Academic Journal of Computing & Information Science
ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

Blockchain Technology Improves Supply Chain: A Literature Review

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ABSTRACT. *Blockchain technology has the characteristics and functions of distribution, information encryption, information irreversibility, intelligent contract, etc. Through improved traceability and traceability, as well as automatic data acquisition and other ways, blockchain helps to reduce the complexity of the supply chain, improve the visibility of the supply chain. Through literature review, it is found that the application of blockchain technology in supply chain mainly includes: improving the transparency of supply chain, to build trust between upstream and downstream; reduce information cost, help to improve the efficiency of supply chain information transmission; help to realize supply chain traceability and tracking function, especially for the food supply chain. Besides, the research on the application of blockchain in the supply chain is analyzed from the aspects of technology, policy, and organization, and it is believed that the technical bottleneck needs to be overcome, other intelligent technologies need to be integrated, and the integration platform of industry-university-research should be constructed.*

KEYWORDS: *supply chain, blockchain technology, trust, information transfer, traceability*

1. Introduction

Great changes have taken place in the operation mode of the supply chain in the Internet era. The mode of e-commerce promoted by the Internet had a significant impact on the supply chain management of enterprises, and supply chain managers pay more attention to the value of consumers and enterprises. However, the supply chain still failed to achieve the key management objectives, such as cost, quality, speed, reliability, risk reduction, sustainability, and flexibility [1]. It is estimated that the cost of operating the supply chain accounts for two-thirds of the total cost of goods, and there is a lot of room for optimization [2]. Besides, due to the unprecedented complexity of the supply chain network and the uncertainties associated with geopolitics, technology, and economy in a globalized market and environment, it is a challenging task to manage today's global supply chain. This requires monitoring the supply chain to meet the requirements of product safety and

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

integrity, technical regulations, supplier's social and environmental responsibility, and ethical procurement. In addition to focusing on the upstream supply network and tracking the sources and sources of raw materials and parts, the supply chain management has also been extended to the downstream, tracking goods along with the multi-layer distribution network [3].

Blockchain technology has the characteristics and functions of distribution, information encryption, information irreversibility, and smart contract, which can achieve the management objectives of the supply chain. Through improved traceability and automatic data acquisition, the complexity of the supply chain is reduced and the visibility of the supply chain is improved. For example, blockchain can force enterprises in the supply chain to comply with standards and regulations through verification mechanisms and smart contracts [4]. However, the blockchain applied to the supply chain is still in its infancy, and most organizations have not gone beyond the analysis stage to enter the adoption stage [5]. Even though the blockchain technology in the supply chain has not been deployed in a practical, specific, and large-scale way, most enterprises and researchers are committed to exploring the potential use of blockchain technology [6]. According to a 2017 Gartner report, blockchain investment in supply chain management is expected to grow at an annual rate of 87%, from $45 million in 2018 to $334.6 million in 2023. Table 1 shows typical supply chain application cases of blockchain. It can be seen that blockchain technology has been attached great importance by global supply chain enterprises.

Table 1 Application of blockchain in supply chain

Time	Company	Case
2016	Provenance	A pilot project was launched in Indonesia to make the fishing industry traceable.
2016.10	Wal-Mart and IBM	Digital tracking project of American agricultural products and Chinese pork based on blockchain
2017.03	Alibaba and PWC	Traceable cross border food supply chain
2017.06	JD.COM	Application of blockchain anti-counterfeiting Traceability Technology to provide consumers with assured agricultural products.
2017.12	Nestle, Unilever, Wal Mart, and IBM	A blockchain system called "food trust" has been developed to cover partners and competitors to maintain a single record-keeping
2018.01	Maersk and IBM	Tracking containers around the world using blockchain technology

Based on the existing research on blockchain technology in the supply chain, this paper sorts out and analyzes the existing literature, on the one hand, it helps to

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

clarify the relevant theoretical context, on the other hand, it points out the direction for future research.

