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RESEARCH ARTICLE

Blockchain-Based Supply Chain Information Sharing Mechanism

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ABSTRACT This paper proposes a blockchain-based supply chain information operation method to solve the current shortage of business information sharing in the supply chain. These approaches include the idea of blockchain application to realize the sharing of supply chain information, the supply chain architecture of production enterprises based on blockchain, and the hierarchical model of supply chain information flow based on blockchain. This paper proposes the information block recording method of internal and external data sources in the supply chain, including the composition structure and the analysis of the multisource data inside and outside the supply chain. In addition, the multisource data information block recording method is also proposed. Building a blockchain-based supply chain system can improve the integration and reconstruction capabilities of the supply chain. The information recording of the internal data of the supply chain and the external related multisource data in the block can improve the learnability of the supply chain. The internal and external information block connection of the supply chain system is the further integration and reconstruction of the supply chain information resources in the blockchain system. The information storage and access control of the blockchain-based supply chain is an information security guarantee system in the supply chain information sharing environment. Through the method of this study, the system can form a business architecture system based on blockchain-based supply chain information sharing.

INDEX TERMS Blockchain, mechanism, supply chain information sharing, security.

I. INTRODUCTION

This paper studies the business system of supply chain information sharing based on blockchain. This study also proposes a blockchain-based supply chain information-sharing mechanism. Through the method of this study, the system can form a business architecture system based on blockchain-based supply chain information sharing. The system also establishes a management mechanism for supply chain information security issues. The proposed method reflects the impact mechanism of blockchain-based information sharing on the supply chain dynamic capabilities, system adaptability, information reliability, and system network effects. This paper clarifies the main influencing factors and the relationships between the cost investment and the benefit of constructing a blockchain-based supply chain information-sharing mechanism. This study uses blockchain to improve the mechanism of supply chain business competitiveness [1], [2].

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II. SUPPLY CHAIN BUSINESS INFORMATION SHARING STATUS ANALYSIS

When The sharing of supply chain information can promote the mutual supervision of business entities and promote the transparency of the supply capacity of the supply side and the specific needs of the demand side. Then, supply chain information is shared to achieve precise docking of supply and demand. Sharing the supply chain information can improve the ‘‘information island’’ status of independent business content information in the supply chain. For example, this ERP

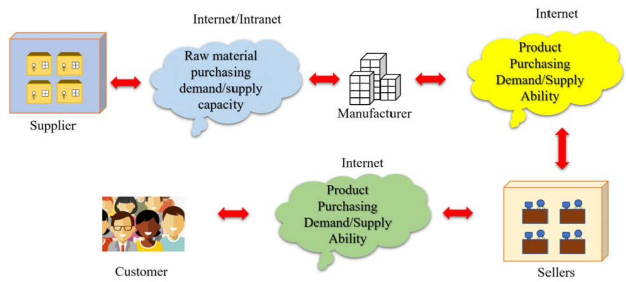

FIGURE 1. Topological structure of supply chain information transmission in the case of business independence.

system, e-ERP system, or even some other integrated information systems, etc., realize the information sharing of some business links of the supply chain and the integration of related businesses [3], [4]. However, it is difficult to share information to respond to changing demands or to support decision-making, and there is no integration and coordination of information and business from the perspective of the overall supply chain [5], [6].

Information sharing can improve the flexibility of business entities to enter the supply chain, improve the relative solidification of business entities of the traditional supply chain management model, and promote the dynamic and precise selection of business entities by the supply chain [7], [8].

At present, because the business contents of the supply chain are generally independent of each other, the mutual supervision between business entities is insufficient. For example, in some supply chains, manufacturers supervise sellers. However, this kind of supervision is one-way local supervision [9], [10]. From the perspective of the supply chain as a whole, there is still a lack of group, multidirectional, and open mutual supervision among various business entities. The information flow and the real-time sharing between different business contents are poor, which has a great impact on its overall operation efficiency. After analysis and research, the topological structure of the current supply chain information transmission is extracted, as shown in Figure 1.

In Figure 1, the online transaction mode between the suppliers and manufacturers, as well as between manufacturers and sellers, is a B2B transaction, and the online transaction mode between sellers and customers is a B2C transaction. As seen from Figure 1, when the businesses are independent of each other, the business contents of each supply chain are only conceptual supply chains. Each business content has its own independent business transaction platform. Once the transaction of each business entity on the business transaction platform is completed, the entire business is completed. Each business entity can only obtain or focus on the supply and demand information related to its own business transactions. It is difficult for every business entity to know the complete supply chain structure and operation. Such a supply chain structure has poor integration and coordination capabilities and poor information sharing. Each business entity makes an extra effort to improve the efficiency of its own business content. The end result is a reduction in the overall efficiency of the supply chain [11], [12].

However, pure information sharing cannot fully improve the efficiency of supply chain operations. The improvement of supply chain operational efficiency is also reflected in the mutual coordination among the business subjects of various business contents. The business decision is jointly generated based on the supply and demand capability information and the external environment information of the jointly owned business entities [13]. In the case of information sharing, agile and real-time dynamic business coordination is formed by various business entities in response to changes in internal and external environmental requirements. We make the internal supply chain a coordinated and interactive whole and respond flexibly to external changes. It is clear that, under such a concept, compared with suppliers, manufacturers, and sellers, customers at the end of the supply chain can be regarded as external subjects of the supply chain [14].

III. BLOCKCHAIN-BASED SUPPLY CHAIN INFORMATION OPERATION APPROACH

A. THE IDEA OF BLOCKCHAIN APPLICATION TO REALIZE THE SHARING OF SUPPLY CHAIN INFORMATION

As a decentralized ledger technology, blockchain effectively realizes the openness and transparency of information. The blockchain system can effectively integrate supply chain business entities into one system, supervise each other and share interests. Therefore, the application of blockchain technology can promote the coordinated management of different business contents using supply chain business entities, realize the sharing of supply chain information by business entities, prevent supply chain-related information from being maliciously altered and destroyed, and become the main body of supply chain business selection and scientific decision-making to provide technical support. However, the classic Bitcoin blockchain has obvious limitations in the application process of specific environments [15], [16]. For example, the openness and the transparency of information can easily lead to a leak of important information and the storage redundancy problem caused by the decentralized storage of blockchain basic data by the authentication subject, etc.

B. BLOCKCHAIN-BASED PRODUCTION ENTERPRISE SUPPLY CHAIN ARCHITECTURE

The supply network chain of production enterprises based on blockchain is constructed by relying on the private network of the enterprise or the internet. At the same time, only the business entities of the supply network chain are required to join the blockchain system through authorization. Such a situation can avoid the interference of users unrelated to the system to the operation of the system and reduce the risk of malicious users jointly forging supply chain information [17], [18]. In the supervision mechanism and competitive environment, various business entities will be more inclined to provide real information and participate in the supervision

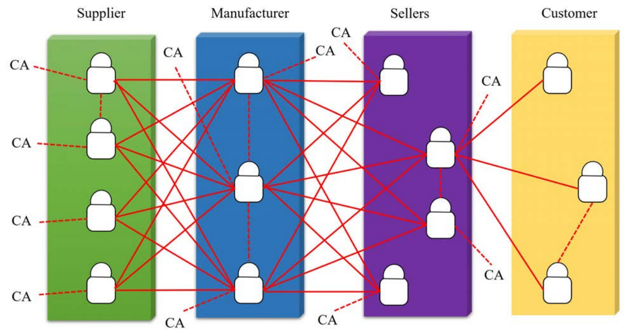

FIGURE 2. Blockchain-based production enterprise supply chain architecture.

