The Current State of Blockchain Applications in Supply Chain Management

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ABSTRACT

In recent years, blockchain technology is expanding to new areas beyond finance, proving its use as an underlying technology for several application areas in supply chain management. There, the technology can be used to improve collaboration and transparency between supply chain partners. In this paper a systematic literature mapping is presented, which investigates the state of the art regarding blockchain-based applications in supply chain management. Identified applications are then analyzed regarding their industry sector, implemented blockchain framework and addressed challenges.

CCS CONCEPTS

• **Information systems** → Data management systems; Information integration; Data exchange.

KEYWORDS

Procurement, Purchasing, Smart Contracts, Systematic Literature Review, Systematic Literature Mapping

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1 INTRODUCTION

Since its first public showing, by empowering cryptocurrencies such as Bitcoin, blockchain technology (BCT) is seen as a disruptive innovation mainly affecting the financial sector. Thus, the technology developed into a general-purpose infrastructure, capable of addressing different kinds of business problems [1]. The development of blockchain applications is often divided into three phases. Blockchain 1.0 describes its initial use with cryptocurrencies. In blockchain 2.0 the blockchain is extended by Smart Contracts, which are still used in the financial sector, whereas in blockchain 3.0 smart contracts are developed further to decentralized autonomous organizational units. Due to its attributes, different branches identify potential benefits and start proof-of-concepts in a variety of application areas. These areas range from the financial and energy sector to the pharmaceuticals and food industry, as well as to many others. [2]

Supply chain networks are a suitable field of application for blockchain technology. This is due to the fact that today's supply chain networks consist of a large number of partners with different kinds of service contracts, including manufacturers, dealers, suppliers as well as logistics- and financial service providers. All of which need a way to securely exchange data. [3] Due to this and increasing globalization and the expansion of business relationships into new markets, it is of great interest to increase the transparency and visibility of supply chain processes. In these cases, the attributes of the blockchain technology can be decisively important. In particular, the ability to realize opportunities without any central authority, creates a disruptive potential for many industries. This potential is increased by the fact that the network partners can share selected data and transactions since data is stored over the network in a tamper-proof manner [4].

In this paper, we present a systematic literature mapping (SLM) for blockchain-based applications in supply chain management (SCM). Therefore, we deliver background information for a deeper understanding of BCT as well as a discussion of other studies and surveys in section 2. In section 3, we discuss the used methodology. Whereas in section 4, we present the SLM results and a subsequent assessment. In section 5, we further analyze the data in a discussion and conclude the paper in section 6. The aim of the study is to give a clear presentation and categorization of current blockchain use cases in supply chain management. In addition, extracted use cases are analyzed regarding their industry sector, proposed blockchain

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framework, and addressed challenges as well as other project characteristics and solution-supported SCM processes.

2 BACKGROUND

In the following, we explain the operating principles of BCT and give an overview of related work in this area.

2.1 Overview of Blockchain Basics and Definitions

BCT is a subcategory of the distributed ledger technologies (DLT) and stores data in time stamped sequential blocks. The single blocks are chained to their respective predecessors by hash functions. A block is an ordered and grouped record that consists of at least two information pieces displayed in its header: the hash to the predecessor block and the hash of its own block. The initial state of the continuous transaction history is stored in the initial genesis block, which does not have a predecessor. The list of all headers and stored transaction information together then form the blockchain. [5]

Hash functions utilized by BCT are one-way functions that convert larger input content into a smaller, fixed-length sequence of characters. Each individual input has its own hash value (checksum or "digital fingerprint"), which cannot be reset or recalculated due to the one-way property. It is not possible to deduce the input value from the hash value. If the input content of a transaction would be changed in any way, the hash value of the transaction and its block would also change completely . This would cause an interruption in the connection to the next block. All other participants in the network are therefore able to distinguish manipulated chains quickly and efficiently because the hashes no longer match the resulting hashes of the validated chain [6].

Blockchains usually consist of different users or "nodes". The Bitcoin blockchain, for example, consists of a large number of nodes and initially distinguishes between mining-nodes (full nodes) and passive nodes (light nodes). Both types can accept or forward transactions from or to other nodes within the blockchain, but light nodes do not participate in the consensus process by validating transactions [7]. The mining nodes are responsible for updating and continuously developing the transaction history within the framework of the agreed consensus protocol, in the case of Bitcoin, proof-of-work. Through the mining nodes the entire blockchain-network is kept running and secure.