2. Blockchain Technology

Blockchain technology is often referred to as a disruptive technology [7] and is often defined as a distributed ledger database used to record transactions between parties verifiably and permanently [8]. Blockchain is a kind of point-to-point distributed network, which has the characteristics of information encryption, which can only be added, but not changed. Moreover, through the consensus mechanism update, both parties do not need a trusted third party to complete economic transactions [9]. In the blockchain system, a series of transactions are recorded in a ledger in a given period and form a data block. Each block is connected with the blocks before and after it by the hash function. Once these blocks are connected to a chain, they cannot be changed or deleted by a single participant, but are verified and managed by automated and shared governance protocols.

The characteristics and functions of blockchain can be summarized as follows [10,11]: (1) Disintermediation. Blockchain is a point-to-point network, so it reduces the dependence on third parties. (2) Transparency. The information in the blockchain can be seen by all participants and can not be changed by a single node, thus reducing fraud and creating trust. Based on this feature, users can choose to remain anonymous or reveal their identities. (3) Safety and Reliability. Algorithms are deployed on the blockchain to ensure that the records on the database are permanent, chronological and that all records on the network are accessible to participants. It is the blockchain's distributed and encrypted features that make it hard to crack. (4) Automation. Blockchains can be programmed to automatically trigger actions (such as payments or other events) between nodes once certain conditions are met, even if the concept of smart contracts becomes possible.

Blockchain technology is rapidly becoming a new distributed and decentralized alternative, which provides higher data protection, reliability, invariance, transparency, and lower management costs. These characteristics make it very suitable for integration in the supply chain management system. At present, blockchain technology is widely used in shipping industry [3], transportation industry [12], food industry [13,14], medicine industry [15,16], manufacturing industry [17,18], etc.

3. Research Topics of Blockchain Technology in Supply Chain

Blockchain technology realizes the specific services of supply chain management, such as providing operation services, reporting services, data management, and analysis in data services. Besides, blockchain can also provide specific business content, such as procurement services, financial services, risk control services in supply chain management, etc. By building a supply chain management platform based on blockchain, enterprises can obtain massive data and

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

record commodity circulation information through source tracking, certificate storage, mutual trust, and information communication, to effectively meet the demand of the supply chain [19]. In addition, blockchain technology can connect supply chain related enterprises, promote the integration of commodity flow, logistics, capital flow, and information flow, reduce operating costs, and improve operation quality. This paper finds that the research on the implementation of blockchain in the supply chain can be divided into three categories: transparency and trust, information transmission efficiency, tracing, and tracking.

3.1 Research Theory and Method

Table 2 Research theory of application of blockchain technology in Supply Chain

Literature	Research Theory	Research Content and Conclusion
[1]	Supply Chain Objective Theory Innovation Diffusion Theory	This paper studies how blockchain may affect key supply chain management objectives and finds that blockchain has more advantages than the financial industry in supply chain activities based on innovation diffusion theory.
[4]	TCA Theory	Blockchain reduces transaction costs and affects governance costs and structure.
[5]	TAM Theory and SNT Theory	Organizations and managers need to develop the necessary infrastructure and enable the system to maximize user productivity.
[20]	BPR Theory	From the perspective of process reengineering, blockchain technology promotes process automation and disintermediation through the use of smart contracts and promotes the multilateral collaboration network among supply chain members.
[6]	Meaning Construction Theory	Using the theory of meaning construction, this paper discusses how the new blockchain technology can change the supply chain.
[21]	MV Theory	Application of MV method to explore the global supply chain operational risk of aviation logistics in the era of blockchain technology.
[22]	PAT Theory TCA Theory RBV Theory NT Theory	This paper considers the main properties of blockchain from the perspective of four theories and provides a theoretical framework for logistics and supply chain management researchers.

