Integrating Blockchain for Advanced Supply Chain Solution

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Abstract-

This paper proposes a novel approach for enhancing supply chain information sharing through blockchain technology. We present methods for integrating blockchain into supply chain management, including the application of blockchain for sharing supply chain information, the design of a blockchain-based supply chain architecture for production enterprises, and a hierarchical model for managing supply chain information flow using blockchain. The paper introduces an information block recording method for capturing internal and external data sources within the supply chain, including a detailed analysis of the composition structure and multisource data analysis. Furthermore, we propose a multisource data information block recording method to augment information sharing capabilities. By leveraging blockchain technology, the proposed blockchain-based supply chain system improves integration and reconstruction capabilities while enhancing the learnability of the supply chain. The connection between internal and external information blocks within the supply chain system facilitates further integration and reconstruction of supply chain information resources. Additionally, the paper discusses information storage and access control mechanisms within the blockchain-based supply chain, serving as a robust information security guarantee system for supply chain information sharing environments. Through the methodologies presented, the system can establish a business architecture system based on blockchain-enabled supply chain information sharing.

***Keywords* – Blockchain, Supply Chain Transparency, Immutable data storage, Consensus mechanism, Security.**

1. INTRODUCTION

In recent years, the adoption of blockchain technology has garnered significant attention across various industries, offering innovative solutions to longstanding challenges. One such area where blockchain holds immense potential is in supply chain management. The ability to securely and transparently share information among multiple stakeholders in a supply chain ecosystem has the potential to revolutionize traditional business models and enhance operational efficiency.

This paper delves into the realm of supply chain information sharing based on blockchain technology. We present a comprehensive study that not only investigates the existing business systems of supply chain management but also proposes a novel blockchain-based mechanism for facilitating information sharing within supply chains. By leveraging blockchain's inherent features such as immutability, decentralization, and transparency, our proposed mechanism aims to address the complexities and inefficiencies inherent in traditional supply chain information management systems.

Furthermore, this study aims to establish a robust management mechanism to address security concerns associated with supply chain information sharing on blockchain networks. By identifying and mitigating potential security threats, our proposed mechanism ensures the integrity and confidentiality of shared data, thus fostering trust among participants within the supply chain ecosystem.

The core focus of this research lies in elucidating the impact mechanism of blockchain-based information sharing on the dynamics of supply chain networks. Through a thorough analysis of the main influencing factors and their interrelationships, we aim to provide insights into the tangible benefits of adopting a blockchain-based approach to supply chain information management. Specifically, we explore the intricate balance between the investment costs and the resultant benefits of constructing a blockchain-based supply chain information-sharing mechanism.

Drawing on insights from existing literature this study underscores the pivotal role of blockchain technology in enhancing the competitiveness of supply chain businesses. By leveraging blockchain's capabilities to streamline information sharing, optimize processes, and mitigate risks, organizations can gain a competitive edge in today's dynamic market landscape.

In summary, this paper serves as a comprehensive exploration of the transformative potential of blockchain technology in the realm of supply chain management. Through empirical analysis and theoretical insights, we aim to contribute to the growing body of knowledge on blockchain-based solutions for advancing supply chain efficiency, security, and competitiveness.

2. LITERATURE REVIEW

Supply Chain Business Information Sharing Status Analysis

The sharing of information within supply chains plays a pivotal role in promoting mutual supervision among business entities and enhancing transparency regarding the supply capacity of the suppliers and the specific needs of the demand side. This transparent sharing facilitates precise alignment between supply and demand, thereby mitigating the inefficiencies associated with information silos prevalent in independent business systems such as e-ERP systems or other integrated information systems. However, despite the benefits, challenges persist in effectively sharing information to respond promptly to evolving demands and support decision-making processes, highlighting the need for integrated and coordinated information sharing across the entire supply chain.

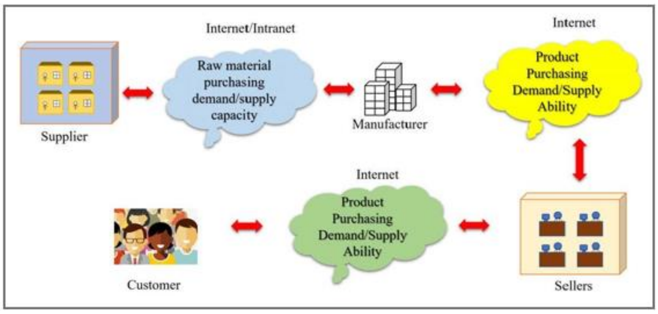

Figure 1: Topological structure of supply chain information transmission in the case of business independence.