Besides the proof-of-work algorithm, there are many different consensus mechanisms. Since proof of work is mainly used in the area of cryptocurrencies and is connected with a very high computing capacity, it is less used in the area of supply chain management. The blockchain frameworks in supply chain areas are usually non-public and make use of more efficient consensus algorithms, such as proof of authority, round robin or practical byzantine fault tolerance [8].The advantages of BCT in this case is that a potentially untrustworthy middleman can be completely avoided. While traditionally the integration of banks, government authorities or law firms was necessary, the use of Blockchains relies on the network that operates the common collective platform.

2.2 Blockchain and Supply Chain Management

Since the late 1990s, innovative developments in information technology have led to the large-scale adaptation of supply chain management methods . One of the technologies that has had a noticeable influence on the further development and adaptation of supply chain management in recent years is BCT [9].

The SCM is defined as "the management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction" [10]. The goal is to design the complete process in consideration of the customer's needs, both in terms of cost and time. The flow of information, goods and services is to be handled in the most efficient way, so that risks are minimized and a better performance can be achieved [11].

Because of its architecture the BCT provides properties that are beneficial for successful SCM. Qualities such as immutability, automaticity, pseudonymity and irreversibility lead to important advantages in SCM like reliability, transparency and efficiency and therefore lead to integration attempts of blockchain solutions in supply chain networks [2] [12].

In the following, related work is presented that already offers literature analysis in the area of blockchain in the field of supply chain management.

2.3 Related Work

A general investigation of the current literature on blockchain applications in SCM has been carried out already by [1], [13] or [14]. Also, some authors focus on a certain industrial sector, such as agriculture [15], the biomedical sector [16] or healthcare [17]. Furthermore, reference [18] prepared a systematic literature review to understand how blockchain-enabled identity management improves supply chain management and -performance, while reference [19], [20] and [21] examined the literature to give a focus on main disruptions of BCT in SCM or procurement [22].

Most of the existing papers, especially the older ones, show a lack of information when it comes to the consideration of challenges. Furthermore, technical specifications are considered only in a few cases. Importantly, the involvement of concrete supply chain processes had a low priority and therefore showed a need for further research.

3 RESEARCH METHODOLOGY AND RESULTS

For the purpose of our study, we follow the comprehensive approach to perform a systematic literature mapping, described by [23], to examine the existing works and studies related to blockchain-based applications in Supply Chain Management. We also followed the guidelines created by [24] while screening the literature for relevant papers. The diagram (Figure 1) below illustrates the five process steps of the systematic literature mapping along with its corresponding outcome.

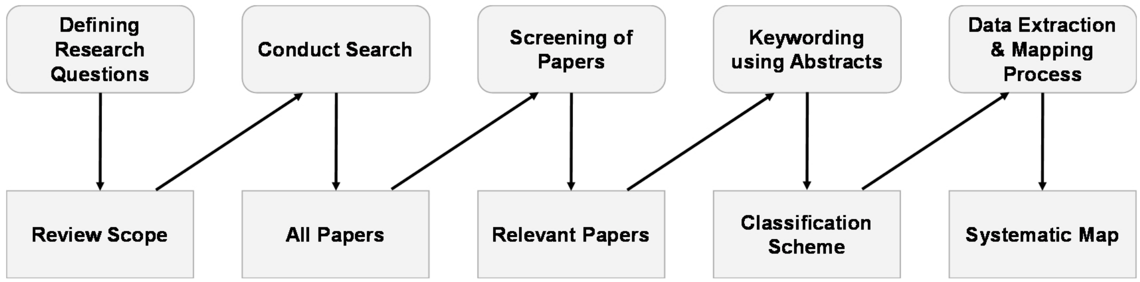

Figure 1: The five-step systematic mapping process based on [23]

Table 1: Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Only peer-reviewed literature	Grey literature or informal studies without concrete evidence
Only literature published between 2019 and 2020	Search terms not found in the title, keyword or abstract

4 DEFINITION OF THE RESEARCH SCOPE AND DATABASE SELECTION

To be able to provide an overview of blockchain-based applications in Supply Chain Management and to identify the quantity and quality of the available papers, we considered the following core research questions in the process of this study:

(i) What type of blockchain projects and corresponding degree of technical implementation (PoC, prototype, live) exist in Supply Chain Management?
(ii) What are the areas and use cases where blockchain solutions are applied to?
(iii) What business-related challenges and supply chain management processes are addressed by the blockchain solution?
(iv) What methods for data collection and data integrity are used by the blockchain solution?