Most of the existing researches on the application of blockchain technology in the supply chain tend to qualitative analysis, such as theoretical analysis, case study,

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

and architecture design. The existing theoretical analysis frameworks are based on supply chain objective theory and innovation diffusion theory [1], transaction cost analysis theory (TCA) [4], technology acceptance model theory (TAM) and social network theory (SNT) [5], process reengineering theory (BPR) [20], and sense-making theory (sense-making) Theory [6], based on mean-variance theory (MV) [21], and other hybrid theories, such as the combination of main agent theory (PAT), TCA theory, the resource-based view (RBV) and network theory (NT) [22]. The specific research contents and conclusions are shown in Table 2. Although the research on the blockchain in the supply chain has involved more theories and analysis frameworks, on the whole, the papers of theoretical analysis type still account for a small proportion, and most of them adopt the traditional theories related to technology, organization, and supply chain, and the emerging theories for blockchain still need to be developed.

3.2 Transparency and Trust

In the case of low trust in the traditional supply chain, partners are often reluctant to provide information to other partners because they regard them as competitors (for example, wholesalers and other wholesalers, retailers, and other retailers) [23]. Therefore, information asymmetry is prevalent in the supply chain, which will further lead to the bullwhip effect and reduce supply chain efficiency [24,25]. Bullwhip effect refers to the distortion of demand information transmitted due to insufficient information sharing between the upstream and downstream of the supply chain, which will result in the low operating efficiency of the supply chain [26]. In addition, due to the globalized business and distributed production, the problems of information asymmetry and information isolation in the supply chain become more and more serious [27]. The cross-border supply chain also needs to pay more attention to the requirements of regulatory authorities, such as customs, quarantine, and other departments. Import regulators are facing the problem of trust due to asymmetric information in the supply chain because it is difficult for them to verify the identity of the certificate of origin issuers in cross-border trade [3].

The implementation of the blockchain promotes the information sharing within the enterprise and the upstream and downstream of the supply chain, effectively establishes the internal trust of the enterprise, enhances the transparency of the supply chain and the cooperation among members, and plays a positive role in improving the operation ability [19,20,24]. The improvement of transparency not only ensures the authenticity of data, reduces cybercrime, and protects stakeholder data, but also reduces the risk in food supply chain operation [28], which is more conducive to reducing the uncertainty of supply and demand. To be specific, the improvement of internal transparency of enterprises can improve the internal monitoring and control ability, eliminate the impact of internal uncertainty, help to make better decisions, and win the trust of consumers; the improvement of supply chain transparency enhances information sharing among business partners, promotes the more effective flow of goods and services, trade and information, helps producers better understand supply chain loopholes, transparent information and

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

data analysis capabilities, and enhances enterprise forecasting and planning functions [4,29]. In addition, the application of blockchain technology enables real-time verification and audit of any transaction or information about products or parties, including the qualification and reputation of each party, as well as the characteristics of the products or services involved, with low cost [3].

3.3 Information Transmission Efficiency

The highest cost of the supply chain is not transportation or supervision cost, but information cost. Firstly, information cost increases with the increase of complexity, length, and quantity of trade in the supply chain. Secondly, with the decrease in transportation and supervision costs, the proportion of information costs are also rising [30]. The cost of information includes the cost of executing contracts, the cost of finding trading partners, and the cost of goods information when goods move in the supply chain [31]. More than 90% of the goods in international trade are handled by the maritime industry every year (International Shipping Association 2017), which is still a traditional industry. A large number of containers are transported between ports around the world with a large number of documents. The cost of processing trade documents may be as high as one-fifth of the cost of goods transfer. In addition, at present, most companies only use their systems for the supply chain management. These isolated systems are difficult to work together, affecting the efficiency of information transmission [32].

Digitizing the supply chain can remove these barriers and create a fully integrated ecosystem for efficiency and transparency. The combination of blockchain and artificial intelligence, workflow automation, and the Internet of things can become the pillar of supply chain digitization [3]. Therefore, the blockchain has the potential to promote the trade facilitation agenda, focusing on cross-border paperless trade [30]. Blockchain and smart contract-based methods can reduce manual intervention and automate business processes of supply chain management involving manual and paper-based transactions (such as automatic payment and ownership transfer), thus greatly reducing business friction and improving service efficiency of supply chain management [20]. Also, as a state machine, the smart contract can timely track the process state changes from suppliers, manufacturers, logistics service providers, distributors, and customers, and improve the efficiency of information transmission.

