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Research on optimization of e-commerce supply chain logistics management model based on blockchain

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Abstract: *This study explores the optimization path of the e-commerce supply chain logistics management model using blockchain technology, breaks the bottlenecks of information barriers, low operational efficiency and high costs in the traditional operation model, adopts design strategies to build a blockchain technology application architecture, integrates distributed ledger technology, smart contract functions, Internet of Things technology and decentralized identity authentication methods, and implements refined improvements in each stage of the e-commerce supply chain. Data collection is conducted on the order execution process, logistics distribution links and cost components of the three e-commerce platforms A, B and C, and an in-depth comparative analysis is conducted on the differences between the traditional model and the blockchain optimization model in terms of efficiency, economic cost and customer satisfaction. The research results show that the optimization measures using blockchain technology have significantly improved the efficiency of order processing and distribution, effectively reduced logistics cost expenditures, and significantly increased customer satisfaction levels.*

Keywords: *blockchain technology; e-commerce supply chain; logistics management; smart contract*

1. Introduction

In terms of information sharing, logistics scheduling, cost control and security protection, the traditional supply chain management model has shown major shortcomings, and there is an urgent need to explore breakthrough solutions. The characteristics of decentralization, immutability and strong transparency are the core highlights of blockchain technology. It has shown great growth potential in many disciplines, especially in the field of supply chain strategic planning and implementation effect evaluation. The application potential of this technology is expected to break the constraints of the existing model [1] . The blockchain system effectively improves the transaction transparency and data protection level by providing instant transaction record traceability, optimizing data sharing mechanism and enhancing system security protection, and systematically reforms the supply chain to achieve a double leap in transparency and operational efficiency, reduce transaction cost investment level, and enhance the trust between enterprises and consumers. The use of blockchain technology to optimize the logistics management model of e-commerce supply chain has significant theoretical significance. This study shows its rich application value and explores the application strategy of blockchain technology in e-commerce supply chain, the execution of smart contracts and the improvement path of its information management level. This study aims to propose an operational optimization method to create an excellent supply chain management service system for e-commerce enterprises.

2. E-commerce supply chain logistics management model

2.1 Composition of the e-commerce supply chain

As shown in Figure 1, in the initial stage of the e-commerce supply chain, suppliers or brands occupy a core position and fulfill their obligations to provide goods to the e-commerce platform. E-commerce enterprises rely on the purchase order mechanism to implement commodity purchasing activities and deliver goods to the designated storage center. In the supply chain system, the warehouse occupies a core

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position and is an indispensable link. It performs commodity storage and supervision functions and implements commodity sorting and pre-packaging procedures according to specific customer needs [2]. After the warehouse operation stage, the goods will be carefully classified and processed in the sorting center, striving to achieve the final success of the distribution. In the implementation stage, in order to ensure the stable supply of goods on the e-commerce platform, enterprises need to implement scientific supply chain management and accurate demand forecasting, and systematically integrate inventory management methods. The goods are ready for distribution and enter the final stage of the "distribution system". Delivery vehicles and other transportation methods are used to deliver the goods to the consumer terminal. This link is closely linked to the customer's shopping experience. It is the most challenging part in the field of e-commerce supply chain. Due to the coordination and close collaboration of the aforementioned stages, the e-commerce platform effectively promotes the circulation of goods from suppliers to consumers, ensuring the rapidity of goods delivery and the high quality of customer satisfaction [3].