Information sharing not only enhances the flexibility of business entities within the supply chain but also fosters dynamic selection and coordination among them. Presently, the supervisory relationships between business entities within supply chains are often unilateral and localized, lacking comprehensive group-wide, multidirectional, and open mutual supervision. This fragmented approach to information flow and sharing significantly impacts the overall operational efficiency of supply chains.

Analyzing the current topological structure of supply chain information transmission reveals a fragmented landscape where businesses operate independently of each other, relying on separate transaction platforms for their transactions. This siloed approach results in limited visibility into the complete supply chain structure and operations, leading to poor integration, coordination, and information sharing among business entities. Consequently, efforts to improve the efficiency of individual business entities often come at the expense of overall supply chain efficiency.

However, it is important to note that while information sharing is crucial, it alone cannot fully optimize supply chain operations. True operational efficiency is achieved through mutual coordination among business entities based on shared supply[5] and demand information and external environmental factors. Agile and real-time dynamic coordination among various business entities, in response to internal and external changes, transforms the internal supply chain into a coordinated and interactive entity, capable of flexible adaptation. In this context, customers at the end of the supply chain are considered external subjects, highlighting the holistic nature of supply chain coordination and responsiveness.

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 .

The Idea of Blockchain Application to Realize the Sharing of Supply Chain Information

Blockchain, as a decentralized ledger technology, offers a promising solution for achieving openness and transparency in information sharing. By leveraging blockchain, supply chain business entities can be effectively integrated into a unified system where they can supervise each other and share interests securely. This application of blockchain technology facilitates coordinated management among various business entities within the supply chain, enabling seamless sharing of supply chain information while safeguarding against malicious tampering or destruction of critical information.

The inherent features of blockchain technology, including decentralization and immutability, make it an ideal candidate for enhancing the transparency and integrity of supply chain operations. Through blockchain, business entities can collaborate more effectively, ensuring that supply chain-related information remains accurate and trustworthy. Additionally, blockchain technology empowers supply chain stakeholders to make informed decisions based on reliable data, thereby optimizing business selection processes and facilitating scientific decision-making.

It is important to acknowledge that the classic Bitcoin blockchain, while pioneering the technology, presents certain limitations when applied to specific environments. For instance, the openness and transparency of information inherent in blockchain can potentially lead to the leakage of sensitive information. Moreover, the decentralized storage of blockchain data by authentication subjects may result in storage redundancy issues, complicating data management processes within supply chain operations.

Insert relevant reference regarding the limitations of the classic Bitcoin blockchain. Insert another relevant reference regarding the challenges of blockchain application in specific environments. Blockchain-Based Production Enterprise Supply Chain Architecture

The supply network chain of production enterprises, when based on blockchain technology, is constructed using either the private network of the enterprise or the internet.

Participation in the blockchain system is restricted to only the authorized business entities of the supply network chain, ensuring that unrelated users cannot interfere with the system's operations and reducing the risk of malicious users colluding to forge supply chain information.

Within the supervision mechanism and competitive environment, various business entities are incentivized to provide authentic information and actively participate in the supervision of supply chain operations to safeguard their own interests while simultaneously striving to enhance the overall efficiency of the supply chain.

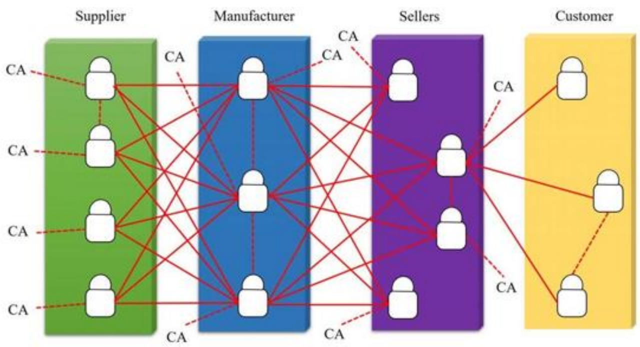

Figure :2 Blockchain-based production enterprise supply chain architecture.