3.4 Tracing and Tracking

The main challenges of the supply chain are traceability and data management [29]. However, most of the existing traceability systems are lack transparency, the data is mainly stored in the enterprise, and the cost of tampering with the data is very low. In addition, in the traditional centralized management mode, when product safety or quality problems occur, the nodes in the supply chain are easy to evade responsibility, and it is difficult to trace the root cause of the problem [33]. Supply chain disputes are usually cumbersome and expensive, as a retrospective audit to

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

determine the cause is often error-prone and costly [34]. Moreover, digital business, including e-commerce, is full of counterfeit products. Counterfeit products account for 2.5% of global trade annually, reaching $461 billion in 2018. In particular, counterfeit products in food and drug chain stores, as well as problems related to food safety and pollution risk, will seriously damage the brand reputation and the well-being of consumers. Therefore, there is an urgent need for effective traceability solutions as the basic quality management tool to ensure the sufficient safety of supply chain products [13].

Blockchain technology can realize the traceability function of the supply chain, and monitor products or goods in real time [27,35]. To improve traceability in the supply chain, decentralized ledgers help to connect suppliers, producers, buyers, regulators, who are distant from each other due to different procedures, policies, or applications [2]. Blockchain technology is especially suitable for the food supply chain and ensuring food safety and traceability of sources can increase consumers' trust [33,36]. Specifically, blockchain can be used to monitor food safety and help reduce corruption and waste, thus reducing operating costs [6]. Due to the characteristics of blockchain, these data are more reliable and less easily tampered with. The data obtained from these nodes can be effectively connected to ensure food quality. Once an outbreak of animal or plant disease occurs, the contaminated products can be traced more quickly [2], to strengthen the risk management of the supply chain. In addition to the traceability function of the supply chain, it is also necessary to manage and monitor the products, especially perishable products. First of all, conventional transaction data and other complex data types, such as temperature measurement, humidity measurement, nutritional specifications, etc., can be easily marked on products using blockchain [37]; secondly, in a traceable shelf-life management system, shelf life and deterioration rate can be determined according to different conditions of food processing sites and foods, thus providing support for food quality decision-making [38]. Besides, blockchain and smart contracts are applied to the price tracking part of the supply chain management system to ensure the transparency of product distribution structure and prevent the company from pursuing excess profits. The price tracking system provides consumers with transparent and reliable price information. Companies can understand the taste of consumers, and consumers can obtain price information to encourage consumption.

3.5 Other Aspects

Research on the e-commerce model based on blockchain technology and the Internet of things technology[39]. Prove the integration mode of smart contracts based on blockchain and traditional e-commerce, and prove the feasibility of the protocol from cost analysis and concept realization (fairness, timeliness, confusion, and non-repudiation) [40]. Discussion on green supply chain and blockchain technology [41,42], and focus on the feasibility of blockchain to improve sustainable supply chain management [43]. Study on the impact of blockchain technology on

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

risk factors in global supply chain operation [21]. Explore the way of combining blockchain technology with employee welfare [44].

4. Research Gaps and Future Prospects

4.1 Technical Level

First of all, the application of blockchain in the supply chain has room for improvement in technology. The traditional blockchain has limited ability to process a large amount of data [29]. The development and implementation life cycle are long, and the scalability, speed, and scalability are limited. Many existing blockchain interfaces are too complex, which hinders the early adoption of blockchain in the supply chain or other similar fields [27]. The dynamic balance between information transparency and sensitive data protection in the blockchain [24], and between performance optimization and privacy protection are also needed to be further studied [35]. Overall control and governance of an oversight based organization may be a significant constraint [45]. When using blockchain technology for information sharing in the supply chain, it is necessary to identify the information to be shared and business-sensitive data, consider what data and calculation should be put on the chain, and consider data protection.

