Research on Optimization of Supply Chain Management of Construction Project Based on Block Chain

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Abstract. In response to logistical challenges within the supply chain management of construction projects, such as information asymmetry, insufficient collaboration, and difficulties in material quality control, this study proposed a management optimization platform based on block chain technology. By leveraging the decentralized, tamper-proof, and highly transparent characteristics of block chain, a supply chain management model was developed to enable information sharing and the automatic execution of smart contracts. This model effectively enhanced the efficiency of information exchange among supply chain participants, optimizes logistics scheduling, and streamlines material management processes, thereby improving the timeliness of data transfer and inventory control. The research findings indicate that this block chain platform offers prominent advantages in promoting efficient operations, enhancing transparency, and ensuring material quality within the supply chain of construction projects. This study provides valuable theoretical and practical insights for improving supply chain management in China's construction industry.

Keywords: block chain technology; construction engineering projects; supply chain management

1 Introduction

1.1 Research Background

In the current era of rapid information technology development, information sharing platforms, such as ontology information platforms, Internet of Things node information management platforms, and Building Information Modeling (BIM) based systems, have achieved a certain level of information exchange and sharing within the construction supply chain, effectively promoting the operation of the supply chain. However, these platforms have deficiencies in data protection, processing, and rights management, such as unclear information ownership, risks of data misuse, and issues with permission control for information modification. These issues restrict trust between entities in the construction supply chain, increase the complexity of supervision and tracking, and impact the transparency and security of information.

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1.2 Research Status

In recent years, to achieve secure information sharing in supply chain management, academic research has gradually turned its focus to optimizing supply chain management across various industries using block chain technology. Block chain technology, as an innovative computational method, features distributed storage, peer-to-peer transmission, consensus mechanisms, and cryptographic algorithms [1], which can provide solutions to these issues. Tang Mengmeng [2] introduced the integration of block chain technology with supply chains in different industries and proposed suggestions for block chain technology to empower supply chains. Chen Jie [3] pointed out that the application of block chain technology can support efficient interoperability in supply chain logistics. Sun Rui [4] constructed an evolutionary game model to compare and analyze the role of block chain technology in solving supply chain financial risks. Zhao Hua [5] embedded block chain technology in the collaborative governance of the agricultural product supply chain, thereby breaking information constraints and ensuring information security. Jin Mudan [6] analyzed the current status of enterprise supply chain management and proposed optimization strategies. Long Chen [7] elaborated on the solutions of block chain in different fields of the timber supply chain, providing a new perspective for the supply chain management of timber, one of the materials for construction projects. In the construction industry, Nan Jiangxia [8] discussed the impact of block chain costs on supply chain strategy selection. Cao Yang [9] constructed a management block chain for information sharing in the construction supply chain. Zhao Qinghua [10] used the "block chain + BIM" platform to optimize the project management process, achieving more refined, visual, and dynamic management of data input, storage, and query for all parties involved in project management. Sun Jianrong [11] constructed a construction market integrity management platform based on block chain technology, prompting all participating units to be honest and trustworthy, and optimizing the construction market environment.

Through reviewing relevant literature, it has been found that block chain technology has been applied to supply chain management in various fields, but research on optimizing the logistics management of construction project supply chains remains relatively scarce. This paper, in response to the existing problems in the supply chain management of construction projects, proposes the combination of "block chain" and "construction project supply chain management" as a technical means, especially in constructing a cutting-edge and efficient information sharing block chain management platform in the logistics segment. The platform aims to optimize the management of logistics information sharing, improve transparency and trust among logistics-related parties, and promote the efficiency of construction supply chain logistics operations.

2 Feasibility Analysis of Block Chain Optimization for Construction Project Supply Chain Management

Block chain is a database technology that connects data blocks in chronological order through a transparent and unalterable manner. Based on cryptographic principles, such as hash algorithms and asymmetric encryption technology, it ensures the integrity and security of data. Each data block is linked under the mark of a timestamp, containing transaction data and verification information, ensuring the traceability of information. It is maintained by various consensus mechanisms, such as PoW (Proof of Work) and PoS (Proof of Stake), allowing multiple nodes to confirm transactions and store data in a decentralized environment. Block chain technology, with its decentralized, publicly transparent, smart contracts, unalterable, and traceable characteristics, has established a new framework for data interaction and management.