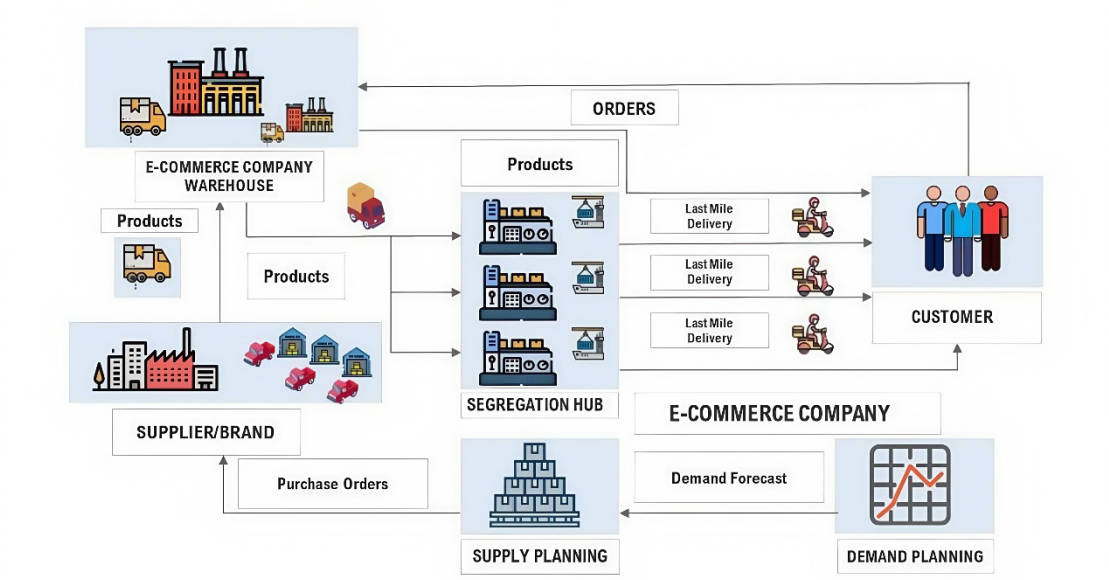

Figure 1 Composition of e-commerce supply chain

2.2 Traditional e-commerce supply chain logistics management model

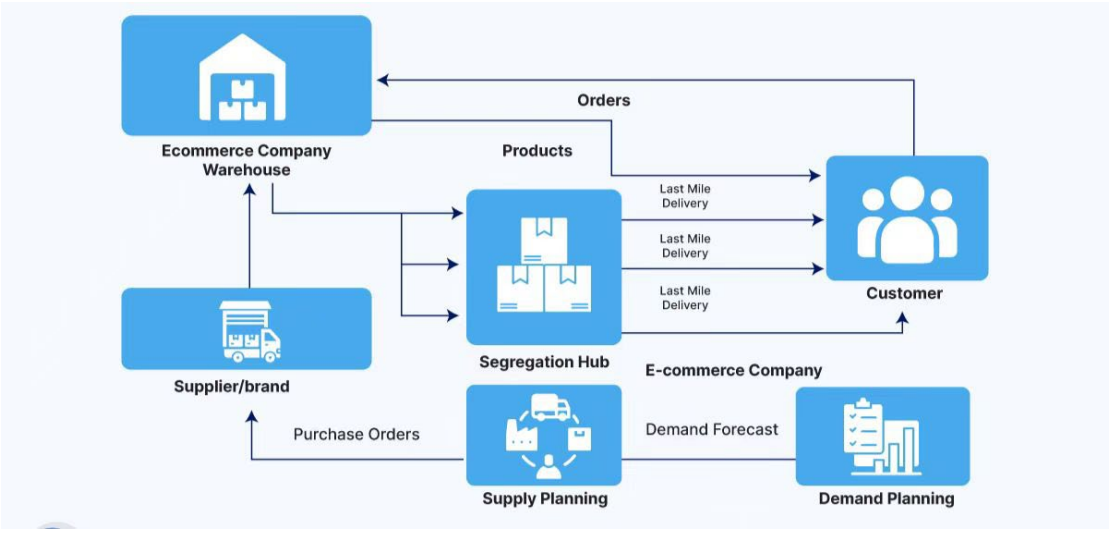

Figure 2 Traditional e-commerce supply chain logistics management model

The logistics management of traditional e-commerce supply chains involves core links such as supplier management, storage facility configuration, transportation and distribution, cargo sorting, and

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terminal distribution (Figure 2). Within the established model, suppliers are responsible for the production and supply of goods. In the commodity supply chain, e-commerce platforms are responsible for purchasing goods from suppliers, and the products are stored in their own or rented storage spaces. Logistics companies that undertake the task of transporting goods from storage facilities to sorting hubs implement sorting operations in accordance with the specific requirements of consumer orders. After the goods have completed the sorting operations, they are effectively delivered to consumers at the end of the supply chain. In the traditional implementation model architecture, information flow within the e-commerce platform is usually managed in an orderly manner by an internal automatic control system, involving relevant business links such as inventory control, order execution, and distribution scheduling. The collaborative and coordinated operation model analysis between each stage adopts the combination of electronic data interchange (EDI) technology and traditional information systems [4] .