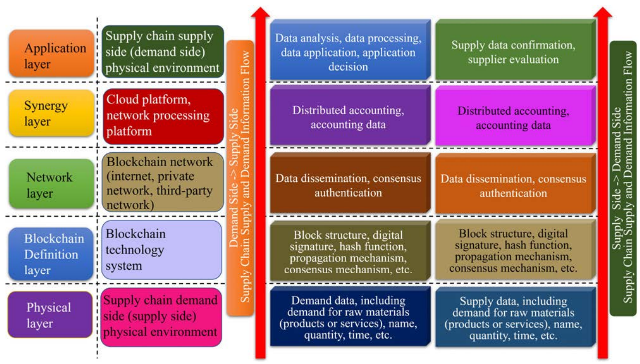

FIGURE 3. Blockchain-based supply chain information flow hierarchical model.

of supply chain operations for their own interests, while striving to maintain the overall efficiency of the supply chain [19], [20].

Figure 2 shows the supply chain architecture of a production enterprise based on blockchain. In Figure 2, ''CA'' represents a certificate authority. That is, each supplier, manufacturer, and the seller will act as an independent certification center to certify the real existence of supply chain information and the rationality of decision-making. Compared with other business entities, this authentication center has greater randomness and instability, so unless otherwise specified, this paper generally does not consider ''customer'' as an authentication center, but ''customer'' can access the block through authorization chain data. The supply chain data are no longer stored separately by the business entity to which they belong; they are stored in a decentralized manner in the blockchain operating system. All business entities can access supply chain data through authorization, reducing the risk of information ''asymmetry'' and ''incompleteness.'' This method ensures the non-destruction and the true traceability of supply chain information, and improves the operation efficiency and information response speed of the supply chain [21].

C. A HIERARCHICAL MODEL OF SUPPLY CHAIN INFORMATION FLOW BASED ON BLOCKCHAIN

In the network environment, the proposal and the final formation of the business content of the supply chain involves the operation of different software and hardware of the network system. The operation of the blockchain involves different levels of the computer network system. Therefore, the operation process of the supply chain based on the blockchain can be described by a hierarchical model where the information of the supply chain flows in its basic network. The hierarchical model of supply chain information flow based on blockchain is shown in Figure 3.

Figure 3 shows the operation process of the blockchain system for the transmission of demand information from the demander to the supplier of certain business content in the supply chain. The operation process of the blockchain system corresponds to the supply information transmission from the supplier to the demander of this business content; that is, the transmission processing procedure of demand information is similar to the transmission processing of supply information. In Figure 3, the information flow processing procedure of the supply chain is divided into five levels, and the definitions and functions of the five levels are as follows.

1) ENTITY LAYER

The entity layer refers to the physical environment for sending information, which can be the demand side or the supply side. These supply chain entities informatize the supply and demand content of supply chain raw materials (such as products, services, etc.) as the basic data for sending.

2) BLOCKCHAIN DEFINITION LAYER

The blockchain definition layer is the definition of the blockchain technology system, including the structure of the block, the principle of digital signatures, the principle of the hash algorithm, how the data are spread in the network, and the authentication subject to the authenticity and validity of the data. The consensus mechanism of authentication and how to decentralize data accounting, etc. Because the operation of the supply chain involves many aspects of data, the characteristics of the data and the security requirements of the system for the data are different. Thus, this layer is a necessary definition layer before the supply and demand data information enters the network.

3) NETWORK LAYER

This layer is the definition of the network that the blockchain relies on, and it is also the network that the supply chain business content exchange relies on. In this layer, the P2P dissemination of supply chain data and the authentication of the dissemination data by the authentication subject should be realized.

4) COLLABORATION LAYER

This layer is responsible for the storage and management of supply chain operation data. A large amount of data of different types is generated due to the operation of the supply chain. In addition, based on the necessities of the supply chain business coordination and decision-making, the supply chain also needs to share external source data related to supply chain business analysis and decision-making outside the system.

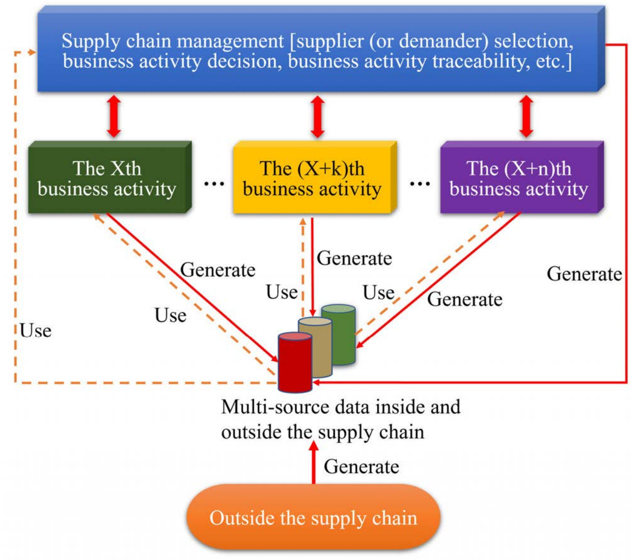

FIGURE 4. The data composed from multiple sources inside and outside the supply chain.

The source and information summary of these external source materials also need to be recorded in the blockchain. Different types of information have various security requirements, and different types of information have various characteristics. Therefore, the cloud processing platform or network processing platform needs to be responsible for the operation and storage management of data.

5) APPLICATION LAYER

This layer defines what the receiver does with the information (demand information or supply information) sent by the sender. The content of the application layer includes the confirmation and analysis of the information after the receiver receives the information and the corresponding decision-making for the information is sent by the sender. In this layer, the analysis of information and the corresponding response activities by business entities other than the recipient in the supply chain system can also be specified.

In Figure 3, the demand information flow and the supply information flow are not defined according to the information flow of the overall business process of the supply chain. They are defined by the information flow of the supply and demand of a certain business content. Therefore, from the perspective of the supply chain as a whole, the expression in Figure 3 may omit some intermediate links in the overall operation of the supply chain.

IV. INFORMATION BLOCK RECORDING METHOD FOR INTERNAL AND EXTERNAL DATA SOURCES IN THE SUPPLY CHAIN

A. THE COMPOSITION STRUCTURE AND ANALYSIS OF MULTISOURCE DATA INSIDE AND OUTSIDE THE SUPPLY CHAIN

Supply chain business decision-making activities include supply-side (or demand-side) selection, business activity decision-making, and business activity traceability. These business decision-making activities will generate information within the supply chain system. The data on which the business decision-making activities of the supply chain are based include the internal data of the supply chain generated by the operation of the system and the external data of the supply chain system introduced from outside the system. Business entities within the supply chain have the right to use blockchain-based supply chain system data. The external business of the supply chain only has the permission to provide data for the blockchain system, though it does not have the permission to access the blockchain data. The composition of multisource data inside and outside the supply chain is shown in Figure 4.

For data from multiple sources outside the supply chain, data collection, filtering, cleaning, analysis, and summarization are quite complex tasks. If the management activity of each supply chain business content is completed by the supply chain business subject as the authentication subject to complete the processing of multisource data, the reality of its realization is very low. Therefore, this paper proposes to build a multisource data analysis center based on the supply chain business, and the multisource data analysis center will complete the data processing task. The external multisource data related to the management of supply chain business content can be classified into the online data of the business entity, the data released by the government and other authoritative organizations, the data provided by the social free organizations, the investigation platform data, and other source data. Each of these categories of information may involve multiple sources. Therefore, the blockchain application improves the integration capability of the supply chain.

The data processing of the external multisource data analysis center of the supply chain based on the blockchain is shown in Figure 5.

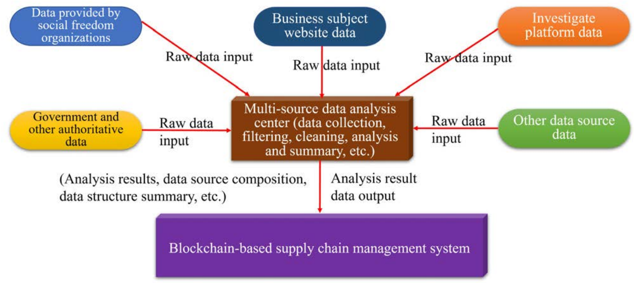

FIGURE 5. Data processing situation of the external multisource data analysis center of the supply chain based on blockchain.