The Scopus electronic databases was examined to gather literature sources utilizing the search string *Blockchain AND "Smart Contract" AND "Supply Chain"*. Besides the term "Blockchain", the term "Smart Contract" was used to exclude papers with a broad and non-technical, visionary focus. The term "Supply Chain" was added to ensure all supply chain related topic are included. In order to guarantee the high quality of considered papers, we utilized the exclusion and inclusion criteria listed in Table 1

The quality of each paper was assessed according to the quality guidelines of [23]. Six key questions were critical in the quality assessment stage of the process:

- Does the paper clearly state their purpose and goals?
- Does the paper answers all of its predefined questions?
- Does the paper present its results in a well-structured way?
- Does the paper offer a clear conclusion that is based on prior results?
- Does the paper elaborate on the focus topic of BCT in supply chain management?
- Does the paper reflect on state challenges and risks of BCT in supply chain management?

Each paper was given a point for every key question that it satisfies, with a total of 6 possible maximum points. These points were used to determine whether or not the paper is included in the following systematic mapping. The answers to the questions are scored with 1 if they are fully satisfying, 0.5 if they are partially satisfying, and 0 if they are not satisfying. The studies with 3 or more points were included for the following analysis steps.

4.1 Screening Results

Table 2 presents the results of the screening. After studies were searched in the defined sources according to the presented search terms, they were examined regarding their fit for the first time based on their title and abstract. During this step, it became clear that a significant portion of the literature are proposed blockchain solutions with a technological and quantitative focus. The remaining studies were analyzed according to the quality assessment. As a result, 39 papers have been included in this study. Initially, a total of 188 studies were collected and then filtered based on the inclusion and exclusion criteria and the quality assessment. The study was conducted on June 24, 2020

5 MAPPING AND RESULTS

In this section, the information extracted from the 39 relevant papers and their contributions to the study are discussed. The relevant papers were analyzed in order to determine which industries blockchain technology is utilized in, the different use cases, the challenges addressed by blockchain, data collection methods, data integrity mechanisms, degrees of technological implementation, and supported SCM processes along with the differing blockchain solutions. The sum of the following results add up to more than the number of screened papers because some extracted datasets correspond to more than one category. Table 3 gives an first overview of the screening results

Table 2: Screening results after each screening process step

#	Screening process	Studies excluded	Remaining Studies
1.	Studies collected from defined sources	-	188
2.	Studies excluded due to criteria/title and abstract only	138	50
3.	Studies screened	-	50
4.	Studies excluded after quality assessment	11	39
5.	Studies included after full text reading and quality assessment	-	39

Table 3: Screening Results

Industry Sector		Use Case		Addressed Challenge	
Agriculture/ Food	17	Tracking/ Tracing	38	Information Asymmetry	39
Cross-sectoral	8	Open Info Access	31	Unknown Provenance	38
Pharma	8	Fraud Prevention	21	Counterfeit/ Fraud	20
Non-fungible Products	6	Automated Payments	11	Business Challenges	19
Construction	2	Inventory Management	6	Sensitive Data	5
Automotive	2	Collaborative SCM	3	IT Security	4
Other	3	Financing	2	Connectivity	3

