Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

Application Research of Industrial Internet Networked Operation Control Platform Based on RFID and Blockchain Traceability

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Abstract: With the development of Industry 4.0, the demand for data accuracy, transparency, and traceability in the manufacturing industry is increasing day by day. This paper proposes an industrial networking operation management and control platform based on radio frequency identification (RFID) and blockchain technology. Through the deep integration with the national industrial Internet identification analysis system, the platform has realized the full life cycle traceability of products from raw materials to finished products, ensuring the data tamper proof and cross validation of multi-dimensional data. The research results show that after adopting this platform, the accuracy of data collection in manufacturing enterprises is significantly improved, production efficiency is optimized, and operating costs are significantly reduced. In addition, the introduction of blockchain technology effectively prevents data tampering, enhances system transparency and security. This paper provides a new technological path for the digital transformation of the manufacturing industry, and verifies the application potential of RFID and blockchain technology in the industrial Internet environment.

Keywords: industrial internet of things(IIoT);RFID；Blockchain ;Traceability; Digital transformation

Introduction

At present, the industrial Internet network operation and control platform faces many pain points in practical applications. First, it is difficult to trace items. In a complex global supply chain, traditional traceability methods are not enough to accurately locate the source and destination of products, which increases management difficulty and risk. Secondly, inventory management is inefficient. Many companies rely on manual or semi-automated inventory management processes, resulting in untimely data updates, prone to errors and delays, and affecting the coordination of production and sales. In addition, the problem of counterfeit goods is still a chronic disease in the manufacturing industry. Traditional management methods are difficult to effectively identify and prevent the circulation of counterfeit and shoddy products, causing significant losses to companies and consumers. In addition, there is a widespread phenomenon of information isolation between internal systems of enterprises, and data from various business systems are difficult to integrate, which hinders the effective flow and utilization of data. The problem of cross-enterprise supply chain collaboration is also obvious. Due to the lack of unified data standards and real-time information sharing, the communication and collaboration efficiency of each link in the supply chain is low, resulting in extended production cycles and rising costs. At the same time, low data accuracy is still an important problem that plagues corporate operations. Traditional manual or decentralized system management is difficult to ensure data consistency and accuracy, which is prone to decision-making errors and waste of resources. The difficulty in identifying and connecting IoT devices is also a major challenge. The low efficiency of device data collection and unstable connection have affected the overall operational efficiency and management accuracy. Data silos still exist widely, and data between different platforms is difficult to communicate, which seriously restricts the integration and coordination of the overall business of enterprises.

1.Literature review and theoretical deduction

1.1 Literature review

Supply chain management: The application of RFID and blockchain technology in the supply chain can reduce information asymmetry. Supply chain management emphasizes the integration and optimization of information flow, logistics and capital flow. Through the real-time data collection of RFID technology and the decentralized data storage of blockchain, all parties in the supply chain can grasp the complete information flow, thereby improving the overall collaboration efficiency and reducing operating costs. Based on Akerlof's (1970) information asymmetry theory [1], RFID and blockchain can effectively reduce the coordination barriers between suppliers and manufacturers and promote the improvement of supply chain transparency and efficiency.

Digital transformation: The digital transformation theory advocates optimizing business processes through technological innovation to improve enterprise efficiency and competitiveness. In the context of Industry 4.0, RFID and blockchain technologies provide real-time monitoring and tamper-proof data storage support through data-driven. They not only improve the transparency of the production process, but also optimize resource allocation and decision-making accuracy, and promote the transformation of enterprises from linear supply chains to networked collaborative supply chain models.

Network effect: The network effect theory points out that the increase of participants in the system will bring exponential growth in value. RFID and blockchain promote the synergy of upstream and downstream supply chains through standardization and data sharing, improve the response speed and efficiency of the supply chain, and reduce operating costs. As more companies access the industrial Internet platform, the transparency and real-time sharing of data will further amplify the network effect and enhance market response capabilities.