B. MULTISOURCE DATA INFORMATION BLOCK RECORDONG APPROACH

Therefore, this paper proposes an approach for block summary records in the blockchain for external multisource data. When the demander needs to know the external multisource data information related to the supplier's transaction during the transaction, the system will send a request to the external multisource data analysis center of the supply chain

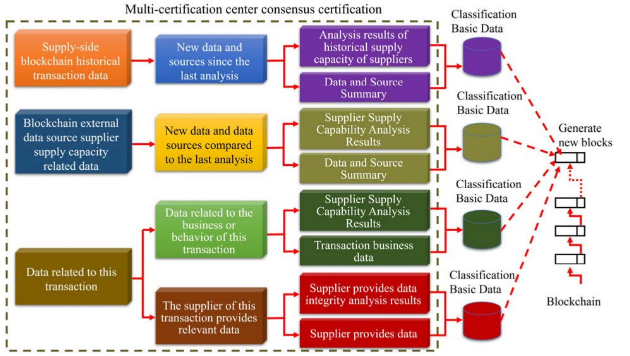

FIGURE 6. Internal and external multisource data block records and block chain generation methods for supply chain management.

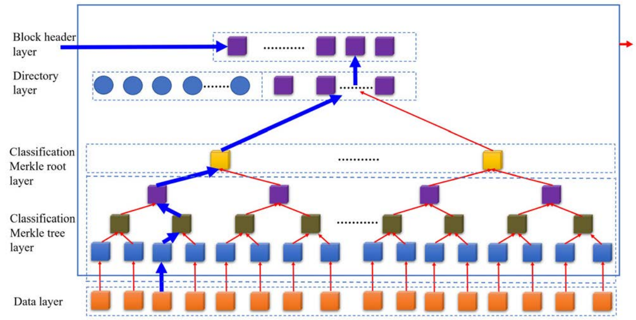

FIGURE 7. A virtual connection network between information of a business entity in a blockchain-based supply chain.

to analyze the supplier's relevant information. Each certification body of the supply chain management system will transmit information collection requirements to the external multisource data analysis center according to the established rules. The multisource data analysis center will determine the dataset for data collection and processing according to the information collection needs. Finally, the relevant result information is returned to each certification body in the supply chain, and the certification body that obtained the accounting right will broadcast the relevant result information of the supplier in the blockchain system. Other authentication subjects (including the demander) in the blockchain system will authenticate and distribute the broadcast information.

We employ the demand side selecting the supply side in the supply chain business as an example. Figure 6 shows the block record and the blockchain generation method of internal and external multisource data in supply chain management. This paper divides supply chain management-related materials into four categories. In the specific application process, supply chain management materials can be divided into different categories according to actual needs, and it is not necessary for the materials to be limited to the classification in Figure 6. For the block record and the blockchain generation method of the internal and external data sources of supply chain management for the supply side to select the demand side, please refer to Figure 6. In Figure. 6, different types of basic data are stored in various data storage bodies (e.g., different databases). Different types of data are mapped with the block body of the corresponding block in the blockchain to ensure that the basic data of the blockchain and the supply chain management are stored separately. Different types of basic data are stored separately by type. It can realize the convenience of blockchain management. These conveniences include ensuring that the blockchain capacity is small, easy to build, and manageable. The orderliness of different types of data management can also realize the logical integrity between the blockchain system and the supply chain management data system through the corresponding mapping relationship.

Due to the particularity of the data structure and the storage of the blockchain-based supply chain management system, the corresponding blockchain system structure must also have its own adaptability. Based on this, this paper proposes the data structure of the block in the blockchain-based supply chain management system, which consists of the following five parts.

1) DATA LAYER
This refers to supply chain management-related information.

2) CLASSIFIED MERKEL TREE BODY LAYER
This means that the data of different classifications constitute different Merkle trees; these Merkle trees do not intersect with each other, and this layer stores the Merkle tree body.

3) CLASSIFIED MERKEL TREE ROOT LAYER
Unlike the classification Merkle tree block layer, this layer stores the root of each different Merkle tree.

4) DIRECTORY LAYER
This layer builds a directory according to the basic data corresponding to the Merkle tree roots of different classifications. The layer is set according to actual needs and a Merkle root is calculated for every N classification Merkle roots.

5) BLOCK HEADER LAYER
The system calculates a total Merkle root for all Merkle roots in the directory layer. The block header will contain this tree root, which also contains the hash value of the block header of the previous block, the version number of this pivot block, the consensus authentication parameters, the timestamps, etc. The data structure of the block in the blockchain-based supply chain management system is shown in Figure 7.

V. SUPPLY CHAIN SYSTEM INFORMATION BLOCK LINK GENERATION APPROACH
This paper proposes building a virtual link relationship between the directory layer of each block of the blockchain and the basic data that have a mapping relationship with this block. The method also constructs a corresponding virtual connection relationship in the directory layer of the corresponding block for the association relationship between the

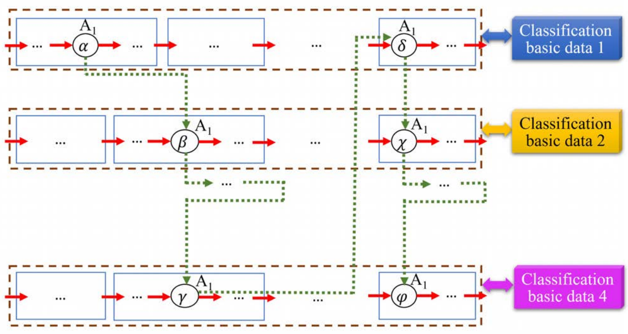

FIGURE 8. Data structure of blocks in a blockchain-based supply chain management system.

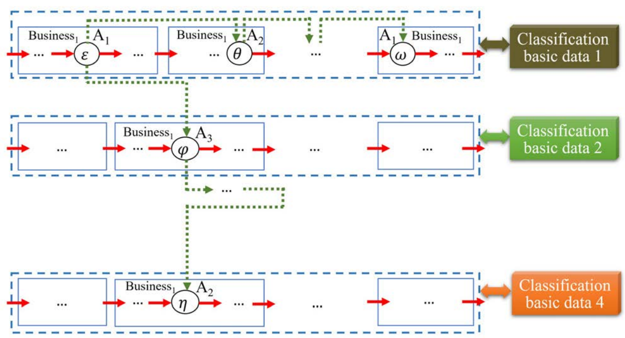

FIGURE 9. Virtual connection network between supply chain business content information based on blockchain.

data having the mapping relationship with different blocks. The data in the blockchain are connected to each other by hash function indicators. Therefore, the relevant basic data that have a mapping relationship with the blockchain can be quickly found through the hash function index and the virtual connection between the directory layer and the directory layer in the block. The structure formed by the corresponding virtual links is the link network of the basic data. In this way, even if the storage body of the classification basic data sets the access permission to the data, the structure and the storage location of the basic data can still be retrieved through the blockchain. Additionally, because the directory layer of information is stored in the block, the immutability of the directory is guaranteed.

A. BUSINESS ENTITY INFORMATION VIRTUAL LINK NETWORK

For a supply chain with a production enterprise as the core, its operation process is described in the order of business operations. Therefore, the production process of the corresponding information of a business entity is also carried out according to the business process of supply chain operations. Figure 8 shows the virtual connection network between the information of a business subject in the blockchain-based supply chain. The solid box refers to the set of basic data corresponding to the corresponding block, and the blocks corresponding to the basic data of different classifications may be the same. In addition, the figure only shows the virtual link network structure of the business subject information and does not show the actual data link network. The corresponding connection relationship of the data in the figure is reflected in the records of each block directory layer of the blockchain. The purpose of this is to quickly traverse the corresponding data through the hash function indicator in the blockchain (for the data traversal process, see the bold line in Figure 7).