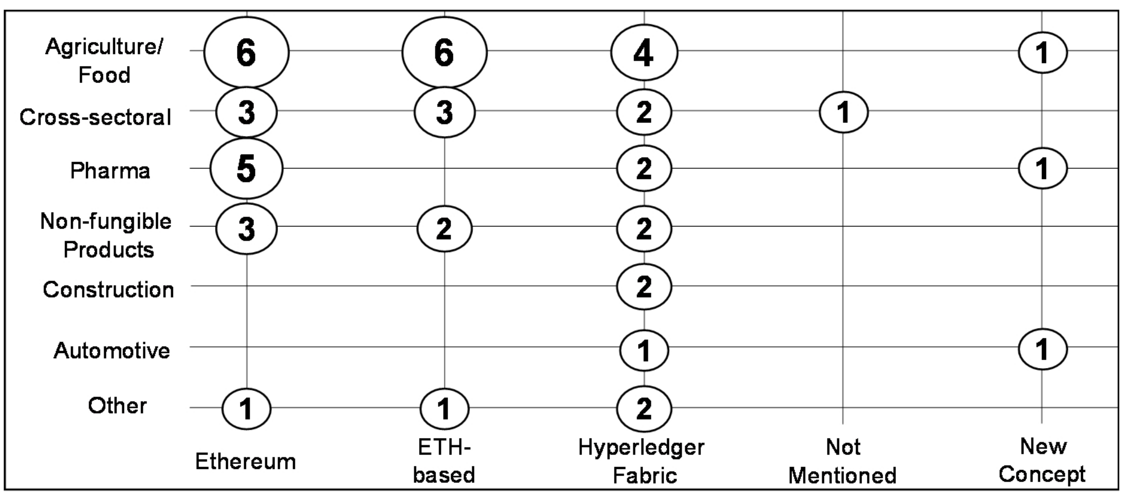

Figure 2: Blockchain solutions in different industry sectors.

5.1 Blockchain Solutions in different Industry Sectors

In the first step, the selected literature was examined for the industry sector of the blockchain solutions. It is noticeable that most solutions are intended as agricultural/food approaches (17) largely due to the need for recording and tracking product information. The pharmaceutical industry can be named as the second largest stand-alone industrial sector, with eight entries mainly because of the issue of drug counterfeiting, see Fig. 2

The type of blockchain was also collected and structured. Notably, consortium blockchains were proposed 21 times and appeared in every sector identified in the search. Consortium blockchains are proposed frequently for supply chain systems due to their higher performance relative to public blockchain solutions in metrics like transactions per second. Also, in contracts to public solutions, consortium blockchains allow for the selection of participants that can send transactions, participate in the blockchain consensus, and view data. Public and private blockchains were proposed 16 and 8 times, respectively. Public blockchains often utilize off-chain databases,

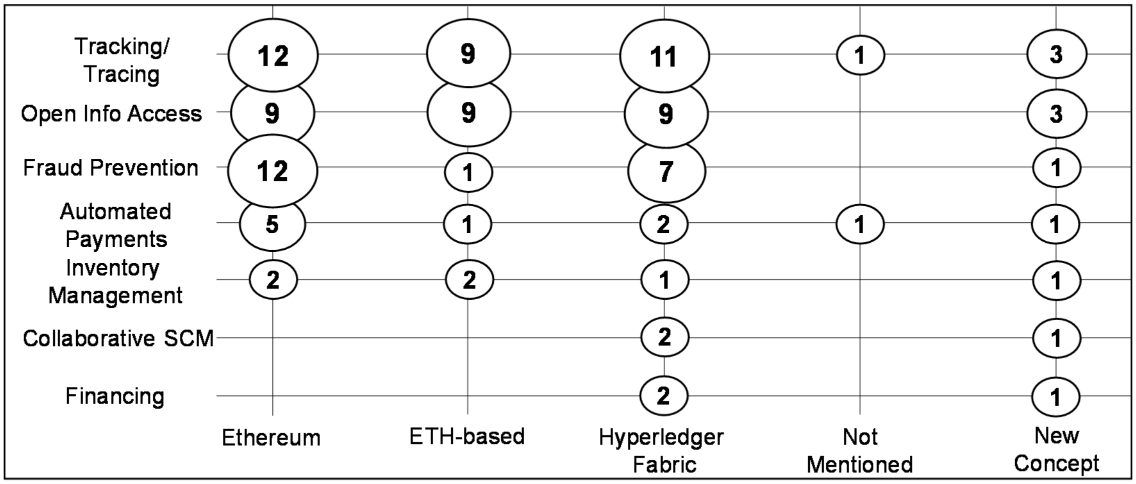

Figure 3: Blockchain solutions in different supply chain use cases.

like IPFS, due to the higher cost of storing data. In case of private blockchains, which more centralized, some papers suggest they should be managed by a trusted third party outside the supply chain. For example, [25] proposes that the Indian government be the network administrator for their blockchain solution.

With regard to the blockchain platform used, most proposed solutions use Ethereum, ETH, (14) or Hyperledger Fabric (12). Some papers suggested the use of modified ETH-based blockchains (9) while others introduced a new concept (3). One paper [26] mentioned using ETH Testnets for metric tests while not specifying the blockchain platform that would be used in practice. Notably, the majority of proposals do not develop new blockchain platform concepts, which suggests that the existing blockchain platforms are mature enough for potential use in SCM. The mapping of the industry sectors, see Fig. 2, is presented as a bubble map.