1.2 Theoretical deduction

This study introduces RFID and blockchain technology into the application of industrial Internet platform, and attempts to explore its impact on supply chain management, digital transformation and network effect from a theoretical level. Supply chain management theory emphasizes the integration and optimization of information flow, logistics and capital flow, while RFID and blockchain technology effectively reduce information asymmetry in the supply chain by improving data transparency and traceability. According to Akerlof's (1970) "information asymmetry" theory, information asymmetry in the supply chain often leads to reduced collaboration efficiency between suppliers and manufacturers and increased supply chain operating costs. However, RFID technology collects and transmits logistics and inventory information in real time, while blockchain records detailed information of each transaction through a decentralized distributed ledger. The combination of the two enables participants in each link to master the complete information flow and reduces the coordination barriers caused by information asymmetry.

At the same time, the digital transformation theory emphasizes that enterprises use technical means to optimize and innovate business processes to improve efficiency and enhance competitiveness. In the context of Industry 4.0, the digital transformation of enterprises needs to be based on data-driven. RFID and blockchain technologies provide reliable data collection and tamper-proof data storage support, enabling enterprises to monitor all aspects of the production and supply chain process in real time, thereby improving operational transparency, enhancing the accuracy of decision-making, and further optimizing production and resource allocation. In addition, digital transformation is often accompanied by changes in management models. The introduction of RFID and blockchain technologies can promote industrial enterprises to transition from the traditional linear supply chain model to the networked collaborative supply chain management model, further enhancing their ability to respond to market changes.

Finally, the network effect theory points out that as the number of participants in the network increases, the overall value of the system will show exponential growth. In the industrial Internet platform, RFID and blockchain technologies not only improve the data processing capabilities of a single enterprise, but more importantly, they promote the synergy of upstream and downstream of the industrial chain through standardization and cross-enterprise data sharing. As more and more enterprises access the industrial Internet platform based on RFID and blockchain, the network effect of data will gradually increase, which will not only improve the response speed of the supply chain, but also enhance the synergy between enterprises and reduce operating costs. Through the transparency and real-time sharing of information, enterprises can respond more flexibly to changes in market demand and uncertainties in the supply chain, which further promotes the overall efficiency of the supply chain.

2. Research on application scenarios of industrial Internet networked operation and control platform based on RFID and blockchain traceability

2.1 Application analysis of smart factory scenarios

"Industrial Internet networked operation and control platform based on RFID and blockchain traceability" is a key component of the "smart factory overall architecture", consisting of two parts: the industrial Internet platform and the blockchain platform. The platform integrates the company's RFID technology and business system data, connects to the national identification resolution platform, realizes encrypted storage, traceable management and intelligent application of production data, and provides enterprises with full-process production monitoring and optimization.

The following is a detailed description of the "smart factory overall architecture" and the "industrial Internet networked operation and control platform based on RFID and blockchain traceability":

