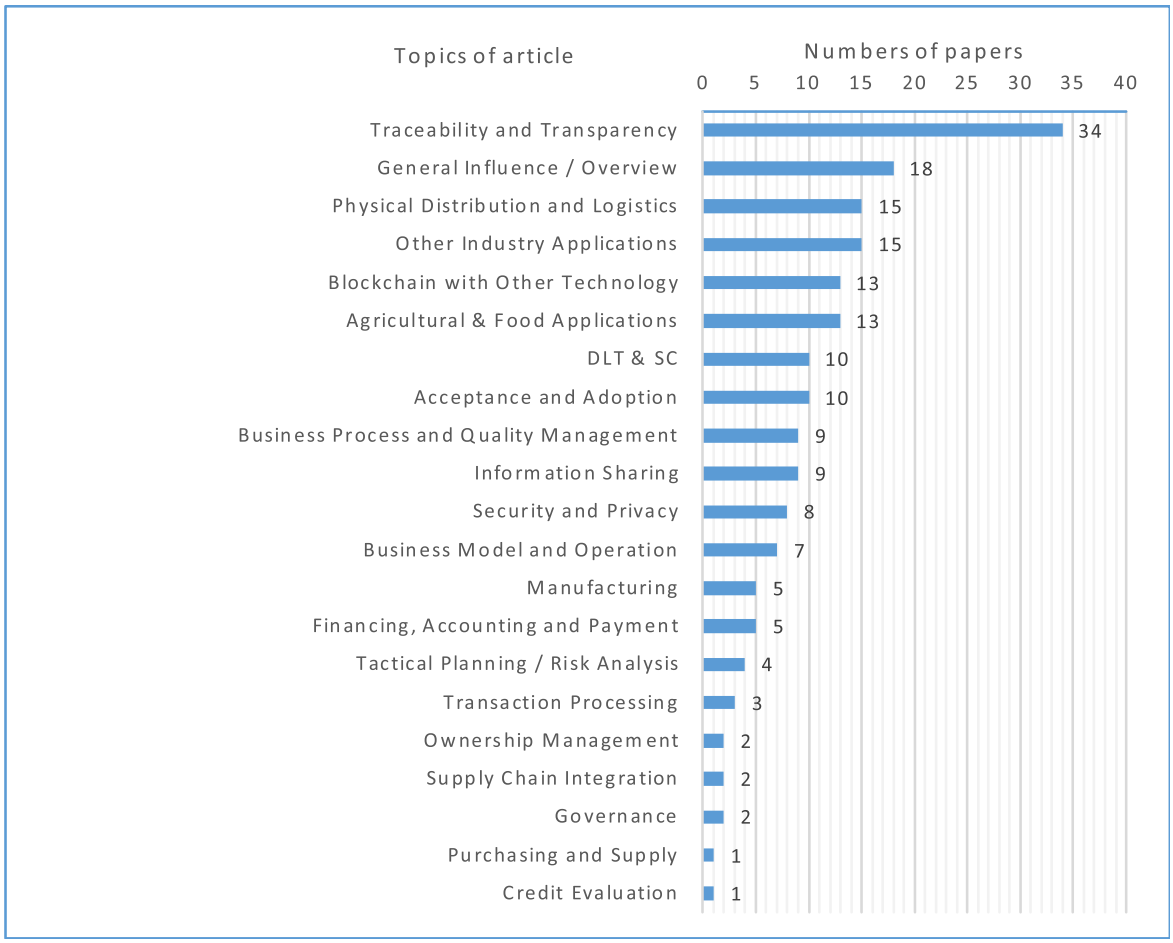

FIGURE 4. Papers classified by topic.

In 2018, based on the extension of topics covered in the previous stage, academic efforts were increasingly devoted to blockchain security and privacy, distributed ledger technologies, and smart contracts. We also learned that blockchain applications in various sectors, e.g., manufacturing, were drawing more attention from technical engineers, practitioners, and scholars. Additionally, more papers in the four-year period investigated blockchain innovation from the perspective of business process reengineering (BPR). In 2019, an explosive interest in various topics, such as blockchain-enabled physical distribution and logistics [72], business process management, information sharing, business operations [73], [74], and risk analysis [75], [76], dramatically emerged. Specifically, empirical studies focusing on blockchain acceptance/adoption [77], [78] appeared to further provide evidence for previous technological forecasts, business models, and proto-concepts [79].