Figure 2 illustrates the supply chain architecture of a production enterprise based on blockchain. In this architecture, 'CA' represents a certificate authority, wherein each supplier, manufacturer, and seller serves as an independent certification center responsible for certifying the authenticity of supply chain information and the rationale behind decision-making processes. Unlike other business entities, the authentication center exhibits greater randomness and instability. Therefore, unless explicitly specified, this paper generally does not consider 'customer' as an authentication center. However, customers can access supply chain data through authorized means.

In this architecture, supply chain data are no longer stored separately by individual business entities but are instead decentralized and stored within the blockchain operating system. All authorized business entities can access supply chain data, thereby reducing the risk of information asymmetry and incompleteness. This approach ensures the integrity and traceability of supply chain information, leading to improved operational efficiency and faster information response times within the supply chain.

Insert relevant reference regarding the reduction of interference by unauthorized users in blockchain-based supply chain systems. Insert another relevant reference regarding the mitigation of risks associated with malicious users in blockchain-based supply chain systems. Insert relevant reference regarding the incentives for authentic information provision and participation in supply chain supervision. Insert another relevant reference regarding the enhancement of overall supply chain efficiency through blockchain-based systems.

The hierarchical model of supply chain information flow based on blockchain comprises five distinct layers, each serving a specific function in the transmission and processing of supply chain data:

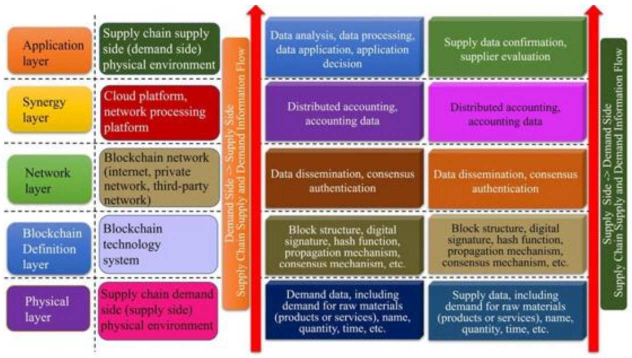

Figure :3Blockchain-based supply chain information flow hierarchical model.

1)Entity Layer: This layer represents the physical environment where supply chain entities operate. It encompasses both the demand side and the supply side, where information related to supply chain raw materials (such as products and services) is generated and sent as basic data.

2) Blockchain Definition Layer: Here, the blockchain technology system is defined, encompassing the structure of blocks, principles of digital signatures, hash algorithms, data spread within the network, and authentication mechanisms for data authenticity and validity. This layer establishes the necessary definitions before supply and demand data information enters the network.

3) Network Layer: This layer defines the network infrastructure upon which the blockchain relies, facilitating the exchange of supply chain business content. It enables peer-to-peer dissemination of supply chain data and authentication of disseminated data by authentication subjects.

4) Collaboration Layer: Responsible for the storage and management of supply chain operation data, this layer handles a variety of data types generated during supply chain operations. It also manages the sharing of external source data necessary for supply chain business analysis and decision-making, recording the source and information summary of these external materials in the blockchain.

5) Application Layer: This layer determines how receivers utilize the information sent by senders, including confirming and analyzing the information and making corresponding decisions based on it. It encompasses activities such as information analysis, response actions by business entities other than the recipient, and decision-making within the supply chain system.

Each layer in the hierarchical model contributes to the effective transmission, management, and utilization of supply chain information within the blockchain-based system. By delineating specific functions and responsibilities, these layers facilitate the seamless flow of information across the supply chain network, ensuring transparency, security, and efficiency in supply chain operations.

3. PROPOSED METHOD

3.1Information Block Recording Method for Internal and External Data Sources in the Supply Chain

The Composition Structure and Analysis of Multisource Data Inside and Outside the Supply Chain

Supply chain business decision-making activities encompass various processes such as supply-side or demand-side selection, business activity decision-making, and traceability of business activities. These activities generate a plethora of information within the supply chain system. The data utilized for supply chain business decision-making activities comprise both internal data generated by the system's operations and external data introduced from sources outside the system.