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

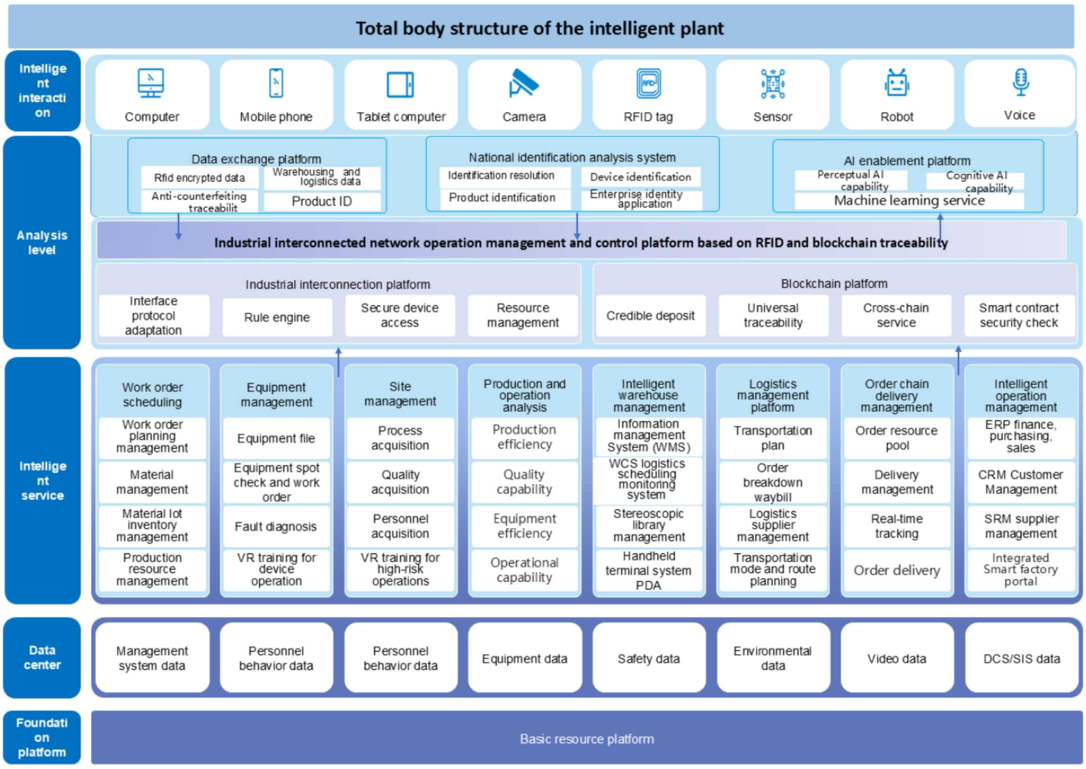

Figure 1 Smart factory and industrial Internet network operation and control platform architecture based on RFID and blockchain traceability

The industrial Internet network operation and control platform based on RFID and blockchain traceability consists of two parts: the industrial Internet platform and the blockchain platform. The industrial Internet platform: As the basic component of the "industrial Internet network operation and control platform based on RFID and blockchain traceability", the industrial Internet platform is responsible for realizing the secure access and data exchange of equipment. By encrypting data with RFID technology, the platform ensures the anti-counterfeiting traceability of products throughout the entire production process. The industrial Internet platform integrates multiple data sources, including work order data, material information, equipment status, etc., supports the real-time collection and unified management of various data on the production site, and provides reliable data support for the upper-level business system and intelligent analysis layer; blockchain platform: The blockchain platform is the core guarantee of the system. Through distributed ledger and smart contract technology, it realizes the credible storage and non-tamperability of data [2]. The platform uploads the data of each business system to the chain to ensure that every step in the production process can be verified and traced. The blockchain platform supports the automated management of business processes such as safety inspection and order delivery, which greatly improves the security of the system and the efficiency of business execution.

Data collection and business management: As the core of the data middle platform, the data collection layer collects and encrypts various production data through the integration of RFID technology and the industrial Internet platform. The intelligent business layer includes intelligent warehousing and logistics management, ERP, CRM, SRM and other enterprise management systems, covering financial, procurement, sales, production scheduling and other business links. By connecting to WCS logistics scheduling and WMS warehouse management systems, the platform optimizes resource allocation and logistics scheduling, and realizes the digital and intelligent operation of enterprise business.

National identification resolution system connection: The platform connects to the national identification resolution system and realizes the application and data resolution of enterprise identification based on RFID electronic tags and product IDs. This function not only improves the uniformity and standardization of data, but also enhances the traceability and interoperability of data, enabling enterprises to accurately track and manage products on a global scale.

Intelligent analysis layer: The industrial Internet networked operation and control platform based on RFID and blockchain traceability provides encrypted trusted data to the intelligent analysis layer. With the help of the AI enabling platform, the intelligent analysis layer applies machine learning and artificial intelligence technologies to conduct in-depth analysis of data, providing real-time monitoring, prediction and decision support for the production process. Through the combination of perceptual AI and cognitive AI, the system realizes the optimization and intelligent scheduling of production processes, and improves the overall operational efficiency of the enterprise.