D. MAIN RESEARCH METHODOLOGIES EMPLOYED AND THE RELATIONSHIP WITH MAIN TOPICS

We followed a similar method of topic grouping to classify research methodologies. Two classification lists were generated and then discussed to diminish disagreement in the final version (Fig. 6).

Since blockchain is an emerging information technology, few studies utilized quantitative methods. Instead, we found more descriptive papers using case studies, proof of concept (POC), theory building, and literature reviews, etc. It should also be noted that there was a number of papers that explored blockchain's technical issue by system design, code/algorithm analysis, and simulation. Table 3 summarizes the connection between research topics and methods. We observed that various methods were adopted when discussing blockchain applications. Since blockchain is in its early development phase, quantitative methods were rarely used in prior research. Few studies used questionnaires and interviews [80] to collect data for qualitative rather than quantitative analysis [18], [81].

Qualitative methods were widely used to describe, predict, and propose blockchain opportunities in the supply chain context while quantitative methods were utilized to evaluate or analyze the performance of various blockchain-based systems. Case studies and comparative analysis have frequently been used to explore the potential influence of blockchain-based supply chains, security and privacy, and

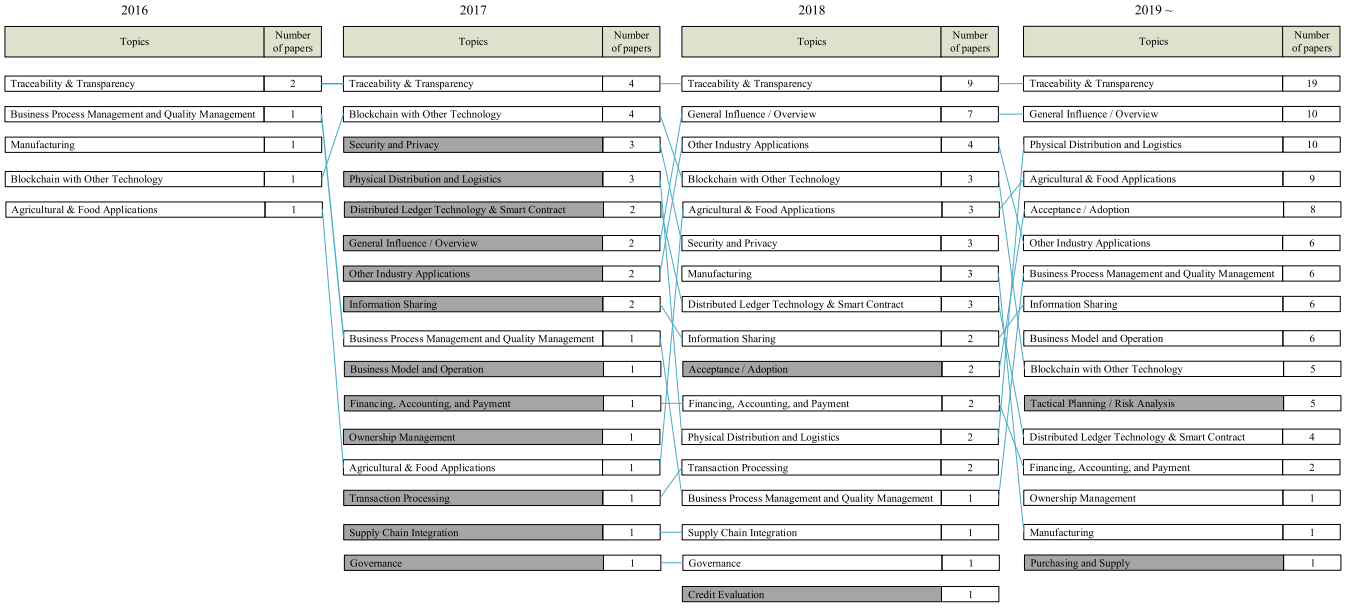

FIGURE 5. Topic relevance over time. Note: Grey background refers to new topics compared to previously listed ones.