2.3 Main problems faced by the traditional model

China's traditional e-commerce supply chain and logistics management model is facing a series of challenges and difficulties. Analysis of information asymmetry and data siloing problems, data sharing between various links has not reached the established standard of real-time sharing, inventory data has a time lag, order processing has a time delay, customer service experience has obvious defects, and in the traditional operation paradigm, coordination and manual intervention are relatively heavy, which can easily lead to reduced work efficiency and increased error rates. The traditional supply chain management model has defects in monitoring various links of the supply chain and information transparency. The tracking technology of the entire flow of goods faces technical challenges. The level of supply chain risk and uncertainty has increased. In the field of logistics and distribution, the "last mile" distribution problem has become increasingly prominent and has become the focus of industry attention. The logistics and distribution costs are high and the efficiency performance is limited. Given the loopholes in the resource allocation model, it is usually difficult to achieve the optimal level of resource scheduling, resulting in improper waste of logistics resource allocation. In the face of emergencies, traditional response strategies have failed to fully reflect their flexible response characteristics. The supply chain's ability to resist external interference is relatively poor, and the overall stability of the system has suffered destructive consequences [5] .

3. Optimization of e-commerce supply chain logistics management model based on blockchain

3.1 Application framework of blockchain technology in e-commerce supply chain

The e-commerce supply chain management framework based on blockchain technology is mainly formed by building multiple core modules. In order to enhance the transparency, operational efficiency and mutual trust of each link in the supply chain, as shown in Figure 3, in the asset registration link, the blockchain technology platform becomes an innovation driver. This function is intended to ensure the thoroughness of the registration, monitoring and verification process of all products and resources in the platform. The information source must meet the dual requirements of traceability and verifiability, and effectively prevent the emergence of counterfeit and inferior products. The transaction information module on the blockchain technology platform records each transaction in detail, ensures the integrity and non-tamperability of transaction data, significantly enhances the trust level of supply chain participants in transaction data, and significantly reduces the number of dispute cases in the transaction link. The logistics information module using blockchain technology can grasp the changes in the transportation status of goods in real time and implement a transparent tracking mechanism for the entire logistics transportation process, thereby achieving a dual improvement in the transparency and operational efficiency of the supply chain. The credit assessment module enabled by blockchain technology realizes the transparency and unalterability of credit data. Financial institutions are able to approve loan applications based on real data, effectively reducing the level of credit risk. Financial institutions and lending companies can directly exchange transaction, logistics and credit data, greatly improving the efficiency of capital raising and the level of information transparency.

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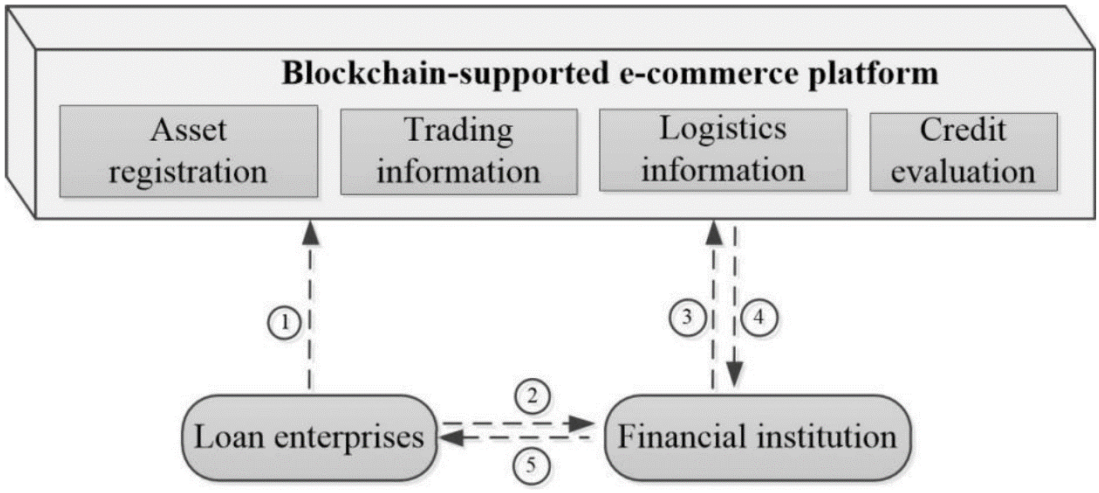