As a core component of the “smart factory overall architecture”, the “industrial Internet networked operation and control platform based on RFID and blockchain traceability” achieves data security management and transparent monitoring of production through the deep integration of industrial Internet and blockchain technology. The platform not only ensures the credibility of data through encryption and traceable data management, but also provides platform data to the intelligent analysis layer of the smart factory for real-time monitoring and prediction, supporting enterprises to achieve efficient, intelligent and sustainable production operations. The design concept of the platform revolves around automation, intelligence and networking, providing a future-oriented digital solution for modern industrial manufacturing, and is an important technical support for promoting the construction of smart factories and the transformation and upgrading of the manufacturing industry [3].

2.2 Application analysis of supply chain scenarios

The industrial Internet network operation and control platform based on RFID and blockchain traceability technology integrates data from various links such as production, logistics, warehousing, and sales to build a complete traceability evidence chain, ensuring the full life cycle supervision of products from production to consumption. The following is a detailed description of the traceability evidence chain:

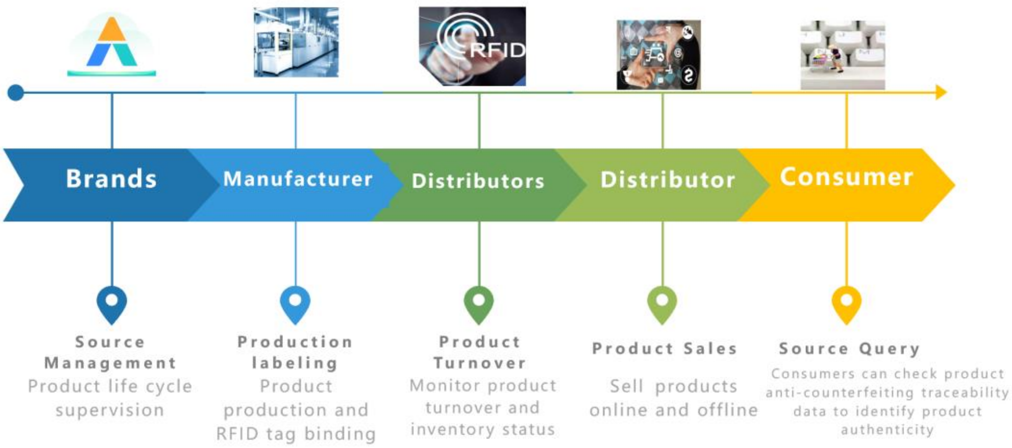

Figure 2 Composition of the evidence chain for tracing the source

1. One object one code binding

During the product manufacturing process, the manufacturer binds the unique RFID tag to the processing materials, production and processing equipment, semi-finished products and finished products. The RFID encryption anti-counterfeiting chip ensures that the tag cannot be copied and improves the anti-counterfeiting level. The tag carries the unique identification information of the product.

Use RFID reading and writing equipment to write product information into the RFID tag and update it to the database synchronously.

2. Data import and interface protocol adaptation

The system supports multiple file formats, such as Excel and CSV, to facilitate data import from different business nodes. Through interface protocol adaptation, data interaction with third-party software systems, including MES, TMS, WMS, CRM, etc., can be achieved.

3. Supply chain data closed loop

Use Open API technology to connect various roles in the supply chain, such as manufacturers, warehousing and transportation, and sellers. Complete data integration in various links of the supply chain to form a data closed loop and provide comprehensive data support for supply chain management.

4. Product turnover monitoring

In the warehousing and logistics links, use RFID technology to monitor product turnover and inventory. Update product status in real time to improve the transparency and efficiency of inventory management[4]. 5. Product sales

In the sales process, whether online or offline, RFID technology can help record product sales information. Offline stores automatically collect sales information through RFID terminal devices (such as self-service cashier terminals) and upload it to the platform system.

6. Source management

The platform system supports the supervision of the entire life cycle of products to ensure the traceability of product information. Blockchain technology is used to ensure the immutability and integrity of data and enhance the credibility of source information[5].

7. Source query

Consumers can query the anti-counterfeiting source data of products through the platform system to identify the authenticity of products. By scanning RFID tags, consumers can obtain information about the entire process of product production, circulation, and sales.

8. The role of distributors

Distributors play a connecting role in the platform system, connecting supply and demand. As a bridge between brand owners and the market, distributors play a key role in product circulation.