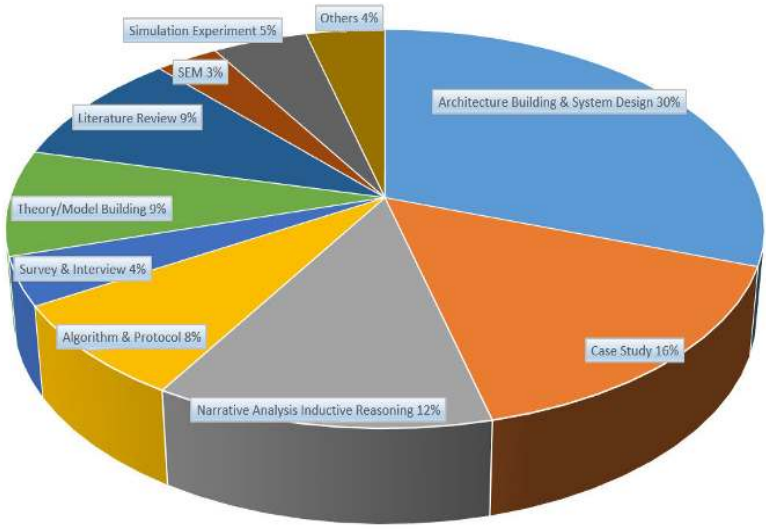

FIGURE 6. Research methods adopted in the corpus.

applications in various sectors. Several of the selected papers, from a technical-oriented perspective, utilized a blockchain-based system design and proposed conceptual frameworks for future system implementation. Some papers included coding segments to enhance understanding, and experimental simulations to assess the performance of blockchain-based systems.

Some authors developed questionnaires and conducted interviews to assess the influence, acceptance, and performance of improvements in supply chain traceability/transparency due to blockchain. Very few papers conducted literature reviews due to the lack of adequate relevant literature. Additionally, some papers focused on the validation and evaluation of prototypes while few paid attention to blockchain-supply-chain theory building. Thus, most research studies adopted system design, case studies, or descriptive analysis to verify the effectiveness and potential of innovative blockchain-supply-chain projects/systems and associated conceptual frameworks.

E. CITATION ANALYSIS

Table 4 summarizes 12 frequently-cited documents (10 journal articles and two conference papers) in the corpus. To answer RQ3, we selected several typically-cited papers, categorized them, and provided complementary research findings for them. This selected list offers an outline of related topics about how blockchain may be applied in supply

TABLE 3. Topics and methods used in the corpus.

Topics \ Methods	Architecture Building & System Design	Case Study	Narrative Analysis Inductive Reasoning	Algorithm & Protocol	Survey & Interview	Theory/Model Building	Literature Review	SEM	Simulation Experiment	Others
General Influence / Overview	68	47,63,73,97	1,100,119,135			117,119,131,132	19,20,98,107			26,112,132
DLT & SC	36,82,89,91,102,116	30	95	111			93			
Business Process Management and Quality Management	16,21,22,37,50,74		40	32		32	3			
Ownership Management	67			27						
Information Sharing	16,37,74113,114,116	114		62,111					126	
Security and Privacy	91,114,116	55	90,92	62						
Business Model and Operation	105	73	1			4,117	107	78		
Acceptance and Adoption		80,128	129		10,18 80,133	77,128	80,134	77,78, 79,134		
Supply Chain Integration		115					20			
Purchasing and Supply		122								
Manufacturing		64,66		53		54				
Physical Distribution and Logistics	74,82,104,105,116,123	48,65,73,128,130	101		52,81	128	72,101		93	
Transaction Processing	96,123			33						
Financing, Accounting, and Payment	34,37	130	66	33						
Governance	96		95							
Credit Evaluation	94									
Blockchain with Other Technology	68,69,70,84,85,104,127	55,97,122	60,92	71						
Traceability and Transparency	16,49,50,51,52,57,70,82, 84,85,87,89,94,96,103, 116,123,124,125,127	30,47,52, 58,124	110	67	18	54,132	59,72,106		57,70,126	88,132
Agricultural & Food Applications	50,51,69,84,85,86,87,94		109,110				59,106			88
Other Industry Applications	49,56,57,67,96,108	55,63,64,80	60,100,120	61,62,108					108	
Tactical Planning / Risk Analysis	76	118	75,120			75,118			75	65

Note: Paper number refers to that in Reference section.

chains. Earlier-published papers may have been cited more frequently compared to more recent publications.