Figure 3 Application framework of blockchain technology in e-commerce supply chain

3.2 Data Sharing and Transparency Improvement

3.2.1 Design and implementation of distributed ledger

The nodes in the blockchain network jointly maintain the data consistency of the ledger, ensure the real-time synchronization of data among multiple participants and ensure its tamper-proof characteristics. In the actual operation stage of implementing the design activities, the transaction data in each block is encrypted using the hash function, and the data chain is built to establish the structural system of each data block as follows:

$$\text{Block} = \left\{ \text{Header}, \text{Body}, \text{Hash}_{\text{previous}}, \text{Hash}_{\text{current}} \right\} \tag{1}$$

It Header includes metadata such as timestamps and block sequence numbers, Body stores specific transaction data, and $\text{Hash}_{\text{previous}}$ ensures continuity between blocks. The blockchain technology architecture uses a consistency algorithm to achieve decentralization and data security of the ledger, effectively eliminating the drawbacks of data silos in the traditional model and significantly improving the transparency and trust of supply chain management.

3.2.2 Data encryption and verification at each link of the supply chain

In the implementation stage of blockchain technology adopted in the e-commerce supply chain field, it is extremely important to ensure the security and authenticity of data at each stage. The data of each transaction link must be strictly reviewed and verified by encryption technology to prevent information resources from being illegally tampered with and maintain data authenticity. Symmetric encryption and asymmetric encryption technology are conventionally used to discuss each transaction activity. The confidentiality of transaction information can be effectively maintained through public key encryption technology. The initiator of the transaction uses his personal private key to digitally sign the information, and the recipient uses the public key to verify the data. The transaction data set based on this analysis is marked as T, and the recognition process can be defined as:

$$S = \text{sgn}_{\text{private}}(T) \tag{2}$$

The recipient verifies the signature using the public key:

$$\text{Verify}_{\text{public}}(S, T) = \text{True} \tag{3}$$

The adoption of this encryption mode and the encryption and verification of data at each link are key means to ensure the security of supply chain information and data accuracy, thereby effectively

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improving the overall trust level of the system.

3.3 Logistics Management Information Optimization

3.3.1 Application of Smart Contracts

The smart contract module used by blockchain technology has the function of automatically executing contract terms. In e-commerce supply chain management, this system is widely used to automate the processing of orders, payments, and distribution. In the operational implementation stage, according to the established conditions, the smart contract can autonomously execute the established tasks. The goods are removed from the warehouse. When the circulation link is started, the automated payment process is triggered to realize the automatic transfer of funds. In the preparation stage of the smart contract, the terms set are: after completing the delivery of the goods, the supplier must simultaneously issue the transport order number. The contract will automatically release the payment constraints according to the predetermined conditions. The formula can be expressed in mathematical symbols:

$$\text{if}(\text{Delivery} = \text{True})\text{and}(\text{Tracking\_Number received})\text{then Execute\_Payment}() \tag{4}$$

The application of smart contract technology has promoted a leap in the level of automation in the e-commerce supply chain, reduced the proportion of manual intervention, enhanced the level of job execution efficiency, and effectively reduced operating costs.

3.3.2 Automated dispatching and tracking system

The e-commerce supply chain system supported by blockchain technology and the automated dispatching and tracking system based on modern technology have greatly enhanced the efficiency of logistics operations. The logistics monitoring platform based on blockchain technology stores the entire process information of goods from the start to the delivery on the chain, and must realize the instant communication and full disclosure of logistics information. In the logistics network layout, the spatial distance between each logistics node can be expressed as di, the speed parameter of the object movement is vi, and the specific time of arrival is expected to be:

$$T_{\text{arrival}} = \frac{d_i}{v_i} \tag{5}$$

When the system is in operation, it is necessary to consider key factors such as traffic conditions, storage space, and the availability of transportation tools. It discusses the principle of optimal path construction using intelligent computing in path selection, implements intelligent adjustment and optimization of logistics resource allocation plans, and adopts intelligent scheduling and tracking mechanisms to greatly enhance the response agility and accuracy of logistics operations.