In Fig. 8, the data of business entity A_1 in different classification basic data (classification basic data 1, classification basic data 2, $\cdots$, classification basic data 4) form virtual links according to the sequence of $\cdots \rightarrow \alpha \rightarrow \beta \rightarrow \cdots \rightarrow \gamma \rightarrow \delta \rightarrow \chi \rightarrow \cdots \rightarrow \varphi \rightarrow \cdots$ (The sequence specified according to the actual situation). In different classifications of basic data, the same business entity has various basic data characteristics due to different roles.

B. BUSINESS CONTENT INFORMATION VIRTUAL LINK NETWORK

The virtual connection network between supply chain business content information based on blockchain is shown in Figure 9. In Figure 9, the business content "Business," the data in the same classification basic dataset form a virtual link in the sequence corresponding to $\cdots \rightarrow \varepsilon \rightarrow \theta \rightarrow \cdots \rightarrow \omega \rightarrow \cdots$ (the sequence is specified according to the actual situation). The basic data corresponding to the business content Business_1 in the same block form a virtual link in the sequence of $\cdots \rightarrow \varepsilon \rightarrow \varphi \rightarrow \cdots \rightarrow \eta \rightarrow \cdots$ (the sequence specified according to the actual situation). Likewise, other virtual links to the underlying data corresponding to the blockchain can also be constructed.

VI. VALUE ANALYSIS OF BLOCKCHAIN

A. VALUE ANALYSIS OF BLOCKCHAIN IN SUPPLY CHAIN MANAGEMENT APPLICATIONS

This subsection discusses the value of the blockchain applied to supply chain management. The connotation of this discussion includes information block records of internal and external data sources in the supply chain, blockchain-based supply chain information retrieval, and blockchain-based supply chain information storage and access control. From the micro perspective of business realization, we discuss the relationship between the cost input of blockchain applied to supply chain management and the investment and benefit of realizing supply chain information sharing, information security, etc. For the convenience of research, it is assumed that the business content of the supply chain is fixed. Supply chain information sharing is an important feature of the application of blockchain technology, and information security is an important issue in its application. As a result, after analysis, the research investment and return are defined. Among them, the cost of blockchain (T_c) includes the system construction cost (A_c) and the operation cost (B_c). The benefits (T_I) include supply chain information sharing (A_I) and information security (B_I).

1) COST–BENEFIT ANALYSIS OF INFORMATION BLOCK RECORDS OF INTERNAL AND EXTERNAL DATA SOURCES IN THE SUPPLY CHAIN

The corresponding blockchain construction cost is A_C^R, including the cost of linking with external data sources $\sum_{i=1}^{n} A_C^{RS_i}$. Among them, n represents the number of external data sources. n and its corresponding data sources are relatively fixed but can also be dynamically adjusted as needed. The construction cost of the blockchain-based supply chain system A_C^{RT} includes the overall deployment cost A_C^{RTT} and the deployment cost of each node $\sum_{j=1}^{m} A_C^{RTS_j}$. Among them, m represents the number of supply chain business entities joining the blockchain system. Each node corresponding to m has a certain stability except for the overall dynamic change. The corresponding one-time standard blockchain operation cost is B_C^R, including information collection cost $\sum_{i=1}^{n} B_C^{RS_i}, i = 1, \cdots, n$ and information records cost $\sum_{j=1}^{m} B_C^{RTS_j}, j = 1, \cdots, m$. Among them, the information collection cost represents different data sources of external multisource data. This information record cost represents the different nodes that can participate and authenticate. The overall operating cost T_C^R of this blockchain in a certain period L is

$$\begin{aligned} T_C^R &= A_C^R + \sum_{k=1}^{q} \alpha_k \bar{B}_C^R \\ &= \left(\sum_{i=1}^{n} A_C^{RS_i} + A_C^{RT}\right) \\ &\quad + \sum_{k=1}^{q} \alpha_k \left(\overline{\sum_{i=1}^{n} B_C^{RS_i} + \sum_{j=1}^{m} B_C^{RTS_j}}\right) \\ &= \left(\sum_{i=1}^{n} A_C^{RS_i} + A_C^{RTT} + \sum_{j=1}^{m} A_C^{RTS_j}\right) \\ &\quad + \sum_{k=1}^{q} \alpha_k \left(\overline{\sum_{i=1}^{n} B_C^{RS_i} + \sum_{j=1}^{m} B_C^{RTS_j}}\right) \end{aligned} \tag{1}$$

In Formula (1), q represents the number of operations of the supply chain business in the blockchain system within period L, and α_k represents the adjustment coefficient of each blockchain operation. This adjustment coefficient can be seen in Section 4 and the working principle of blockchain, α_k shows a decreasing trend with the increase of the k value, and $\alpha_k \rightarrow 0$. $\overline{B_C^R}$ represents the average value of B_C^R of a standard blockchain running cost. The revenue A_I^R of the supply chain information sharing of the blockchain in period L, including the analysis results of external multisource data information and among the nodes of the supply chain. The shared revenue of this results in the supply chain $\sum_{k=1}^{q} \lambda(k) A_I^{RT}$. Among them, $\lambda(k)$ is the adjustment coefficient; $\lambda(k)$ shows an overall decreasing trend with an increasing k value, and $\lambda(k) > 0$. For the supply chain based on blockchain, the shared revenue of the management system operation data among the nodes of the supply chain is $\sum_{k=1}^{q} \varphi(k) \sum_{j=1}^{m} \beta(j) A_I^{RS_j}$. Among them, $\varphi(k)$ and $\beta(j)$ are adjustment coefficients, $\varphi(k)$ shows an overall decreasing trend with the increase of the k value and $\varphi(k) > 0$, $\beta(j)$ shows an overall decreasing trend with the increase of the j value trend and $\beta(j) > 0$. The revenue B_I^R of supply chain information security of blockchain operation in period L is negative and set to $-\sum_{k=1}^{q} \eta(k) B_I^{RT}$. Among them, $\eta(k)$ is the adjustment coefficient, $\sum_{k=1}^{q} \frac{\eta(k)}{q} \rightarrow 1$. Then, the overall operating income T_I^R of the blockchain in a certain period L is

$$\begin{aligned} T_I^R &= A_I^R + B_I^R \\ &= \left(\sum_{k=1}^{q} \lambda(k) A_I^{RT} + \sum_{k=1}^{q} \varphi(k) \sum_{j=1}^{m} \beta(j) A_I^{RS_j}\right) \\ &\quad - \sum_{k=1}^{q} \eta(k) B_I^{RT} \end{aligned} \tag{2}$$

2) COST–BENEFIT ANALYSIS OF INTERNAL AND EXTERNAL INFORMATION BLOCK LINKS IN THE SUPPLY CHAIN SYSTEM

The corresponding cost T_C^C includes the connection cost formed during the operation of the blockchain (the connection cost of the corresponding data) $\sum_{k=1}^{q} \delta_k \overline{\sum_{j=1}^{m} A_C^{CTS_j}}$. $A_C^{CTS_j}$ represents the operating cost of each node and $\overline{\sum_{j=1}^{m} A_C^{CTS_j}}$ represents the standard connection generated by one blockchain operation $\sum_{j=1}^{m} A_C^{CTS_j}$. This formula is the mean value of the sum of the costs of each node, and δ_k represents the adjustment coefficient of each blockchain operation $((\sum_{k=1}^{q} \delta_k)/q \rightarrow 1)$. Then, the overall operating cost T_C^C of the blockchain in a certain period L is

$$T_C^C = \sum_{k=1}^{q} \delta_k \overline{\sum_{j=1}^{m} A_C^{CTS_j}} \tag{3}$$

The corresponding revenue (T_I^C) is mainly reflected in the revenue from information sharing. The overall operating income (T_I^C) of the blockchain in a certain period L is

$$T_I^C = \sum_{k=1}^{q} \mu(k) A_I^{CT} \tag{4}$$

Among them, $\mu(k)$ is the adjustment coefficient; $\mu(k)$ shows an overall decreasing trend with increasing k value, and $\mu(k) > 0$.