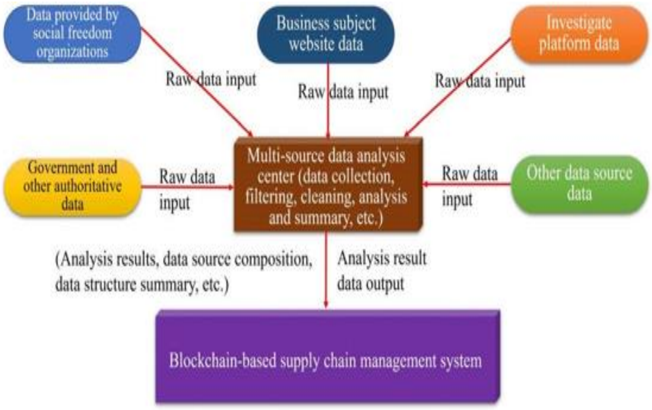

Figure 4: Data processing situation of the external multisource data analysis center of the supply chain based on blockchain.

Within the supply chain system, business entities possess the right to access blockchain-based supply chain system data. On the other hand, external entities involved in the supply chain are only granted permission to provide data for the blockchain system without access to the blockchain data itself. The composition of multisource data within and outside the supply chain is illustrated in Figure 4.

Managing data from multiple external sources outside the supply chain involves complex tasks such as data collection, filtering, cleaning, analysis, and summarization. However, expecting each supply chain business entity to manage these activities independently is unrealistic. To address this challenge, this paper proposes the establishment of a multisource data analysis center based on supply chain businesses. This center would be responsible for processing multisource data related to supply chain business management.

External multisource data related to supply chain business management can be classified into various categories, including online data from business entities, data released by government and authoritative organizations, data provided by social organizations, data from investigation platforms, and other source data. Each category may involve multiple sources, highlighting the complexity of data management in the supply chain context. Leveraging blockchain technology enhances the integration capabilities of the supply chain by facilitating the processing and integration of these diverse data sources.

The data processing workflow of the external multisource data analysis center within the supply chain based on blockchain technology is depicted in Figure 4.

3.2Multisource Data Information Block Recording Approach

This paper proposes an approach for recording block summaries in the blockchain to manage external multisource data effectively within the supply chain. When a demander requires external multisource data related to a supplier's transaction during a transaction, the system sends a request to the external multisource data analysis center of the supply chain.

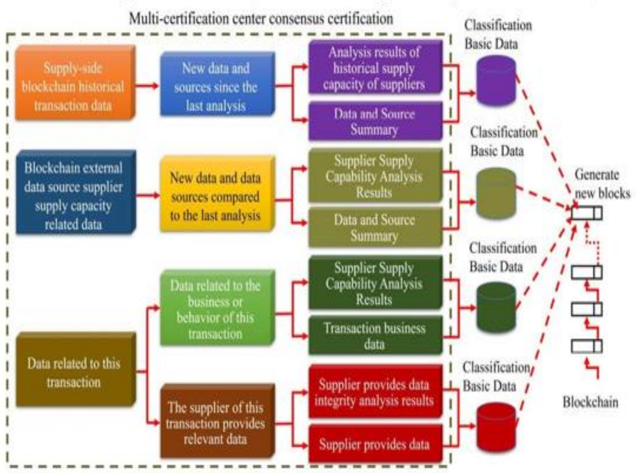

FIGURE 65. Internal and external multisource data block records and block chain generation methods for supply chain management

Figure 5 illustrates the block record and blockchain generation method for internal and external multisource data in supply chain management. The process involves certification bodies of the supply chain management system transmitting information collection requirements to the external multisource data analysis center based on established rules. The center then determines the dataset for data collection and processing, returning relevant result information to each certification body in the supply chain. The certification body with accounting rights broadcasts the relevant result information of the supplier in the blockchain system, which is authenticated and distributed by other authentication subjects, including the demander.

Taking the demand side selecting the supply side in the supply chain business as an example, Figure 6 demonstrates the block record and blockchain generation method for internal and external multisource data. Supply chain management materials are categorized into four types, but the classification can vary based on actual needs. Different types of basic data are stored in various data storage bodies and mapped with the block body of the corresponding block in the blockchain to ensure separate storage of blockchain and supply chain management data. This separation facilitates efficient blockchain management, ensuring small blockchain capacity, easy construction, and manageability. It also maintains logical integrity between the blockchain system and the supply chain management data system through corresponding mapping relationships.