3.4 Solutions to improve efficiency and reduce costs

3.4.1 Cargo Tracking Combining Blockchain and IoT

In the field of e-commerce supply chain, the integration of IoT and blockchain technology has realized new possibilities for real-time tracking of goods, implemented traceability tracking and feedback of logistics operations, and used sensors in IoT technology to collect data on ambient temperature, humidity and spatial location information. The data is serialized and stored in the blockchain database to ensure that the data cannot be tampered with and realize its real-time guarantee mechanism for real-time updates. The sensor detection results show that the specific coordinates of the goods are currently located at point Pi, and the real-time data is synchronized to the blockchain technology system to form an unalterable cargo track:

$$\text{Log blockchain} = \{P_i, \text{Timestamp}, \text{Sensor\_Data}\} \tag{6}$$

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The cargo tracking system based on the Internet of Things and blockchain technology can accurately monitor the status of cargo at each node of the supply chain, improve the inventory management structure, and enhance the accuracy of logistics distribution and customer satisfaction.

3.4.2 Disintermediation of transaction and payment process

Disintermediation can be achieved with the help of blockchain technology, which reduces the level of intermediary cost input in the transaction link and enhances the efficiency of payment operations. In the conventional e-commerce supply chain system, the payment settlement process often requires the participation of multiple intermediaries. With the support of blockchain, the two parties to the transaction can implement direct point-to-point fund settlement. During the payment activity implementation stage, cryptocurrency or digital cryptocurrency is used as a settlement method. The transaction process can be automated with the help of smart contract technology. The buyer confirms the receipt of the goods at the stage of goods receipt confirmation, and the smart contract automatically executes the payment operation to realize the automation of the payment process:

$$\text{if}(\text{Received} = \text{True})\text{then Execute\_Payment}() \tag{7}$$

The decentralized payment system significantly reduces transaction costs and enhances the efficiency of payment operations.

3.5 Ways to Enhance Trust and Security

3.5.1 Decentralized identity authentication and verification

Decentralized identity authentication technology is the core application of blockchain in e-commerce supply chain management. Through the stable and secure authentication mechanism provided by the blockchain network, this system strives to replace the traditional centralized authentication system. Within the established mechanism framework, participants in the supply chain, whether they are suppliers, consumers or logistics companies, are given a proprietary digital identity, and their identities are verified by means of private keys. Assume that the identity authentication procedure is:

$$\text{Verify}_{blockchain}(ID, \text{Signature}) = \text{True} \tag{8}$$

Decentralized identity authentication technology can effectively verify the true identity of transaction participants, improve transaction credibility, strictly control the spread of counterfeiting and fraud, and optimize the reliability and trust level of the supply chain structure.

3.5.2 Application of blockchain anti-tampering technology

One of the core advantages of blockchain technology is its inherent immutability. In the field of e-commerce supply chain, all transaction and logistics data must be stored on the blockchain technology platform to build an immutable historical database. The hash value of each data block is connected with the hash value of the previous block to ensure the continuous chain structure of the data. Once the data is illegally tampered with, the hash value of the complete chain will be adjusted, and any form of tampering attempt will be quickly identified and stopped. Relying on blockchain technology to achieve data immutability, each node in the e-commerce supply chain has achieved data integrity and accuracy, effectively blocking the risks of operational errors and fraud that may occur in traditional systems.

4. Testing process

4.1 Selection of test objects and data

This study selected three e-commerce platforms of different sizes as the test objects of the experiment. The annual transaction volume of platform A reached 50 million, the annual transaction volume of platform B was about 12 million, and the annual transaction volume of platform C was 3 million. Each platform has a variety of commodity categories, involving electronic equipment, clothing and food, etc.