3) COST–BENEFIT ANALYSIS OF SUPPLY CHAIN INFORMATION STORAGE

The corresponding cost of supply chain information storage is T_C^S; this cost includes the system construction cost A_C^{ST} (referring to the overall environment deployment cost A_C^{STT}) and the operation cost of each node of the cloud platform at all levels

$$A_C^{STS_g}, \cdots, A_C^{STW_h}, \sum_{l=1}^{p} \omega_l \overline{\sum_{g=1}^{x} A_C^{STS_g}}, \ldots, \sum_{s=1}^{v} \theta_s \overline{\sum_{h=1}^{y} A_C^{STW_h}}.$$

The above formula represents the cloud storage cost of different levels in period L. These $p, \cdots, v$ represent the cloud storage times of different levels in period L. These $x, \cdots, y$ represent the number of cloud storage nodes at different levels. These $\omega_l, \cdots, \theta_s$ represent the adjustment coefficients corresponding to each cloud storage. When $\left(\sum_{l=1}^{p} \omega_l\right)/p \to 1, \cdots, \left(\sum_{s=1}^{v} \theta_s\right) v \to 1$, then the overall blockchain in a certain period L with the running cost T_C^S is

$$T_C^S = A_C^{STT} + \sum_{i=1}^{p} \omega_l \overline{\sum_{g=1}^{x} A_C^{STW_g}} +, \cdots, + \sum_{s=1}^{v} \theta_s \overline{\sum_{h=1}^{y} A_C^{STW_h}} \tag{5}$$

The corresponding benefits of supply chain information storage T_I^S include the reduction of the information sharing level due to storage management (one standard operation, denoted as A_I^S) and the improvement of the information security level (one standard operation, denoted as B_I^S). The overall operating income T_I^S of the blockchain in a certain period L is

$$T_I^S = -\sum_{k=1}^{q} \xi(k) \overline{A_I^S} + \sum_{k=1}^{q} \sigma(k) \overline{B_I^S} \tag{6}$$

Among them, the adjustment coefficient $\xi(k)$ shows an overall decreasing trend with the increase of the k value, and $\xi(k) > 0$; the adjustment coefficient $\sigma(k)$, $\sum_{k=1}^{q} \frac{\sigma(k)}{q} \to 1$.

Access control is usually access to data by business subjects in business decision-making. The cost is related to the specific access control settings of the system. The benefit is related to a reduction in the level of sharing of storage management information.

4) COMPREHENSIVE ANALYSIS

We assume that the multisource data inside and outside a certain fixed period of time L remain unchanged and the blockchain authentication node remains unchanged. Then, we combine the above analysis results.

One-time input costs $\sum_{i=1}^{n} A_C^{RS_i}, \sum_{j=1}^{m} A_C^{RTS_j}, A_C^{RTT}$ and A_C^{STT} can be aggregated into fixed costs

$$\sum_{i=1}^{n} A_C^{RS_i} + \sum_{j=1}^{m} A_C^{RTS_j} + A_C^{RTT} + A_C^{STT}.$$

The blockchain business entity completes the generation of the blockchain and the corresponding data link while recording the block. Therefore,

$$\sum_{k=1}^{q} \delta_k \overline{\sum_{j=1}^{m} A_C^{CTS_j}}$$

can be merged with $\sum_{k=1}^{q} \alpha_k \left(\overline{\sum_{i=1}^{n} B_C^{RS_i} + \sum_{j=1}^{m} B_C^{RTS_j}}\right)$, which is

$$\sum_{k=1}^{q} \left[\delta_k \overline{\sum_{j=1}^{m} A_C^{CTS_j}} + \alpha_k \left(\overline{\sum_{i=1}^{n} B_C^{RS_i} + \sum_{j=1}^{m} B_C^{RTS_j}}\right)\right].$$

The total cost of cloud storage at all levels is

$$\sum_{i=1}^{p} \omega_l \overline{\sum_{g=1}^{x} A_C^{STS_g}} +, \cdots, + \sum_{s=1}^{v} \theta_s \overline{\sum_{h=1}^{y} A_C^{STW_h}}.$$

Hierarchical cloud storage can be realized by computer system design, and it is relatively mature now. The corresponding cost

$$\sum_{i=1}^{p} \omega_l \overline{\sum_{g=1}^{x} A_C^{STS_g}} +, \cdots, + \sum_{s=1}^{v} \theta_s \overline{\sum_{h=1}^{y} A_C^{STW_h}}$$

is no longer the focus of the users' attention.

Formula

$$\sum_{k=1}^{q} \left[\delta_k \overline{\sum_{j=1}^{m} A_C^{CTS_j}} + \alpha_k \left(\overline{\sum_{i=1}^{n} B_C^{RS_i} + \sum_{j=1}^{m} B_C^{RTS_j}}\right)\right]$$

is determined by the blockchain-based supply chain smart contract and the consensus authentication mechanism. The corresponding functions are automatically run by the blockchain system, and the corresponding costs are generated. When the consensus authentication nodes in the blockchain system are not large enough, the cost of running smart contracts in the blockchain system is negligible. Therefore, it is necessary to formulate a reasonable consensus authentication mechanism to avoid huge expenses for each supply chain business operation. Formula $\sum_{i=1}^{n} A_C^{RS_i} + \sum_{j=1}^{m} A_C^{RTS_j} + A_C^{RTT} + A_C^{STT}$ is determined by the development level of blockchain technology.

The cost investment of the blockchain-based supply chain system is mainly realized by system construction. When blockchain technology develops to a certain extent, the system construction cost will no longer be an important factor.

The income includes the overall income of the supply chain system, $\sum_{k=1}^{q} \lambda(k) A_I^{RT}, -\sum_{k=1}^{q} \eta(k) \underline{B_I^{RT}}$, $\sum_{k=1}^{q} \mu(k) A_I^{CT}, -\sum_{k=1}^{q} \xi(k) \overline{A_I^S}, \sum_{k=1}^{q} \delta(k) \overline{B_I^S}$, and the income of each node, $\sum_{k=1}^{q} \varphi(k) \sum_{j=1}^{m} \beta(j)_I^{RS_j}$.

Formula $-\sum_{k=1}^{q} \eta(k) B_I^{RT}, \sum_{k=1}^{q} \delta(k) \overline{B_I^S}$ is a measure of revenue in information security. Applying the blockchain will lead to information sharing and cause information security problems. The supply chain information storage mechanism will play a role in ensuring information security, though at the expense of the information sharing level $-\sum_{k=1}^{q} \xi(k) \overline{A_I^S}$.

The application of the blockchain proposed in this study in the supply chain management system. This application will improve the sharing of multisource data outside the supply chain in the supply chain. An example can be seen in formulas $\sum_{k=1}^{q} \lambda(k) A_I^{RT}$ and $\sum_{k=1}^{q} \mu(k) A_I^{CT}$. We improve the sharing of information among various business entities in the supply chain, such as formula $\sum_{k=1}^{q} \varphi(k) \sum_{j=1}^{m} \beta(j)_I^{RS_j}$.

For a supply chain management system, ensuring supply chain information security and effectively realizing supply chain information sharing are the fundamental purposes of supply chain management. The analysis results of the cost input and benefit in the supply chain information sharing mechanism is based on blockchain. With the maturity of blockchain application technology, on the basis of a small investment in the technology application, blockchain can effectively promote the improvement of supply chain efficiency. This is a further optimization of the supply chain management architecture based on the existing supply chain management system.