Early research focused on the examination and prediction of blockchain-enabled improvements on supply chain traceability and transparency [82], [83]. For example, Tian [84], [85] developed frameworks combining blockchain with RFID and the IoT. These papers serve as references for other applications in various industries, especially the agricultural sector [86], [87], [88]. Later, research interests moved toward the discussion of blockchain system design [89], security and privacy issues [90]–[93], credit evaluation [94], and governance [95], [96]. Evidence from pilot studies has urged scholars to examine blockchain's role in meeting SCM objectives [97]. Researchers have asserted that areas, such as extended visibility and traceability, supply chain digitalization and disintermediation, improved data security and smart contracts, are worthy of further study [19]. We suggest that a second-run SLR must be conducted to include more emerging research efforts regarding the various supply chain applications of blockchain.

V. DISCUSSION

Blockchain, with its unique characteristics, has received growing attention from engineers, researchers, and practitioners in the last decade. Through a series of explorations and implementations of several pilot projects in various sectors, blockchain technology has found practical applications from both academic and practical perspectives [98]–[101]. To answer the research questions in this paper as well as provide a better understanding of future blockchain developments, we attempted to bridge the gap in extant knowledge regarding blockchain applications and future research work with the findings from our literature review. The major research issues for the achievement of supply chain objectives are elaborated and discussed as follows.

A. TRACEABILITY AND TRANSPARENCY

Traceability and transparency have long been critical issues in supply chain activities. Typical pain points include critical intermediaries, process hand-offs, over-centralized business operations, etc. Blockchain, as a distributed shared ledger technology, may help increase traceability and extend supply chain visibility by its consensus mechanism and shared ledger. Every single node participating on a blockchain platform collaboratively maintains and validates transaction records in the common ledger. The major players, including suppliers, manufacturers, shippers, distributors, and customers, have duplicated transactional records and access permission to monitor the progress of process flows [102]. These inherent characteristics greatly reduce the need for trusted centralized authorities, allowing for immutable transactions and improved efficiency in supply chain activities.

TABLE 4. List of frequently cited documents in the corpus.

Paper	Highlights	Applied Scenarios	Key findings
[97]	Influence on SCM objectives	Global supply chains	Multiple case studies are conducted to address blockchain capabilities for achieving key supply chain management objectives.
[86]	Agricultural supply chain system	Agriculture industry	A dual-chain ("user information chain" and "transaction chain") agricultural business resource public block chain is proposed to provide security guarantee mechanism and improve the utilization of business resources.
[92]	Security and Privacy	Global supply chains	This paper evaluates blockchain's roles in strengthening supply chain cybersecurity related to IoT devices and protecting privacy. Policy implications are suggested on establishment of public–private partnership and governmental provision of legal clarity on smart contracts.
[66]	Architectural system design	Manufacturing industry	A proposed blockchain architecture was developed to facilitate a high security, scalability and a well-structured cloud system The design can bring more advantages to cloud manufacturing than the security and scalability.
[122]	Development of system design principles	Purchasing and supply management	Blockchain technology from the purchasing and supply management perspective may be envisioned to allow the flexible interconnectivity of autonomous purchasing systems and machine-to-machine interaction via smart contracts. Blockchain is viewed as a procurement value driver to product information records which is useful for supplier capability assessment.
[96]	Governance of blockchain-based system	Medical industry	Gcoin-based blockchain as the base of the data flow of drugs is proposed to create transparent drug transaction data. The regulation model of the drug supply chain could be altered from the inspection and examination only model to the surveillance net model. The proposed model is able to improve distributed governance and prevent drug counterfeits.
[18]	Blockchain acceptance	Food provenance	Consumers are overwhelmed by the amount and complexity of certification labels. As a transparency and traceability system, blockchain technology implementation appears to have significant positive influences on consumers' purchasing decisions, mediated by consumers' quality perceptions.
[85]	Traceability with IoT	Agri-food industry	A food supply chain traceability system for real-time food tracing based on HACCP (Hazard Analysis and Critical Control Points), blockchain and Internet of things, could provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security.
[84]	Traceability with RFID	Agri-food industry	A RFID and blockchain combined system can realize the traceability with trusted information in the entire agri-food supply chain, which would effectively guarantee the food safety, by gathering, transferring and sharing the authentic data of agri-food in production, processing, warehousing, distribution and selling links.
[19]	Comprehensive literature review	Global supply chains	A systematic literature review in supply chain context shows trust as a key driver for blockchain adoption. The value lies in four areas: extended visibility and traceability, supply chain digitalization and disintermediation, improved data security and smart contracts.
[79]	Adoption drivers	Global supply chains	Empirical study using supply chain and network theory, as well as the technology acceptance models (TAMs), is conducted to provide evidence and report on blockchain adoption behavior at the individual level. The developed model investigated main drivers and reported distinct adoption behaviors between Indian- and USA-based professionals.
[73]	Business operation	Global supply chains	A multiple case study is conducted to develop an explanatory model for the interaction of actors in a blockchain-based operational supply chain. The study analyzed the impact of blockchain on replacing operational intermediaries and found certain blockchain's impacts on business models for logistics industry.