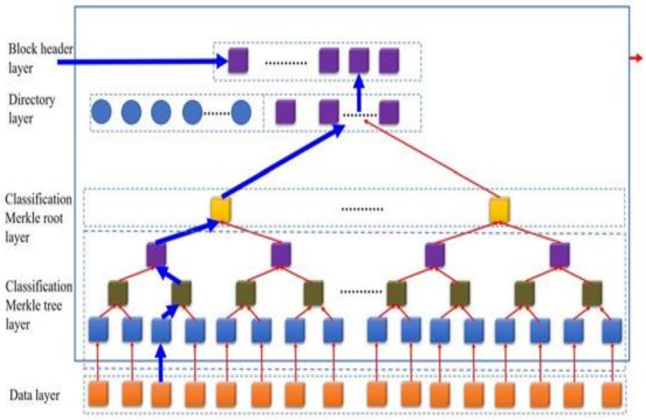

FIGURE 6. A virtual connection network between information of a business entity in a blockchain-based supply chain.

Given the unique data structure and storage of blockchain-based supply chain management systems, the corresponding blockchain system structure must be adaptable. This paper proposes a data structure for blockchain-based supply chain management systems, comprising the following five parts.

Figure 6 depicts a virtual connection network between information of a business entity in a blockchain-based supply chain, emphasizing the interconnectedness facilitated by blockchain technology within the supply chain ecosystem.

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.

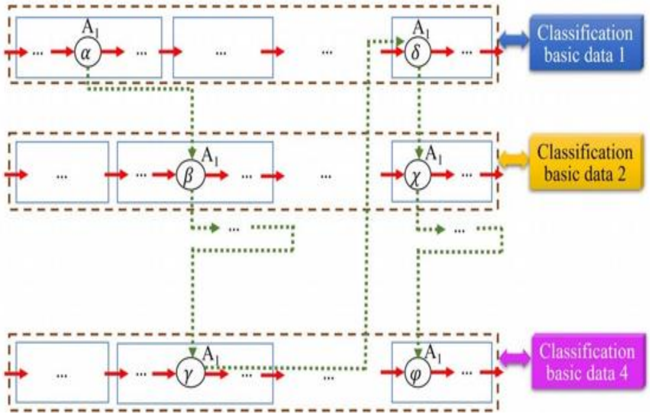

FIGURE 7. Data structure of blocks in a blockchain-based supply chain management system.

3.3Supply Chain System Information Block Link Generation Approach

This paper proposes establishing virtual link relationships between the directory layer of each block in the blockchain and the basic data that share a mapping relationship with that block. Additionally, it suggests constructing corresponding virtual connection relationships within the directory layer of each block to associate data with mapping relationships across different blocks. By leveraging hash function indicators, relevant basic data with mapping relationships to the blockchain can be swiftly located through the virtual connection between directory layers within blocks. This structure, formed by virtual links, constitutes the link network of basic data. Even if access permissions are set for data stored in the classification body, the structure and storage location of basic data can still be retrieved through the blockchain. Furthermore, the immutability of the directory is ensured because the directory layer of information is stored in the block.

Business Entity Information Virtual Link Network

In a supply chain centered around a production enterprise, the operation process follows the sequence of business operations. Accordingly, the production process of business entity information aligns with the supply chain's operational business process. Figure 8 illustrates the virtual connection network between business subject information in a blockchain-based supply chain. The solid box represents the set of basic data corresponding to each block. It's important to note that blocks corresponding to basic data of different classifications may be the same. The figure presents the virtual link network structure of business subject information, highlighting the connection relationships reflected in each block's directory layer records within the blockchain.

In Figure 7, the data of business entity A1 in different classification basic data forms virtual links according to a specified sequence. These links represent various basic data characteristics of the same business entity across different classifications due to different roles.