5.2 Use Cases

In addition to the industry sectors, the use cases of the proposed blockchain solutions were surveyed. One use case dominates currently very clearly. The literature presents 38 proposals for blockchain-based tracking and tracing of goods. The second most frequent use case, which deals with open info access, has 31 listings. In third, fraud prevention has 21 listings with a significant portion being related to drug counterfeiting. Although most solutions involved storing product information, relatively few solutions dealt with inventory management. Comparable to the results presented before in terms of the industrial sector used, Ethereum and Hyperledger Fabric solutions map to the most use cases, see Fig. 3

5.3 Addressed Challenges

The business-related or supply chain management specific challenges that are addressed by the solutions was collected. The individual challenges were identified 128 times. The problem of information asymmetry is present in all of the papers analyzed because the blockchain solutions were designed to bring transparency between supply chain parties and record product information that includes supply origin. Also, in this analysis step, the blockchain types Ethereum and Hyperledger Fabric address the most challenges, see Fig. 4

5.4 Solution Status and SCM Processes

The degree of technological implementation was collected to establish the nature of proposed solutions currently in academia for SCM. The results show that there is an increasing trend towards quantitative analysis of blockchain solutions for SCM although the majority of solutions are at an early, not yet mature stage. Metrics test were most common (22) and show that academics are coding and implementing some form of the solution. Metrics test generally focused on network TPS and latency. The second most common was found to be code specification mostly through the use of pseudocode (18). 9 papers did not show any degree of technological implementation and instead gave conceptual proposals. There were significantly less solutions with proof of concepts (4), working prototypes (3), and live betas (1). Only [27] presented a solution that was live and seeing significant use in industry.

The specific SCM processes that were supported by the blockchain solution were collected and structured according to [28]. The results are presented in Fig. 5. All papers supported order fulfillment and supplier relationship management because these are the key aspects of SCM that require transparency between supply chain members. However, the financial aspects of order fulfillment were largely neglected seen by the low number of entries for the addressed challenges of automated payments and financing. Customer service management was supported 28 times, generally through the use of QR codes scanned with mobile apps that allow customers to query product information. The product data that was associated with the blockchain solution, often stored off-chain, was used to support demand management seven times. Manufacturing flow management and product development and commercialization were rarely supported by the blockchain solutions because these processes often involve less communication and collaboration between supply chain partners relative to other SCM processes.

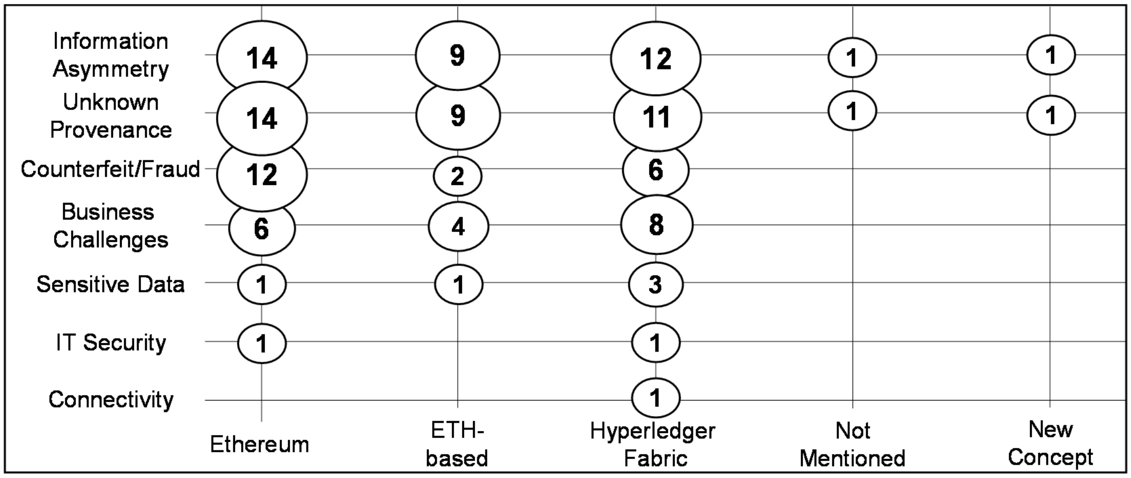

Figure 4: Blockchain solutions and their addressed challenges.