B. VALUE ANALYSIS OF BLOCKCHAIN IN THE COMPETITION OF THE SUPPLY CHAIN BUSINESS SYSTEM

By simulating and analyzing the distribution relationship of a certain type of supply chain business between the blockchain-based supply chain system and the traditional supply chain system, it proves the economic value of the blockchain applied to the supply chain. We assume that the specific form of a certain type of supply chain business includes two types of supply chain business based on blockchain and traditional supply chain business. The different participation status of a certain type of supply chain business entity in a certain type of supply chain business in the blockchain-based supply chain business and the traditional supply chain business. The main body of the supply chain business may be one of the group of suppliers, the group of production enterprises, the group of sellers, and the group of customers. This situation reflects the distribution relationship of this type of supply chain business between the blockchain-based supply chain business and the traditional supply chain business. Assuming that the total demand of business entities for a certain type of supply chain business is fixed, the sum of the business quantity of this type of supply chain business in the blockchain-based supply chain business and the traditional supply chain business is also fixed. For the convenience of research, the supply chain business provider (core production enterprise) and a certain type of business entity (participant, such as supplier group, seller group, etc.) are set as a whole. From the perspective of transaction credit, the blockchain-based supply chain business is a risk-free business for supply chain business providers (the risk here refers to the accuracy of business decisions, which is determined by the level of information sharing of the supply chain business itself). Traditional supply chain businesses are risky businesses for supply chain business providers.

It is assumed that the supply chain business participant (marked as P) realizes all their life needs by participating in the supply chain business. The consumption in period t of P is c_t. The numbers of traditional supply chain businesses (marked as M) and the blockchain-based supply chain businesses (marked as N) owned by P are α_t and β_t, respectively. The quantity of the overall supply chain business (marked as T) is $\alpha_t + \beta_t$. The revenue of P period t is x_t. We assume that the rate of return in period t of M is r_t and the variance is $V(r)$. The rate of return for period t of N is r_t^f. P pursues the maximization of the present value of its own utility, which is $\max\limits_{\{c_t+s,\alpha_t+s,\beta_t+s\}} V_t = \sum\limits_{s=0}^{Y} \beta^s U(c_t+s)$. Among them, $U(c_t+s)$ is the immediate utility, $0 < \beta = \frac{1}{1+\theta} < 1$ is the discount factor, and θ is the discount rate. Cooperation between supply chain business entities is usually relatively stable. Therefore, Y represents a sufficient number of time periods. The constraints are $\Delta s_{t+1} + c_t = x_t + r_t s_t + v_{t+1}$, where x_t denotes the business income and s_t denotes the capital stock. $v_{t+1} = \delta(r_t - r_{t-1}) s_t$ is the newly added foreign capital in period $t+1$. v_{t+1} may be greater than, equal to or less than 0. $\delta > 0$ is the growth coefficient of the foreign capital. External capital is affected by the yield difference between the previous two periods and the current capital stock. The following introduces the asset allocation theory of economics to analyze the market allocation relationship between a traditional supply chain business and a blockchain-based supply chain business (that is, the distribution relationship between the business entity transaction between the traditional supply chain platform and the blockchain-based supply chain platform).

We write $V_t = \sum\limits_{s=0}^{Y} B^s U(c_{t+s})$ in recursive form; then, we write $V_t \approx U(c_t) + \beta V_{t+1}$, differentiate c_t, and obtain the first-order condition for taking the maximum value as

$$\begin{aligned}\frac{\partial V_{t+s}}{\partial c_{t+s}} &\approx \frac{\partial U_{t+s}}{\partial c_{t+s}} + \beta\left[\frac{\partial V_{t+s+1}}{\partial c_{t+s}}\right] \\ &\approx \frac{\partial U_{t+s}}{\partial c_{t+s}} + \beta\left[\frac{\partial U_{t+s+1}}{\partial c_{t+s}} + \beta\frac{\partial V_{t+s+2}}{\partial c_{t+s}}\right] = 0 \end{aligned} \tag{7}$$

Due to the variability of the external environment of the supply chain, $\frac{\partial V_{t+s+2}}{\partial c_{t+s}} \approx 0$, which is

$$\begin{aligned}\frac{\partial V_{t+s}}{\partial c_{t+s}} &\approx \frac{\partial U_{t+s}}{\partial c_{t+s}} + \beta\left[\frac{\partial V_{t+s+1}}{\partial c_{t+s}}\right] \\ &\approx \frac{\partial U_{t+s}}{\partial c_{t+s}} + \beta\left[\frac{\partial U_{t+s+1}}{\partial c_{t+s}}\right] = 0 \end{aligned} \tag{8}$$

since the constraints of the two periods $t+s$ and $t+s+1$ are

$$\begin{cases}\Delta s_{t+s+1} + c_{t+s} \\ = x_{t+s} + r_{t+s}s_{t+s} + \delta(r_{t+s} - r_{t+s-1}) s_{t+s} \\ \Delta s_{t+s+2} + c_{t+s+1} = \\ x_{t+s+1} + r_{t+s+1}s_{t+s+1} + \delta(r_{t+s+1} - r_{t+s}) s_{t+s+1}\end{cases} \tag{9}$$

From formulas (9), we can obtain

$$\frac{\partial c_{t+s+1}}{\partial c_{t+s}} = -\left[(1 + r_{t+s+1}) + \delta(r_{t+s+1} - r_{t+s})\right] \tag{10}$$

because there is a differential relationship

$$\frac{\partial U_{t+s+1}}{\partial c_{t+s}} = \frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\frac{\partial c_{t+s+1}}{\partial c_{t+s}} \tag{11}$$

Substituting equation (10) into equation (11), we obtain

$$\begin{aligned}&\frac{\partial V_{t+s}}{\partial c_{t+s}} \\ &= \frac{\partial U_{t+s}}{\partial c_{t+s}} \\ &\quad -\beta\left[\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\left((1 + r_{t+s+1}) + \delta(r_{t+s+1} - r_{t+s})\right)\right] = 0\end{aligned} \tag{12}$$

For traditional supply chain businesses and blockchain-based supply chain businesses, according to formulas (9), we can obtain

$$\begin{aligned} & c_{t+s}+\alpha_{t+s+1}+\beta_{t+s+1} \\ & \quad = x_{t+s}+\alpha_{t+s}\left(1+r_{t+s}\right)+\beta_{t+s}\left(1+r_{t+s}^{f}\right) \\ & \qquad +\delta\left(r_{t+s}-r_{t+s-1}\right)\alpha_{t+s}+\delta\left(r_{t+s}^{f}-r_{t+s-1}^{f}\right)\beta_{t+s} \quad (13) \end{aligned}$$

Let $Q_{t+s}=\alpha_{t+s}+\beta_{t+s}$, $q_{t+s}=\frac{\alpha_{t+s}}{Q_{t+s}}$, $1-q_{t+s}=\frac{\beta_{t+s}}{Q_{t+s}}$; then, the budget constraint can be rewritten as

$$\begin{aligned} & c_{t+s}+Q_{t+s+1} \\ & = x_{t+s}+Q_{t+s}\left(1+r_{t+s}^{f}+q_{t+s}\left(r_{t+s}-r_{t+s}^{f}\right)\right) \\ & \quad +\delta\left[\left(r_{t+s}^{f}-r_{t+s-1}^{f}\right)+q_{t+s}\begin{pmatrix}\left(r_{t+s}-r_{t+s-1}\right) \\ -\left(r_{t+s}^{f}-r_{t+s-1}^{f}\right)\end{pmatrix}\right]Q_{t+s} \\ & = x_{t+s}+Q_{t+s}\left(1+r_{t+s}^{p}\right)+\delta\Delta r_{t+s}^{q}Q_{t+s} \\ & = x_{t+s}+\left[\left(1+r_{t+s}^{p}\right)+\delta\Delta r_{t+s}^{q}\right]Q_{t+s} \quad (14) \end{aligned}$$

Among them, $r_{t+s}^{p}=r_{t+s}^{f}+q_{t+s}\left(r_{t+s}-r_{t+s}^{f}\right)$ represents different business systems (traditional supply chain system and the income of the asset portfolio in the blockchain-based supply chain system), and $\Delta r_{t+s}^{q}=\left(r_{t+s}^{f}-r_{t+s-1}^{f}\right)+q_{t+s}\left(\left(r_{t+s}-r_{t+s-1}\right)-\left(r_{t+s}^{f}-r_{t+s-1}^{f}\right)\right)=\Delta r_{t+s}^{f}+q_{t+s}\left(\Delta r_{t+s}-\Delta r_{t+s}^{f}\right)$ represents the growth rate of new foreign capital.