Business Content Information Virtual Link Network

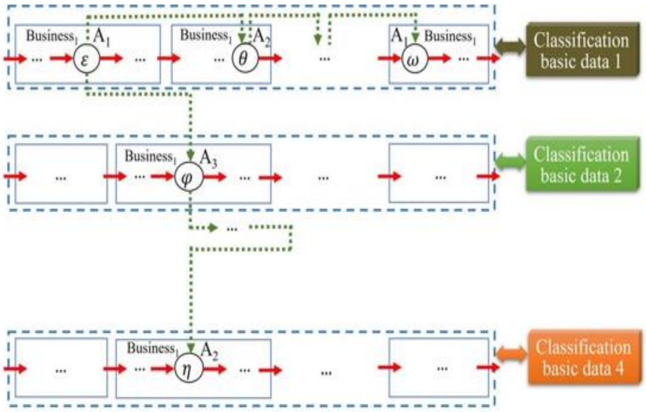

FIGURE 9. Virtual connection network between supply chain business content information based on blockchain

Figure 8 illustrates the virtual connection network between supply chain business content information based on blockchain. In this depiction, the business content 'Business' showcases data within the same classification basic dataset forming virtual links in a specified sequence. Similarly, the basic data corresponding to business content Business1 in the same block form virtual links in another sequence. These virtual links allow for the construction of connections to underlying data corresponding to the blockchain.

3.4 VALUE ANALYSIS OF BLOCKCHAIN

The suggested method's study of the aforementioned content demonstrates that the benefits of present supply chain business entities entering the supply chain system for transactions are reasonably steady over time and should be discounted when evaluating their business transaction benefits. The rate of return and the attitude of corporate entities toward risks are the primary determinants of the market share of various firms. In the realm of supply chain management, blockchain technology is actually acknowledged and being more widely used. The cost-free liberalization of business entities joining a supply chain system cannot be fully realized by the market mechanism and the current business content management system. Equation (19) can be analyzed to determine the percentage of traditional supply chain systems in all supply chain enterprises.

$$\left[\left(r_{t+s+1}-r^f_{t+s+1}\right)+\delta\left(\left(r_{t+s+1}-r_{t+s}\right)-\left(r^f_{t+s+1}-r^f_{t+s}\right)\right)\right]^2$$

The benefits of current supply chain business entities joining the supply chain system for transactions are rather stable over time and should be discounted when evaluating their business transaction benefits, according to the suggested method's analysis of the aforementioned content.

The main factors that determine a firm's market share are its rate of return and its corporate entities' attitude toward risks. In the field of supply chain management, blockchain technology is becoming increasingly generally accepcted

$c_{t+s+1}\, q_{t+s+1} =$

Q_{t+s+1}

$$\times\left(r_{t+s+1}-r^f_{t+s+1}\right)+\delta\left(\Delta r_{t+s+1}-\Delta r^f_{t+s+1}\right)$$

$$/\sigma_{t+s}\left[\left(r_{t+s+1}-r^f_{t+s+1}\right)+\delta\left(\left(r_{t+s+1}-r_{t+s}\right)-\left(r^f_{t+s+1}-r^f_{t+s}\right)\right)\right]^2 \quad (19)$$

$$\sigma_{t+s} = -\frac{c_t \dfrac{\partial U^2}{t+s+1}}{\left(\frac{\partial U_{t+s+1}}{\partial c_{t+s+1}}\right)^*}{}_{+s+1}\left(\partial^2{}_c{}^{t+s+1}\right)^*$$

where σ_{t+s} is the relative risk coefficient.

and utilized. The current business content management system and the market mechanism are not able to completely fulfill the cost-free liberalization of business entities entering a supply chain system. The percentage of traditional supply chain systems in all supply chain firms can be found by analyzing equation (19).

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

5. RESULTS

The integration of blockchain technology into supply chain management offers profound benefits and solutions to various challenges encountered in modern-day logistics. By leveraging blockchain's decentralized ledger system, organizations can enhance transparency, traceability, and security throughout the supply chain network.

One significant result of integrating blockchain is the improved transparency and visibility of transactions and product movements. With blockchain, every transaction and data exchange is recorded in a tamper-proof and immutable ledger, providing stakeholders with real-time access to accurate information. This transparency reduces the risk of fraud, counterfeiting, and errors, fostering trust among supply chain partners and facilitating better decision-making processes.

The integration of blockchain technology enhances the security of supply chain data and transactions. By employing cryptographic techniques and consensus mechanisms, blockchain mitigates the risk of data tampering, unauthorized access, and cyber-attacks. This heightened security not only protects sensitive information but also fosters greater trust and integrity within the supply chain ecosystem, ultimately leading to more efficient and resilient operations.

Transaction Speed (TS): The ability of the blockchain to process transactions within a given timeframe. It's crucial for supply chain applications to process transactions quickly to maintain real-time tracking.