Secondly, the reliability of data collection still needs to be explored. Binding the physical world to the information stored on the blockchain requires full trust because it relies on the assumption that the stored information accurately reflects reality. At present, commercial and academic circles are focusing on near field communication (NFC) chips, electronic tags, and the Internet of things devices to solve these problems [3]. However, even seemingly secure input data from sensors or RFID tags can be easily manipulated before verification on the network. Opportunistic behavior always exists in the initial stage of data input, which will increase the unpredictable governance cost [4]. Especially in the food supply chain, the staff may create false or incorrect data. Therefore, we need to think about how to transfer real-world data to the blockchain and study-specific measures based on blockchain technology to prevent forgery of data and food certification [38].

4.2 Policy and Legal Level

The development period of blockchain technology is relatively short, and there is a lack of recognition at the government and regulatory levels [30,45]. In the context of the global supply chain, each node of the blockchain may be located in a different part of the world. At present, it is not clear which country or region the blockchain needs to follow, or which court has the right to decide important issues related to blockchain. Moreover, the globally distributed characteristics of blockchain make it unable to handle the numerous legal requirements of all different countries. According to the distribution characteristics of decentralized blockchain, the relevant legal and regulatory framework should clarify the responsibilities of

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

relevant parties accurately and timely, and stipulate their actions accordingly [3]. In addition, it is also necessary to specify from the legal level which data should be stored in the blockchain and which data should be kept confidential according to law [46]. For the sake of transparency and documentation, the stored personal data violates the privacy legislation. In the open network, especially in the cross-border blockchain platform, balancing personal privacy is a challenging task. Therefore, the following research needs to focus on the analysis of the rights and responsibilities of blockchain, and stipulate the boundary scope of blockchain from the legal level; at the same time, the legal framework on the formation and recognition of contracts should adapt to the development of blockchain technology.

4.3 Organizational Level

The application of blockchain in the supply chain generally lacks user acceptance [38, 45]. The lack of technical knowledge is a serious obstacle to the organization's adoption of blockchain. The application of blockchain technology requires practitioners to have a high level of technology and ability, but the relevant talents of blockchain are scarce, and the cost of technical training is high [27]. Although compared with the traditional long-term supply chain partnership, the set cost of blockchain is low because of the lack of trust [4], the adoption rate of blockchain system is likely low due to the lack of knowledge and low acceptance at the organizational level. This will further break the comprehensiveness of information related to the supply chain, make transparency more difficult, and hinder the traceability of goods flow. When some participants in the supply chain will not see the benefits of data transparency, they may strengthen the protection of their data [46], and the blockchain application will lose its value to the participants. Therefore, it is necessary to persuade the participants in the logistics chain to use the application, increase the investment in the cultivation of blockchain technical talents, and control the training cost by the combination of production, teaching, and research.

4.4 Future Prospects

Mastering the core technology resources of blockchain is the key to the successful development of enterprises in the era of blockchain. Although the potential of blockchain in the supply chain has been proved in many aspects of literature, the technology is relatively immature and lacks the power of commercial application. Moreover, most of the relevant research focuses on the feasibility of the technology, and the research on the actual measurement of its commercial value and supply chain efficiency is relatively scarce, which may become an obstacle to its realization. Therefore, in the future, it is necessary to further identify the potential challenges of blockchain from theory and application, including technical complexity, system applicability, cultural impact, collaboration issues, cost, security, and other aspects, such as studying the technical limitations of blockchain delay, throughput, size and bandwidth, version control, hard branch, and multiple branches.

ISSN 2616-5775 Vol. 3, Issue 4: 73-85, DOI: 10.25236/AJCIS.030409

Secondly, the boundary conditions of sharing quality assurance information among supply chain partners still need to be studied, and the balance between shared data and privacy protection should be clarified. Besides, the programmable performance of blockchain makes automatic quality control and performance evaluation based on machine learning tools possible. We can consider combining blockchain technology with intelligent technology (big data, machine learning, etc.). Finally, to realize the subversive potential of blockchain, solutions supported by industry and government are needed. At present, the private sector is leading the blockchain effort, while government agencies are lagging. Few efforts have focused on integrating the needs and requirements of government agencies. The government and the industry should work together to find a solution for the mutual supply of blockchain.

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