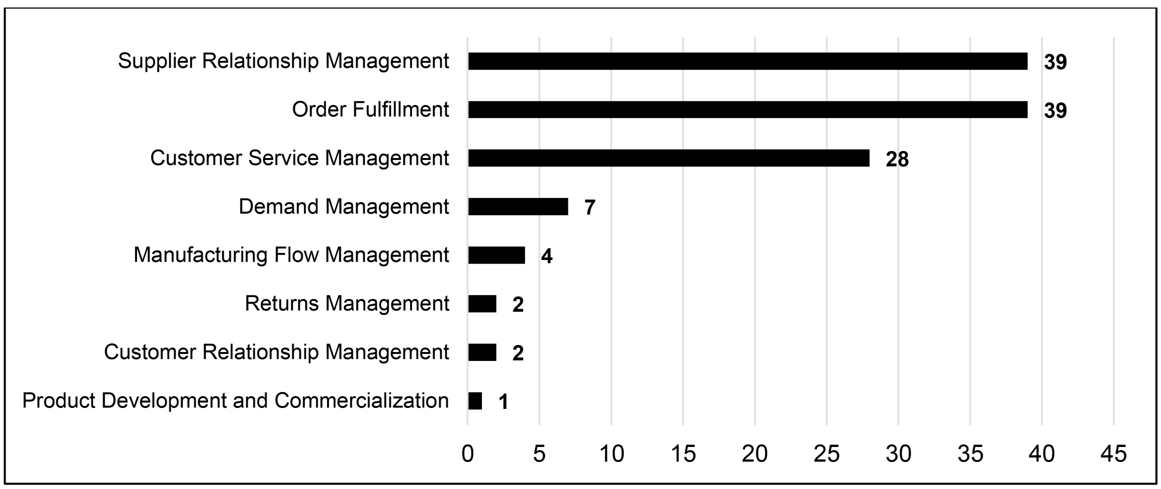

Figure 5: Supply chain management processes.

Customer service management and returns management were not supported by the majority of papers. It is not clear, through reading the literature, what value propositions blockchain solutions may have for those two processes.

5.5 Data Collection and Integrity

Information about how blockchain solutions input and collect the data stored on the system was collected as shown in Fig. 6. The majority of the blockchain solutions rely on supply chain parties' staff input (38), generally for inputting order transactions between parties into the system. Internet of things (IoT) devices were often used to collect and upload product information to the proposed systems (24). 14 of the papers mentioned the use of scanning through barcodes or quick response codes. Third party input (5), customer input (4), and external oracles (1) were also proposed as data collection mechanisms. It was often unclear to what degree inputs into the blockchain were automated in proposed solutions and whether the solutions would affect staffing or incur significant staff training costs. Although the papers explained the logic behind the system, few papers described how organizations would, in day-to-day operations, use the systems. Five solutions involved regulators or other trusted third parties to insert information into the system, like food certification authorities issuing ingredient certifications in [29]. In addition, [30] described the possible use of external oracles to feed data into smart contracts for resolving disputes related to unsatisfactory order fulfillment, like reporting fires.

The mechanisms for ensuring that the information stored in the system is true by the blockchain solutions were collected. Trusted third parties were most often used to improve the validity of data (16). 10 solutions did not mention any mechanism for increasing data integrity. Reputation history (8), financial penalties generally carried out through smart contracts (6), and product inspections (5) were also used. Two papers described a dispute process carried out on the blockchain solution for resolving issues between supply