Formula: TS=Time Period/Total Transactions

Block Confirmation Time (BCT): The time it takes for a block to be added to the blockchain. In supply chains, faster block confirmation times can lead to more up-to-date tracking information.

Formula: BCT=Total Blocks/Total Time to Confirm Blocks

Cost Efficiency (CE): Measures the cost of conducting transactions on the blockchain versus the savings or value generated by enhanced supply chain management.

Formula: CE=(Total Savings from Supply Chain Improvements−Total Blockchain Operation Costs)/ Total Blockchain Operation Costs

Security Level (SL): The ability of the blockchain to protect against unauthorized access.

5.1Transaction Velocity (TS)

Trial Current Approach Suggested Approach Transaction Speed (TS) 1000–2500Blue hue: Current techniqueGreen hue: Suggested approach The comparison picture for Transaction Speed (TS) displays the daily transactions for the current approach and the suggested blockchain approach. The number of transactions per day is increased from 1,000 to 2,500 using the suggested way.

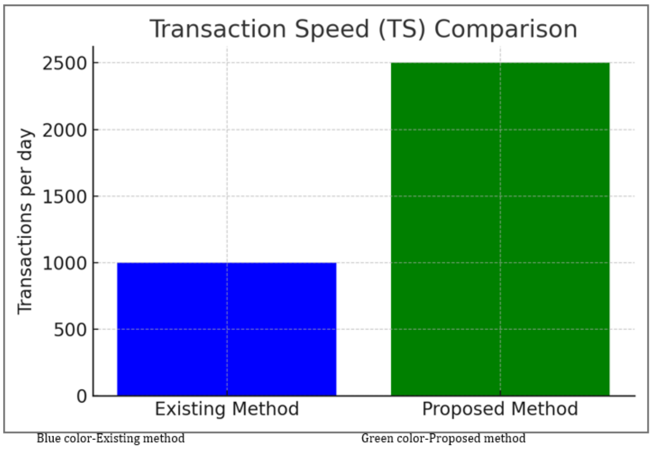

Figure 10 Transaction Speed (TS) Comparison

The number of transactions per day grows from 1,000 to 2,500 with the proposed blockchain technique. This suggests that the system's ability to handle transactions has significantly improved, which may result in increased throughput and efficiency for processes that depend on these transactions.

5.2: Crucial Entry Moment

The proposed blockchain approach and the current system's average confirmation time in minutes are depicted in the visual illustration for the Block Confirmation Time (BCT) comparison. The block confirmation time is significantly reduced by the suggested way from 10 minutes to just 2 minutes. The time needed for block confirmation can be drastically lowered using the suggested blockchain approach, from 10 minutes to just 2 minutes. This decrease suggests a more effective procedure for confirming and documenting transactions on the.

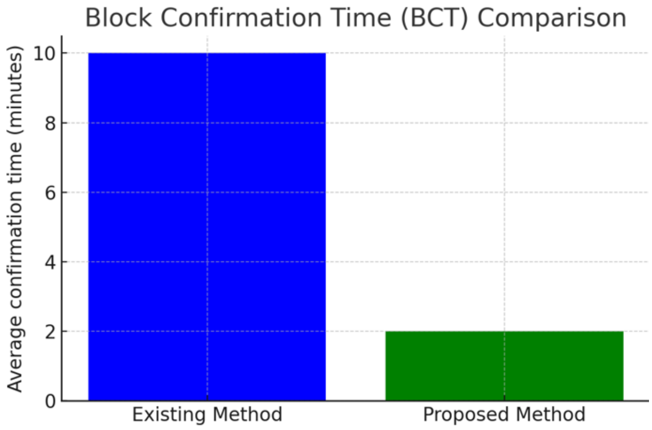

Figure 11:Block Confirmation Time(BCT) Comparison

5 Conclusion

The proposed study creates a blockchain-based, five-layer model of supply chain information flow, comprising the entity layer, blockchain definition layer, network layer, collaboration layer, and application layer. This approach separates data from the supply chain into two categories: internal operations data and externally related data sources. It also presents the composition and data structure features of the chain's internal and external data sources and suggests a block recording method for multisource data information that is located both inside and outside the chain. Hashing function indicators link the entire blockchain. This serves as the foundation for the proposal of a virtual link structure for the construction of blockchain-related data, as well as the analysis of a virtual link generating example. Data transparency and openness are features of the traditional blockchain.

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