(1) Decentralization and transparency. Decentralization refers to the process of transactions in the construction industry, no longer relying on traditional third-party central institutions to control the core data resources of the project [12]. Block chain technology uses a distributed ledger, giving each node (computer or server) high autonomy, capable of independently storing, updating, and verifying information. These nodes are interconnected, enhancing the system's resilience and security, ensuring that data throughout the entire life cycle of the construction project is more secure and reliable. The public transparency of block chain allows the database to be open to the public within a certain range, with transactions and records visible to all participants, while protecting privacy through asymmetric encryption, all business records are verifiable and unalterable. This openness solves the problem of information barriers, achieving transparent records and supervision from raw material supply to the construction process, reducing the risk of information asymmetry.

(2) Smart contracts. Smart contracts are computer protocols that automatically execute contract terms, allowing trusted transactions without a third party. Smart contracts run on the block chain, ensuring that once the contract is written, it cannot be changed, and when preset conditions are met, the contract will automatically execute the corresponding operations [13]. In the supply chain management of construction projects, the allocation of building materials relies on traditional paper-based dispatch order management, lacking accurate demand forecasting, inventory control strategies, and supply chain collaboration difficulties, which can lead to over-purchasing or shortages of materials, affecting the overall progress and reducing the control ability and stability of project progress. Through smart contracts, demand forecasting, inventory control, and allocation operations can be automated.

(3) Immutability and traceability. Block chain is a chain-like structure formed by connecting blocks in chronological order. Each block has a unique hash value and timestamp, and once information is recorded on the chain, it is difficult to be changed or deleted. Traditional construction material information, due to manual collection and recording, is prone to over-reporting, under-reporting, and substituting inferior goods with superior ones. Using the immutability and traceability of

block chain, all records about construction materials such as production, testing, transportation, and reception, once recorded, cannot be changed, providing a reliable basis for material quality verification.

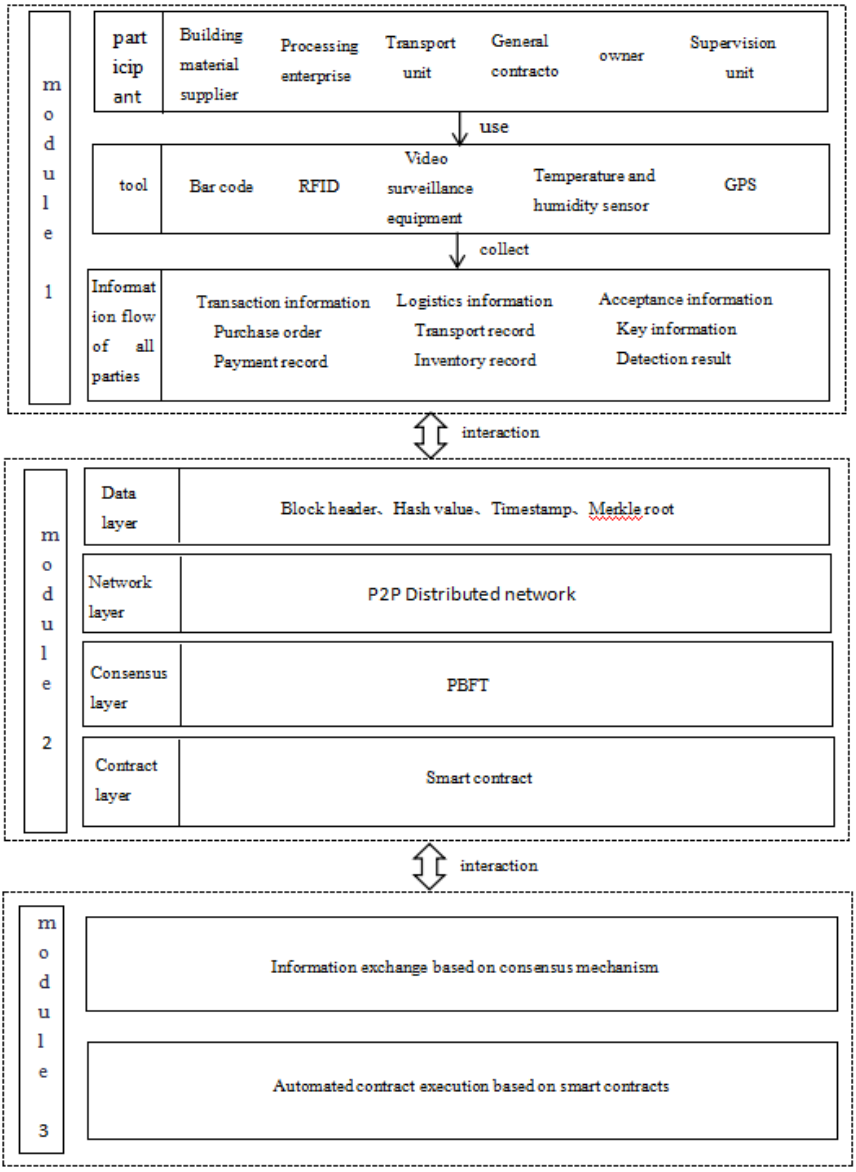

Fig. 1. Construction project supply chain management model based on block chain technology