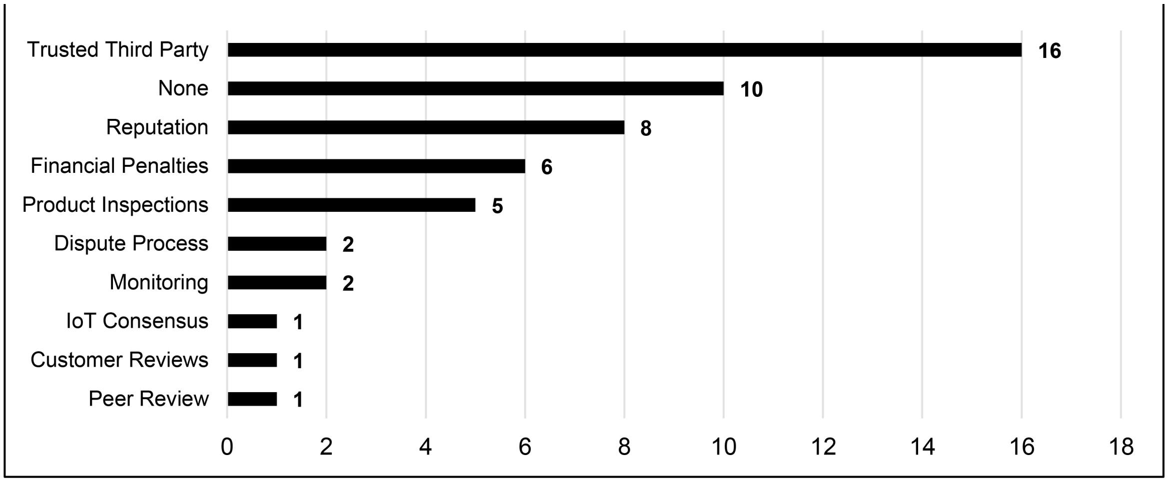

Figure 6: Data integrity mechanisms.

chain parties while most papers did not describe scenarios where involved parties are not honest.

6 DISCUSSION OF FINDINGS

Throughout the review, it became clear that most of the blockchain solutions are being developed for the agriculture and food industry. Nevertheless, the pharmaceutical and cross-sectoral sectors are also relevant. Also, academics seem to be satisfied with building solutions on top of Ethereum and Hyperledger Fabric considering that using new frameworks were rarely proposed. Considering use cases, most of the solutions aim at the tracking and tracing of products or fraud prevention. This is also reflected in the addressed challenges, as the problems of information asymmetry and unknown provenance were mentioned frequently.

With regard to methods for collecting input data, internet of things devices have been proposed often to address real-time transparency of product information, and staff input is heavily relied on. The quality of data input into the blockchain systems is not adequately addressed by current literature as seen by a significant portion of papers that do not address the use or need of data integrity mechanisms. Instead, academics have largely focused on the security and immutability of data once it is on the blockchain itself. One area of concern is the reliance on trusted third parties for ensuring data integrity because this can become a bottleneck and enable dishonest actors to input bad data into the blockchain solution.

Overall, the proposed solutions are in the metrics testing phase, and many have not implemented the proposed systems with firms. With regard to supported supply chain management processes, SCM processes that involved fewer supply chain parties were rarely addressed. This includes product development and commercialization; customer relationship management; and returns management. Although neglected, the returns management process may warrant further exploration due to its role in identifying product improvement opportunities.

7 CONCLUSION AND FUTURE WORK

In this paper, we present a systematic literature mapping on blockchain-based solutions in the field of supply chain management. In addition to the solutions' associated industry sector, use cases and addressed challenges were identified. Also, the solutions were mapped based on their data collection methods, data integrity mechanisms, degree of technical implementation, and supported SCM processes.

Thereby, the paper is subject to the following limitations. The use of the search term "smart contract" may have biased results towards solutions that use Ethereum. Also, it was often not possible to understand the proposed blockchain consensus mechanisms as well as the potential network administrators that would operate the blockchain system due to the solutions being at an early developmental stage. Therefore, it was sometimes challenging to differentiate between a consortium and private blockchain.

The question of how academics can best contribute to blockchain research remains open. Currently, the majority of focus has been on proposing blockchain concepts in different use cases. In future, academics should focus on increasing collaboration with industry organizations to further test the proposed solutions through prototypes and betas. This approach may be beneficial to small and medium enterprises (SME's) that may not have the capital to develop blockchain solutions themselves. There will be also value in academics helping optimize and especially quantify the social and ecological impact, as well as the and economic value of existing blockchain solutions in industry. Future research directions may also revolve around the development of input data integrity mechanisms, further automation, and the connection to external oracles and other blockchain systems as well as frameworks for incorporating complex business logic, with dispute settlement processes, into smart contracts. Other largely unexplored areas include the role of second layer scaling solutions, built on top of SCM blockchain systems; networking solutions, the economic and legal implications of the use of payments through cryptocurrencies, like stablecoins; and incorporation of other emerging technologies, like machine learning.

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