From equation (12), we can obtain

$$\begin{aligned} \frac{\partial V_{t+s}}{\partial c_{t+s}} &= \frac{\partial U_{t+s}}{\partial c_{t+s}}-\beta\left[\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\left(\left(1+r_{t+s}^{p}\right)+\delta\Delta r_{t+s}^{q}\right)\right] \\ &= 0 \end{aligned} \quad (15)$$

In addition,

$$\begin{aligned} \frac{\partial V_{t+s}}{\partial q_{t+s+1}} &\approx \beta\left[\frac{\partial V_{t+s+1}}{\partial c_{t+s+1}}\frac{\partial c_{t+s+1}}{\partial q_{t+s+1}}\right] \\ &\approx \beta\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}Q_{t+s+1}\left[\left(r_{t+s+1}-r_{t+s+1}^{f}\right)\right. \\ &\quad \left.+\delta\left(\Delta r_{t+s+1}-\Delta r_{t+s+1}^{f}\right)\right] \end{aligned} \quad (16)$$

From equation (14), we know

$$\begin{aligned} & \frac{\partial U_{t+s+1}}{\partial c_{t+s+1}} \\ & = \partial\left[x_{t+s+1}+Q_{t+s+1}\left(1+r_{t+s+1}^{f}\right.\right. \\ & \quad \left.+q_{t+s+1}\left(r_{t+s+1}-r_{t+s+1}^{f}\right)\right)+\delta\left(\left(r_{t+s+1}^{f}-r_{t+s}^{f}\right)\right. \\ & \quad \left.\left.+q_{t+s+1}\left(\left(r_{t+s+1}-r_{t+s}\right)-\left(r_{t+s+1}^{f}-r_{t+s}^{f}\right)\right)\right)Q_{t+s+1} \right. \\ & \quad \left.-Q_{t+s+2}\right]/\partial c_{t+s+1} \end{aligned} \quad (17)$$

Setting, $\left(\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\right)^{*}$, as shown at the top of the next page. equation (17) uses Taylor's formula at $q_{t+s+1}=0$, takes the approximate value, and substitutes it into formula (16); then, we can obtain

$$\begin{aligned} & \frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\left[\left(r_{t+s+1}-r_{t+s+1}^{f}\right)+\delta\left(\Delta r_{t+s+1}-\Delta r_{t+s+1}^{f}\right)\right] \\ & \approx\left(\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\right)^{*}\left[\left(r_{t+s+1}-r_{t+s+1}^{f}\right)\right. \\ & \quad \left.+\delta\left(\Delta r_{t+s+1}-\Delta r_{t+s+1}^{f}\right)\right] \\ & \quad +\left(\frac{\partial U_{t+s+1}^{2}}{\partial c_{t+s+1}}\right)^{*}Q_{t+s+1}q_{t+s+1}\left[\left(r_{t+s+1}-r_{t+s+1}^{f}\right)\right. \\ & \quad \left.+\delta\left(\left(r_{t+s+1}-r_{t+s}\right)-\left(r_{t+s+1}^{f}-r_{t+s}^{f}\right)\right)\right]^{2} \end{aligned} \quad (18)$$

From equation (18), we can obtain

$$\begin{aligned} q_{t+s+1} &= \frac{c_{t+s+1}}{Q_{t+s+1}} \\ &\quad \times\left(r_{t+s+1}-r_{t+s+1}^{f}\right)+\delta\left(\Delta r_{t+s+1}-\Delta r_{t+s+1}^{f}\right) \\ &\quad /\sigma_{t+s}\left[\left(r_{t+s+1}-r_{t+s+1}^{f}\right)\right. \\ &\quad \left.+\delta\left(\left(r_{t+s+1}-r_{t+s}\right)-\left(r_{t+s+1}^{f}-r_{t+s}^{f}\right)\right)\right]^{2} \end{aligned} \quad (19)$$

$\sigma_{t+s}=-\frac{c_{t+s+1}\left(\frac{\partial U_{t+s+1}^{2}}{\partial^{2}c_{t+s+1}}\right)^{*}}{\left(\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\right)^{*}}$ where σ_{t+s} is the relative risk coefficient.

From the analysis of the abovementioned content, the proposed method shows that the current supply chain business entities entering the supply chain system for transactions are relatively stable within a certain period of time, and their business transaction benefits need to be analyzed by discounting. The main factors that determine the market share of different businesses are the rate of return and the attitude of business entities toward risks. In fact, even blockchain technology is recognized and popularized in the field of supply chain management. The current business content management system and the market mechanism cannot completely realize the cost-free liberalization of business entities entering a supply chain system. In the analysis of equation (19), q_{t+s+1} represents the proportion of traditional supply chain systems in all supply chain businesses, which is currently the mainstream of the supply chain businesses. $\frac{c_{t+s+1}}{Q_{t+s+1}}$ is the proportion of the total business Q_{t+s+1} used for consuming c_{t+s+1}. The relative risk coefficient σ_{t+s} is the attitude of business participants toward the risk (the accuracy of the decision-making is determined by the level of information sharing in the supply chain business itself). $\frac{c_{t+s+1}}{Q_{t+s+1}}$ and σ_{t+s} are determined by the subjective wishes of business participants and have nothing to do with the level of information sharing in the supply chain business itself.

$r_{t+s+1}-r_{t+s+1}^{f}$ is the expected excess rate of return, which represents the extra rate of return expected by supply chain business participants due to information asymmetry and low business decision-making efficiency. The higher the value of $r_{t+s+1}-r_{t+s+1}^{f}$ is, the higher the ratio of α_{t+s+1} to Q_{t+s+1}. This situation indicates that the level of information sharing

$$\left(\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\right)^{*} = \frac{\partial \left[x_{t+s+1} + Q_{t+s+1}\left(1 + r^{f}_{t+s+1}\right) + \delta\left(r^{f}_{t+s+1} - r^{f}_{t+s+1}\right) Q_{t+s+1} - Q_{t+s+2}\right]}{\partial c_{t+s+1}},$$

in the supply chain is low. The transaction entities corresponding to the core production enterprises can obtain higher rates of return due to information asymmetry. These business players are more willing to enter the traditional supply chain business. Therefore, when the core production enterprises of the supply chain realize that the level of information sharing in their own supply chain system is low, it will be their correct choice to improve the level of information sharing in their own systems. Therefore, core production enterprises will be more motivated to build their own supply chain system based on blockchain so that their own supply chain system will be transferred from the traditional supply chain system to the blockchain-based supply chain system. This $\Delta r_{t+s+1} - \Delta r^{f}_{t+s+1}$ is the difference between the growth rate of the participant's rate of return under the traditional supply chain management system and the blockchain-based supply chain management system. The larger the difference is, the more likely the participants are to increase capital investment in the traditional supply chain management system. Thus, the supply chain management system based on blockchain must continuously manage the information sharing level within the system. To make this type of business more attractive to participants, capital investment in this business should be increased.