3 Optimization System of Construction Project Supply Chain Management Based on Block Chain Technology

3.1 System Optimization Model

The construction project supply chain management model based on block chain technology mainly includes a data integration module, a block chain auxiliary module, and a supply chain management optimization module, as shown in Figure 1. The data integration module serves as an integrated database for storing key business information from various parties in the construction project supply chain; the block chain auxiliary module mainly assists in data transmission, query, verification between nodes, and provides related auxiliary service functions; the supply chain management optimization module uses the characteristics of block chain to optimize information interaction and contract execution in the supply chain, divided into two major parts: information interaction based on consensus mechanisms and contract automation based on smart contracts.

Compared to other existing systems, our platform demonstrates exceptional scalability, primarily benefiting from the distributed architecture and modular design inherent in block chain technology. This implies that as the scale of construction projects grows or new demands arise, the platform can be easily expanded without the need for complex system reconfigurations. Furthermore, the platform seamlessly integrates into existing construction project management practices, providing project managers with an intuitive and user-friendly interface that reduces learning costs and implementation difficulties. By fusing with existing technologies such as BIM (Building Information Modeling) and the Internet of Things, the platform can further enhance the efficiency and transparency of supply chain management while ensuring data accuracy and real-time updates. This high degree of integration convenience and scalability positions our platform as a significant direction for future development in the field of construction project supply chain management.

After delving into the optimization model of construction project supply chain management based on block chain technology, it is imperative to further explore the expansion potential of this model. Specifically, this model is not confined to material management and logistics optimization; its underlying logic and characteristics empower it to expand and encompass other crucial aspects of construction projects, such as labor management and project financing.

Firstly, in the realm of labor management, the transparency, decentralization, and immutability of block chain technology can provide an efficient and reliable labor data management system for construction projects. By uploading key information such as workers' identity details, skill certifications, work hour records, and wage payments onto the block chain, the authenticity and traceability of this information can be ensured, thereby reducing instances of false work hours and wage fraud. Additionally, the automatic execution feature of smart contracts can automate labor management processes, such as work hour calculation and wage dis-

bursement, thus enhancing management efficiency and minimizing human errors and disputes.

Secondly, in the context of project financing, block chain technology can also play a pivotal role. By uploading critical information such as contracts, transaction records, and asset proofs onto the block chain during the project financing process, the transparency and security of the information can be guaranteed, fostering greater investor trust in the project. Furthermore, the smart contract functionality of block chain can automate some complex operations in the financing process, such as conditionally triggered payments and automatic settlement, thereby reducing financing costs and improving financing efficiency.

3.2 Module Functions

(1) Data Integration Module. The data integration module is mainly responsible for obtaining and storing various formats of documents, images, reports, contracts, etc., generated by various management behaviors of supply chain participants at different stages of the project. It uses barcodes, RFID, video monitoring devices, and temperature and humidity sensors to collect various information flows involved in the supply chain management of construction projects. The collected information flows will be uploaded to the block chain, with barcodes or RFID tags attached to materials and equipment, containing key information such as name, specifications, model, manufacturer, and quality inspection results [14]. These data records are crucial for tracking and analyzing the causes of problems. In addition, during the storage, storage, and outbound stages of materials and equipment, the use of video monitoring systems and temperature and humidity sensors can monitor the status of engineering materials in real-time. If there are any improper operations or substandard storage environments, the data of the corresponding materials will be immediately transmitted to the data layer for processing.

(2) Block chain Auxiliary Module. The block chain auxiliary module can be divided into the data layer, network layer, consensus layer, and contract layer. The data layer is the core of the block chain system, responsible for storing and recording important information. The information blocks include many elements, such as block headers, hash values of the current and previous blocks, timestamps of the current block, Merkle roots, and data related to engineering materials; the network layer's main responsibility is to encapsulate the construction of the network and propagation protocols. In the construction of the construction material supply chain system, point-to-point communication technology is specially introduced; the consensus layer contains various consensus algorithms, and its core task is to verify the authenticity of information in the block chain network through consensus mechanisms. This paper selects the practical Byzantine fault tolerance as the data formula algorithm to achieve consensus between nodes in the block chain network, ensuring the correct packaging and verification of blocks, and effectively defending against malicious nodes attacking the system[15]; the contract layer contains encoded smart contracts negotiated by multiple parties, which ensure that once the evaluation conditions are met, the construction material supply

process is automatically completed, and the system executes the relevant contract terms. Combining these service levels, a highly secure and trustworthy supply chain management system is constructed, greatly enhancing the efficiency and transparency of construction project supply chain management.