From the results we reviewed, we can note that nascent blockchain-based supply chain studies focus on the discussion of its potential to improve traceability and transparency [103]. Industrial pilots such as Provenance, Walmart, and Everledger have illustrated the capability to improve the visibility of physical movement, asset transfer, and quality assurance. The integration of blockchain and emerging technologies, such as the IoT and advanced sensing technology, will enable improved real-time monitoring of logistics activities [104]. By introducing better disclosure of supply chain activities and improving accountability across supply chain players, blockchain may mitigate disputes among businesses. With its immutable attributes, the distributed ledger system also reduces the need for reconciliation among traditional siloed databases. In this sense, stakeholders may capture value and alleviate risks when conducting transactions.

Moreover, smart contracts may facilitate process automation and provide better real-time monitoring of product/service visibility [105]. The design of smart contracts aims to achieve the functional demands of supply chain stakeholders. While trust is often weak among unfamiliar trading parties, blockchain may leverage its advantages to create value in supply chain activities. A blockchain ledger system may also provide authenticity verification of property or documents via digital signatures or other encrypted measures, which increases security and averts counterfeit [27], [71]. Enterprises may benefit from the reduced processing of paper-based documents as well save the considerable costs involved in tracking and obtaining proof of information authenticity. Accordingly, an improved supply chain working scheme with better traceability and transparency, less intermediation, and process automation is attainable when making blockchain transactions with counterparties. Moreover, blockchain's distributed governance and transparency attributes may also provide solutions to malicious alterations in a centralized system.

B. STAKEHOLDER INVOLVEMENT AND COLLABORATION

Joint participation of supply chain actors can enhance the overall performance of a blockchain ecosystem [106], [107]. From a systemic perspective, blockchain may leverage its potential through a large-scale collaboration of stakeholders as supply chain friction mainly stems from dispersed disconnection among parties [108]. However, blockchain may not be a panacea as certain challenges and barriers still remain in the further adoption of blockchain technology [109]–[111]. First, the willingness of supply chain stakeholders dominates the level of employment as blockchain-based architecture is still in its nascent stages. Some unsolved technical issues

include transaction throughput, scalability, security and privacy, block capacity, and power consumption issues. Supply chain participants are accustomed to the trust mechanism supported by centralized authorities and have less confidence in the effectiveness of a distributed trustless paradigm. Cultural mindset and extant business processes need to be changed before blockchain adoption.

Second, activities for business process redesign and migration need to be well planned. The successful establishment of a blockchain-based operating environment requires coordination among the legacy databases of various parties [75], [112]. Firms have to choose appropriate types of blockchain applications and scholars have reported several judging criteria for reference. For example, a private blockchain is suitable for an intra-organizational context as it has a higher level of centralization and security. Public blockchains are open to public participation without permission while a consortium blockchain provides mid-level of decentralization. Researchers have addressed the importance of establishing a governance model, considering blockchain configuration and operations among stakeholders. Additionally, information sharing and system interoperability are key concerns for blockchain architectural design [113], [114].