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The data based on this test mainly comes from the order execution, inventory changes and logistics distribution information in the past six months. The order delivery cycle data records the time interval between the consumer's order and the merchant's delivery. The average order processing time of platform A is 12 hours, the standard service time of platform B is 15 hours, and the service time of platform C is 10 hours. The commodity inventory turnover rate, as a measure of the efficiency of commodity circulation, reveals its circulation speed. The monthly average result of the inventory turnover of platform A is 4.5 times, and the monthly visit frequency of platform B is 3.8 times, reflecting the average monthly visit level. The monthly usage frequency of platform C is stipulated as six times. This data records the entire delivery time from the time the goods are shipped from the warehouse to the hands of consumers. The average delivery cycle of platform A is two days, the service cycle of platform B is fifty-six hours, and the service time stipulated by platform C is forty hours. The logistics cost system mainly consists of three parts: warehousing fees, distribution fees, and order processing fees. Platform A prices transportation operations at 15 yuan/order, platform B's order service fee is charged at 20 yuan per order, and platform C's transaction price is 12 yuan/order. Customer satisfaction data is collected and organized based on consumer feedback information. The user satisfaction survey results of platform A show that the satisfaction score is 4.2 points, with a full score of 5 points. The comprehensive score of platform B is 3.9 points, and the comprehensive evaluation of platform C is 4.5 points.

4.2 Test steps

The first phase of the test was to collect the order, inventory and logistics data of the past six months from the databases of the three platforms A, B and C. The order data recorded in detail the key time sequence information such as the order generation time, delivery time and arrival time. The inventory data system comprehensively recorded the key parameters such as the storage quantity of various commodities and their turnover efficiency. The logistics data analysis involved time control at each stage of transportation, distribution route optimization and distribution timeliness monitoring. The data collection phase was successfully completed, and all data was stored in the encryption platform supported by blockchain technology. Each order and its logistics details were securely processed using the hash encryption algorithm in blockchain technology to maintain the integrity and non-tamperability of the data. The simulation test program was implemented in the blockchain architecture to simulate the entire distribution process from the generation stage to the delivery stage, and from the warehousing stage to the customer's receipt. During the test implementation phase , the order processing cycle of platform A was shortened from 12 hours to 8 hours. After technical upgrades, the service time of platform B has been shortened from 15 hours to 10 hours. The project implementation cycle of platform C has been optimized and reduced from 10 hours to 7 hours. The logistics distribution timeliness of platform A has been optimized and has been adjusted from 48 hours to 40 hours. The service optimization cycle of platform B has been shortened from 56 hours to 45 hours. After technical upgrades, the project of platform C has been optimized and the execution time has been shortened to 32 hours, with a significant improvement in efficiency. The transportation cost of platform A was adjusted, and the cost per order was reduced from 15 yuan to 12 yuan, achieving cost control. Platform B implemented price adjustment, and the original unit price of 20 yuan/order was reduced to the current unit price of 17 yuan/order. Platform C implemented a new charging standard, and the unit price was adjusted to 10 yuan per order. The increase in the values of customer satisfaction-related indicators shows that the service quality is recognized. The customer satisfaction index of platform A climbed to 4.5 points, and the satisfaction evaluation was excellent. The score level of platform B was upgraded to 4.3 points, and the score level of platform C was adjusted to 4.7 points. According to the established steps, this study systematically analyzed the optimization effects of the e-commerce supply chain logistics management model using blockchain technology in improving operational efficiency, reducing operating costs, and improving customer satisfaction, and systematically compared and sorted out the advantages of the traditional model.

5. Results Analysis

5.1 Changes in logistics efficiency after optimization

A comparative analysis of the traditional e-commerce supply chain and the supply chain optimized by

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blockchain technology was carried out. The optimized logistics system showed a significant increase in efficiency. According to Table 1, the order processing time of platform A was compressed to 8 hours, which was 4 hours less than before. The service time of platform B was streamlined from 15 hours to 10 hours. The service time of platform C was compressed and adjusted from 10 hours to 7 hours. The logistics management system using blockchain technology can effectively improve the timeliness of order processing. Analysis and discussion of the performance index system of cargo transportation time, the platform compressed the service time from the original 48 hours to 40 hours, the service time of platform B was adjusted from 56 hours to 45 hours, and the service time of platform C was adjusted to 32 hours, which was 8 hours less than before. The transparency and real-time update mechanism of blockchain technology significantly reduced the delay of logistics distribution. During the logistics operation stage, the use of automated execution methods such as smart contracts has significantly improved the timeliness of order circulation in key links such as warehousing management, sorting operations, and distribution processes, reduced the proportion of manual intervention, and achieved dual optimization of logistics scheduling accuracy and response speed. Given the instant and synchronous feedback of information in each link, the overall operating efficiency of the supply chain has been greatly improved.