(3) Supply Chain Management Optimization Module. The core of the supply chain management optimization module can be summarized in two parts: one is information interaction based on consensus mechanisms, using specific algorithmic mechanisms to select authorized representatives in the alliance chain, who are responsible for the responsibility management of material information in the network. Given the complexity of the construction project supply chain management process, involving multiple entities and changing on-site construction demands, the DPOS mechanism is used to select authorized representatives [16]. Authorized representatives are responsible for the creation of new blocks and the broadcasting of block generation information. After the initiation of engineering material transactions, their information will be broadcast to all nodes in the block chain network, and each node will receive and verify the validity, including digital signatures and legal review of material transactions; the second is the automatic execution of contracts based on smart contracts, composed of related algorithms, script code, and smart contracts themselves. The purpose is to reduce manual intervention in supply chain management and automate the execution of material demand forecasting, inventory control, and allocation operations, achieving automated control of business processes. Once the contract trigger conditions are met, the system will automatically execute the relevant terms, enhancing the collaboration efficiency between all parties and ensuring the fairness of contract execution.

3.3 Validation Plan for Block Chain Solution Applicability and Effectiveness

To validate the practical applicability and effectiveness of the proposed block chain-based supply chain management optimization model in various types of construction projects, a comprehensive validation plan is devised. This plan includes the following key steps:

(1) Pilot Project Selection: A diverse range of construction projects will be selected as pilot cases, encompassing residential buildings, commercial complexes, infrastructure projects, and others. These projects will represent different scales, complexities, and logistical requirements, providing a comprehensive testbed for the block chain solution.

(2) Implementation and Monitoring: The block chain system will be implemented in these pilot projects, integrating with existing supply chain management systems and processes. Continuous monitoring will be conducted to observe the system's performance, identifying any issues or inefficiencies in real-time.

(3) Date Collection and Analysis: Comprehensive data collection will be conducted throughout the pilot phase, capturing metrics such as information exchange efficiency, inventory control accuracy, contract execution timeliness, and overall supply chain transparency. This data will be subjected to rigorous analysis using

statistical methods to quantify the improvements achieved by the block chain solution.

(4) Stakeholder Feedback: Regular feedback sessions will be held with stakeholders, including contractors, suppliers, project managers, and owners, to gather their insights and perceptions of the block chain system. Their feedback will be crucial for assessing the system's usability, reliability, and overall impact on project operations.

(5) Bench marking and Comparison: To further validate the solution's effectiveness, bench marking studies will be conducted against traditional supply chain management systems. By comparing key performance indicators such as cost savings, time reductions, and error rates, the advantages of the block chain-based approach will be clearly demonstrated.

4 Problems encountered and solutions

During the development and testing of a block chain-based construction project supply chain management platform, we encountered several specific challenges and limitations. Firstly, the complexity of the technology and the demand for high specialization posed major obstacles. While the decentralization, immutability, and transparency of block chain technology offer significant advantages for supply chain management, they also require the development team to possess profound knowledge in cryptography, distributed systems, and smart contract programming. Additionally, the complexity and diversity of the construction supply chain make data integration and standardization a formidable task, necessitating the overcoming of data barriers across different systems, formats, and participants.

To address these issues, we plan to take the following measures in future iterations:

(1) Technical Training and Team Expansion: Strengthen team members' training in blockchain technology, smart contract programming, and distributed systems, while considering the introduction of external experts with relevant experience to enhance the team's overall technical capabilities.

(2) Data Standardization and Integration: Collaborate with various participants in the construction supply chain to establish unified data standards and interface specifications to facilitate data integration and sharing. Furthermore, adopt advanced data processing and analysis technologies to improve data processing efficiency and accuracy.

(3) Performance Optimization: Explore and research performance optimization solutions for block chain networks, such as adopting layered architectures, optimizing consensus algorithms, and introducing side chain technologies, to enhance the system's processing speed and responsiveness.

5 Conclusion

This paper analyzes the specific problems existing in the construction project supply chain, elaborates on the application feasibility of block chain technology in supply chain management, constructs an optimization system for construction project supply chain management with block chain at its core, and discusses the functions of each module in the system in depth, which will greatly enhance the efficiency and transparency of construction project supply chain management. In the future, with the continuous deepening and improvement of block chain technology, it can play a greater role in the field of construction project supply chain management, further promoting the digital transformation and optimization and upgrading of the industry's supply chain.

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