This $\left[\left(r_{t+s+1}-r^{f}_{t+s+1}\right)+\delta\left((r_{t+s+1}-r_{t+s})-\left(r^{f}_{t+s+1}-r^{f}_{t+s}\right)\right)\right]^{2}$ is the volatility of excess returns. The smaller the volatility is, the higher the proportion of α_{t+s+1} to Q_{t+s+1}, that is, if the participants in the supply chain business can obtain stable excess and high returns under the premise of supply chain information asymmetry. These participants will be more willing to enter the traditional supply chain system for transactions; then, the traditional supply chain management system will pursue the stability of the relative yield difference.

This paper analyzes supply chain business profitability r^{f}_{t+s} based on blockchain and the influencing factors of its value. When the operation cost of the supply chain business system based on blockchain is low, the investment of core production enterprises to realize information sharing decision-making will be small, and the core production enterprises will have higher income. At this time, supply chain business participants entering the blockchain-based supply chain business will also obtain a higher rate of return r^{f}_{t+s}. Therefore, the cost of blockchain technology and its applications should be reduced to promote the development of blockchain technology applications. These improved methods will be the basis for promoting the application of the blockchain-based supply chain business system and an important measure to promote the sharing of information in the supply chain system.

VII. CONCLUSION

The proposed research builds a five-level model of supply chain information flow based on blockchain, including the entity layer, the blockchain definition layer, the network layer, the collaboration layer, and the application layer. This method divides supply chain data into supply chain internal operation data and external related data source data, introduces the composition and data structure characteristics of internal and external data sources in the supply chain, and proposes a block recording method for multisource data information inside and outside the supply chain. The blockchain is connected as a whole by hash function indicators. Based on this, a virtual link structure for building blockchain-related data is proposed, and an example of the generation method of virtual links is analyzed. The characteristics of the classic blockchain are the openness and transparency of data, which causes the problem of data confidentiality. Based on this, it is proposed to store the basic data of the blockchain in the ''front-end cloud platform'' and ''back-end cloud platform'' in stages and implement access control. The construction of the supply chain information sharing mechanism based on blockchain improves the dynamic capability of the supply chain. Cost–benefit analysis is used to analyze the value of blockchain in supply chain management applications. The traditional supply chain system and the blockchain-based supply chain system are analyzed using asset allocation theory.

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REFERENCES

[1] I. A. Omar, R. Jayaraman, M. S. Debe, H. R. Hasan, K. Salah, and M. Omar, ''Supply chain inventory sharing using ethereum blockchain and smart contracts,'' *IEEE Access*, vol. 10, pp. 2345–2356, 2022.

[2] M. Du, Q. Chen, J. Chen, and X. Ma, ''An optimized consortium blockchain for medical information sharing,'' *IEEE Trans. Eng. Manag.*, vol. 68, no. 6, pp. 1677–1689, Dec. 2021.

[3] T. Guggenberger, A. Schweizer, and N. Urbach, ''Improving interorganizational information sharing for vendor managed inventory: Toward a decentralized information hub using blockchain technology,'' *IEEE Trans. Eng. Manag.*, vol. 67, no. 4, pp. 1074–1085, Nov. 2020.

[4] H. Xiao, W. Zhang, W. Li, A. T. Chronopoulos, and Z. Zhang, ''Joint clustering and blockchain for real-time information security transmission at the crossroads in C-V2X networks,'' *IEEE Internet Things J.*, vol. 8, no. 18, pp. 13926–13938, Sep. 2021.

[5] D. Lee and M. Song, ''MEXchange: A privacy-preserving blockchain-based framework for health information exchange using ring signature and stealth address,'' *IEEE Access*, vol. 9, pp. 158122–158139, 2021.

[6] Y. Wang, A. Zhang, P. Zhang, and H. Wang, ''Cloud-assisted EHR sharing with security and privacy preservation via consortium blockchain,'' *IEEE Access*, vol. 7, pp. 136704–136719, 2019.

[7] X. Yang, M. Li, H. Yu, M. Wang, D. Xu, and C. Sun, "A trusted blockchain-based traceability system for fruit and vegetable agricultural products," *IEEE Access*, vol. 9, pp. 36282–36293, 2021.
[8] P. K. Wan, L. Huang, and H. Holtskog, "Blockchain-enabled information sharing within a supply chain: A systematic literature review," *IEEE Access*, vol. 8, pp. 49645–49656, 2020.
[9] H. Chai, S. Leng, Y. Chen, and K. Zhang, "A hierarchical blockchain-enabled federated learning algorithm for knowledge sharing in internet of vehicles," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 7, pp. 3975–3986, Jul. 2021.
[10] M. Baza, N. Lasla, M. M. E. A. Mahmoud, G. Srivastava, and M. Abdallah, "B-ride: Ride sharing with privacy-preservation, trust and fair payment atop public blockchain," *IEEE Trans. Netw. Sci. Eng.*, vol. 8, no. 2, pp. 1214–1229, Apr. 2021.
[11] P. Alemany, R. Vilalta, R. Munoz, R. Casellas, and R. Martinez, "Evaluation of the abstraction of optical topology models in blockchain-based data center interconnection," *J. Opt. Commun. Netw.*, vol. 14, no. 4, pp. 211–221, Apr. 2022.
[12] X. Zhang and X. Chen, "Data security sharing and storage based on a consortium blockchain in a vehicular ad-hoc network," *IEEE Access*, vol. 7, pp. 58241–58254, 2019.
[13] Z. Yu, D. Xue, J. Fan, and C. Guo, "DNSTSM: DNS cache resources trusted sharing model based on consortium blockchain," *IEEE Access*, vol. 8, pp. 13640–13650, 2020.
[14] L. Tan, K. Yu, N. Shi, C. Yang, W. Wei, and H. Lu, "Towards secure and privacy-preserving data sharing for COVID-19 medical records: A blockchain-empowered approach," *IEEE Trans. Netw. Sci. Eng.*, vol. 9, no. 1, pp. 271–281, Jan. 2022.
[15] H. Sheng, S. Wang, Y. Zhang, D. Yu, X. Cheng, W. Lyu, and Z. Xiong, "Near-online tracking with co-occurrence constraints in blockchain-based edge computing," *IEEE Internet Things J.*, vol. 8, no. 4, pp. 2193–2207, Feb. 2021.
[16] L. Liu, J. Feng, Q. Pei, C. Chen, Y. Ming, B. Shang, and M. Dong, "Blockchain-enabled secure data sharing scheme in mobile-edge computing: An asynchronous advantage actor–critic learning approach," *IEEE Internet Things J.*, vol. 8, no. 4, pp. 2342–2353, Feb. 2021.
[17] M. A. Rahman, M. M. Rashid, M. S. Hossain, E. Hassanain, M. F. Alhamid, and M. Guizani, "Blockchain and IoT-based cognitive edge framework for sharing economy services in a smart city," *IEEE Access*, vol. 7, pp. 18611–18621, 2019.
[18] X. Jiang, F. R. Yu, T. Song, Z. Ma, Y. Song, and D. Zhu, "Blockchain-enabled cross-domain object detection for autonomous driving: A model sharing approach," *IEEE Internet Things J.*, vol. 7, no. 5, pp. 3681–3692, May 2020.
[19] Z. Shahbazi and Y.-C. Byun, "Blockchain-based event detection and trust verification using natural language processing and machine learning," *IEEE Access*, vol. 10, pp. 5790–5800, 2022.
[20] D. Na and S. Park, "Blockchain-based dashcam video management method for data sharing and integrity in V2 V network," *IEEE Access*, vol. 10, pp. 3307–3319, 2022.
[21] J. Ma, T. Li, J. Cui, Z. Ying, and J. Cheng, "Attribute-based secure announcement sharing among vehicles using blockchain," *IEEE Internet Things J.*, vol. 8, no. 13, pp. 10873–10883, Jul. 2021.

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