Table 1 Changes in logistics efficiency after optimization

Platform	Order Processing Time (Before)	Order Processing Time (After)	Delivery Time (Before)	Delivery Time (After)
A	12 hours	8 hours	48 hours	40 hours
B	15 hours	10 hours	56 hours	45 hours
C	10 hours	7 hours	40 hours	32 hours

5.2 Cost Control and Reduction

For cost control, the blockchain technology solution shows excellent optimization potential. Relying on the automation and transparent operation of blockchain technology, the transportation cost has been effectively reduced after comprehensive management. Platform A optimized the transportation cost and reduced the cost per order from the original 15 yuan to 12 yuan. Platform B adjusted the service fee, and the fee per order was 17 yuan after adjustment. Platform C adjusted the charging standard, and the unit price dropped from 12 yuan to 10 yuan/order. This change is mainly attributed to the significant improvement of supply chain transparency by blockchain technology, which eliminated redundant operations in the process (Table 2). The implementation of smart contracts greatly simplifies the cumbersomeness of the payment process, significantly reduces the errors and cost consumption caused by manual operations, and the cargo tracking system combining the Internet of Things and blockchain technology significantly reduces the cost of empty transportation and warehousing. The accuracy of inventory monitoring has reached an unprecedented level, successfully reducing the warehousing cost investment caused by excess inventory, and implementing a decentralized payment method to streamline the costs of intermediate links, effectively reducing the additional expenses of the payment link.

Table 2 Cost control and reduction

Platform	Transportation Cost (Before)	Transportation Cost (After)
A	15 RMB/Order	12 RMB/Order
B	20 RMB/Order	17 RMB/Order
C	12 RMB/Order	10 RMB/Order

5.3 Improved customer satisfaction and trust

By introducing blockchain technology to optimize the supply chain management model, customer satisfaction and trust have been significantly improved. According to the data collected in the survey, the customer satisfaction score of platform A has increased from 4.2 points to 4.5 points, the score of platform B has increased significantly from 3.9 points to 4.3 points, and the score of platform C in Table 3 has increased from 4.5 points to 4.7 points (Table 3). The integration of blockchain technology allows consumers to track the logistics process of each order in real time, significantly improves the transparency and reliability of the logistics distribution process, and significantly reduces the frequency of customers' anxiety psychological reactions. With the acceleration of delivery speed and the real-time sharing of logistics information, the time customers wait for service is significantly shortened, thereby

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greatly improving the overall shopping experience level. Based on the anti-tampering characteristics of blockchain, the authenticity and security of order information can be effectively guaranteed, which greatly increases the level of consumer trust in e-commerce platforms, the trust of customers in the company has steadily increased, and the level of customer loyalty to the company has increased significantly, showing a positive brand image. The user repurchase rate and recommendation enthusiasm have both increased significantly. This phenomenon shows that blockchain technology has a significant effect on improving supply chain efficiency and deepened the trust interaction with consumers.

Table 3 Customer satisfaction and trust improvement

Platform	Customer Satisfaction (Before)	Customer Satisfaction (After)
A	4.2	4.5
B	3.9	4.3
C	4.5	4.7

6. Conclusion

This study explored and implemented the optimization path of the e-commerce supply chain logistics management model based on blockchain technology. The introduction of blockchain technology has significantly improved the transparency, operational efficiency and trust level of the supply chain. After optimization, the efficiency of the logistics system has increased significantly, the time efficiency of order processing and delivery services has been significantly reduced, and the freight cost has been greatly reduced. Customer satisfaction with the service experience and trust in the company have been effectively improved. The implementation of the integrated solution of distributed ledger technology, smart contract mechanism and decentralized identity authentication technology has greatly promoted the traceability of logistics activities and the efficiency of information flow, and significantly optimized the collaborative relationship and automation implementation between various links in the supply chain. In view of the continuous advancement of blockchain technology and the gradual expansion of its application scope, intelligence, transparency and low cost will become the three core trends of the future development of e-commerce supply chain management.

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