C. SUPPLY CHAIN INTEGRATION AND DIGITALIZATION

Blockchain has the technical capability to play a critical role in information sharing [115], [116], value/property transfer, and trust provision [108]. The way in which supply chain partners achieve strategic and business objectives using blockchain technology relies on the integration of business processes with the type of blockchain employed. From a value-creation perspective, blockchain enables the incorporation of a new business model [117] with disruptive innovation [118] and different levels of disintermediation, which allows for better transparency, security, privacy, and becomes a driving force of cooperation among untrusted parties. Blockchain-based financial applications grant a dramatic reduction on transaction costs with re-engineered processes since a synchronized ledger may significantly enhance the level of overall efficiency [119]. For example, researchers have suggested a blockchain-based letter of credit process, which may greatly improve efficiency in global trade context [16], [37].

Digitalization of physical properties and intelligence rights may be the next stage of development in blockchain application [19]. Digitalization allows the transfer of value across a distributed ledger system due to blockchain's capability for maintaining data integrity [120], free from malicious tampering and cyber-attacks [121]. Blockchain networks could also facilitate the transmission of digitalized stakes [122] and provide validation of document authenticity, which can mitigate transactional disputes. Moreover, blockchain and smart contracts facilitate process flows and improve the efficiency of payment transfers and settlements. Smart contracts, serving as digitalized protocols, could enable the tracking of supply chain events and document flows, which can streamline business operations and facilitate the execution of business logic. Therefore, supply chain digitalization is expected to promote stakeholder involvement in achieving common objectives.

D. COMMON FRAMEWORKS AND BLOCKCHAIN-BASED PLATFORMS

In a blockchain-based platform, smart contracts play a crucial role in connecting business logic and process execution in supply chain activities. For example, event-driven mechanisms are widely adopted when designing smart contract communications [37], [123]. Programmable codes are utilized to allow triggers when supply chain activities change states. For example, smart contracts trigger corresponding notifications to supply chain stakeholders when certain preset conditions are met, such as goods arrival, payment received, or shipping documents approved. Trial pilots with a variety of blockchain platforms have been devoting efforts to realize the better performance of supply chain flows. Typical examples and platforms that have been widely adopted by financial organizations are Ethereum, Hyperledger, R3 Corda, Ripple, Wave, etc. Different rationales dominate blockchain-based architectural designs, and various blockchain applications in supply chain activities demand joint collaborations among participating actors [124].

The findings we reviewed show that blockchain system planning and design is scenario-oriented [125]. We may take international trade supply chain as an example to shed light on the selection criteria for blockchain type and platform. When oriented toward disclosing information to the general public, a public chain with permissionless accessibility is preferable to improve the visibility of front-end workflow. Ethereum provides public chain settings for supply chain customers to trace physical asset provenance, authenticity and logistics status [126]. Conversely, local trade dealing with internal processes, services, and transactions may require the adoption of a permissioned private chain. Hyperledger may deploy at enterprise private network for sensitive information sharing and exchange in trade context. In an international trade setting, a consortium chain deployed between public and private chains could leverage its mediating role to facilitate transaction validation and the governance structure of grouped stakeholders [37]. The dominant players in a consortium chain play predefined roles, and its semi-decentralized structure may facilitate business operations in preferred-access control and authority administration [127]. While R3 Corda, as a platform targeting financial applications, may support trade finance and with capability to administer agreements and contracts, Ripple focus on facilitating monetary and payment transactions among trade counterparties. Wave's pilot demonstrates blockchain's potential uses in electronic document submission which greatly result in huge reduction on transaction cost and document transmission. The aforementioned blockchain platforms are applicable to different supply chain use cases, and researchers may also conduct

comparisons of industrial pilots to understand how their features help achieve supply chain objectives [128].

The formation of a common framework may orient the level of participation since the greatest concern for supply chain players is how the framework distributes value to each entity and what value does the business capture within the blockchain ecosystem. Interactions among stakeholders and the sustainability of blockchain networks are essential for future blockchain development [129]. For example, a consortium blockchain framework may predominantly allocate governance to a specific group of leading enterprises [130]. These players act as value distributors and may orient the operations of permission control, credit evaluation, and regulation design. Participating entities may comprise suppliers, distributors, public sectors, and financial service providers. A sound framework with an efficient value-distributed ecosystem can extend both the technical and social influence of a blockchain framework.

E. THEORETICAL CONTRIBUTIONS AND RESEARCH IMPLICATIONS

In this literature review, we reexamined recent blockchain studies in the SCM context. Several studies focus on the general fact that blockchain may disrupt traditional supply chain practices. Many studies adopted the perspective of transaction cost [131]. Blockchain, as a shared distributed ledger, has the potential to mitigate trust issues among stakeholders, which in turn could alleviate business frictions, improve the visibility of supply chain activities, as well as the significant manipulations of human- and paper-based administration. With blockchain's digital ledger, participants can enjoy the timeliness of information transmission among entities. In this regard, enterprises can harvest this benefit by reducing the costs of information-related searching, bargaining, and policing [130]. Additionally, smart contracts can enhance the level of automation by facilitating the operation and execution of business processes, as seen in the system designs of the reviewed articles. Based on the principal agent theory, the use of smart contracts may improve the interactions and relations among supply chain participants, i.e., the principals and the agents in various value-chain-related industries. A collaborative framework, based on assorted blockchain platforms, can mitigate issues of information asymmetry through better control of contract execution and supervision. Blockchain-based business models in the supply chain ecosystem have been less discussed in the extant literature [132], while the need for holistic evaluation from supply chain practitioners remains strong. This phenomenon may be because blockchain development is still in a nascent stage and certain technical challenges remain unresolved. Based on the findings we reviewed, researchers have focused more on the improvement of disparate processes and business performance than the overall examinations of how blockchain adopters may derive economic gains from value creation and revenue strategies. Future research on managerial issues should address the perspective of resource allocation and network collaboration. This theoretical work may help analyze, elaborate, and forecast the impacts of blockchain in supply chain management.

This paper has identified key research topics and the methodologies required to explore blockchain in the supply chain field. However, operational challenges such as how to determine whether blockchain adoption is required remain at the discretion of managers and practitioners. The use of blockchain should be carefully considered in terms of product (or service) characteristics, alternative surrounding technologies, and a firm's supply chain strategies. As the challenges of migrating from a legacy system to blockchain-based applications may influence the adopter's incentives, a careful consideration of implementation costs, technical limitations, barriers to entry, economic benefits, difficulties across multi-tier actors, and regulative compliance should be conducted before a final decision is made. In this study, Table 2 reports blockchain applications in potential industries while Table 3 summarizes the topics and methodologies adopted by researchers. The positioning of this research with its adopted methodologies contributes to the understanding of blockchain by providing an overview of blockchain research and highlighting the distribution of and gaps in extant literature. Only a few extant works of research have been devoted to large-scale adoption surveys from the perspectives of cost analysis, trade-off considerations, implementation difficulties, and relational impacts with supply chain actors. Work on blockchain's impact on multi-tier networks and the diversity of implementation strategies in various business sectors is still scarce. This presents promising areas for future research. Academic researchers can devote their efforts on less-explored fields, while practitioners could conduct empirical studies to evaluate the effectiveness of blockchain-supply-chain adoption or implementation [133], [134]. Based on previous review studies, this work synthesizes and analyzes research contributions from recent published literature to highlight that blockchain can reform the traditional paradigm of supply chain operations and develop a more sustainable environment for the overall supply chain ecosystem [129], [135]. Finally, the call for supply chain incumbents to deliver blockchain promise based on its disruptive features may further harvest tangible benefits. More research efforts focusing on empirical evidence when adoption, technological usability, and solutions to business long-term uncertainties, are required to fill research gaps and guide managerial practices.

VI. CONCLUSION AND FUTURE WORK

This article aimed to provide a systematic review and analysis of extant literature focusing on SCM from a blockchain and smart contract perspective. Efforts to use these emerging technologies to innovate supply chain applications have fragmented research into focusing on various topics. Research efforts are evolving from technological studies, prototype architecture design, to a rather diverse focus on industrial applications, managerial implications, and social impact. To date, we are conscious of the research motivation of

not only the pursuit of specific supply chain objectives but also for more open collaborative networks, autonomy, and distributed governance. The main contribution of this study is a systematic review of extant studies and citation analysis to provide a better understanding about the trajectories and applications of such technologies.

Nevertheless, future work must address several blockchain-related technical issues such as throughput, security, scalability, and interoperability. Similar efforts are limited and related quantitative study regarding these topics is still rare. More research work needs to address the diffusion of blockchain technology, BPR, and their managerial implications and social impact. Promising areas for blockchain applications and research include the logistics, medical, insurance, and public sectors. We expect this study to provide an overview of extant blockchain-related supply chain research and shed light on potential research gaps and directions for future works.

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