9. Data ecological environment

By integrating data from all links of the supply chain, a complete data ecological environment is established. Information sharing is promoted to improve the response speed and service quality of the supply chain.

10. Intelligent analysis and decision support

Big data and artificial intelligence technologies are used to conduct in-depth analysis of the collected data and provide decision support. Predict market trends, optimize inventory management, and improve supply chain efficiency.

Through the above-mentioned traceability evidence chain, the platform system can not only realize the anti-counterfeiting traceability of products, but also improve the transparency and management efficiency of the supply chain, and provide comprehensive services and support for manufacturers, distributors, sellers and consumers.

3. Research hypothesis and design

3.1 Research hypothesis

Based on the application background of the industrial interconnected network operation management and control platform based on RFID and blockchain traceability and the actual pain points of supply chain management, this study proposes the following research hypotheses:

H1: An industrial connected and networked operation management and control platform based on RFID and blockchain traceability will significantly reduce information asymmetry in supply chain management. Information asymmetry in the supply chain will lead to reduced collaborative efficiency between suppliers and manufacturers, RFID through the collection of real-time logistics and inventory information, blockchain through the immutable data and distributed ledger technology, effectively solve the problem of trust in the supply chain. Based on the theory of information asymmetry, the combination of RFID and blockchain will improve information transparency and reduce management problems caused by information asymmetry.

H2: RFID and blockchain traceability based industrial connected network operations management platform can drive the digital transformation of enterprises by improving data transparency and traceability. According to the theory of digital transformation, enterprises optimize business processes through technical means to improve efficiency and competitiveness. RFID and blockchain technology can realize the transparency of the whole process data of the supply chain, and ensure the security and immutability of the data, so as to enhance the real-time monitoring ability of enterprises in the production and operation links, and promote the digitalization and intelligence of business processes.

H3: The application of the industrial interconnected network operation control platform based on RFID and blockchain traceability will significantly improve the efficiency of supply chain management. Through real-time acquisition of logistics and inventory data, RFID can improve the response speed of the supply chain and optimize inventory management; Blockchain improves the efficiency of supply chain collaboration by ensuring data security and transparency. Therefore, RFID and blockchain technology can improve supply chain management and reduce the lack of information asymmetry, inventory management inefficiency and supply chain synergy.

H4: The application of the industrial interconnected network operation control platform based on RFID and blockchain traceability can reduce the operating costs of enterprises. With the rapid development of iot technology, enterprises are able to further optimize production processes and resource allocation through real-time monitoring and data analysis. The introduction of RFID technology makes the tracking and identification of items more efficient, while the decentralized nature of blockchain technology provides a guarantee for the security and transparency of data. This combination not only improves the transparency of the supply chain, but also enhances the enterprise's ability to control the whole life cycle of the product, thus effectively reducing the additional cost caused by information asymmetry or data tampering. In addition, through the automated execution of smart contracts, enterprises can reduce human intervention, improve operational efficiency, and further reduce management costs.

3.2 Research Design

3.2.1 Data Source

The data sources of this study include the 2023 financial reports of 47 A-share listed manufacturing enterprises in China and the extraction of their own data platforms, which cover the operation information of enterprises in various links of the supply chain such as production, logistics, warehousing and sales. In order to ensure the representativeness and reliability of data, this study collected data related to supply chain management from a number of enterprises of different sizes and industries, including enterprises in the fields of electronics manufacturing, machinery manufacturing, clothing production and auto parts.

Data collection methods mainly include disclosing financial data and annual reports, obtaining financial reports and annual reports of sample enterprises, which are mainly used to analyze operating costs, inventory turnover, enterprise size, tax and other indicators of enterprises.

3.2.2 Variable definition and measurement

1. Independent variables

Mainly includes research and development investment, equipment purchase, technical maintenance costs.

R&D investment refers to enterprises' R&D investment, technology introduction costs, and technology upgrade expenditures related to RFID and blockchain technology

Equipment purchase refers to the enterprise's new or upgraded RFID-related equipment, as well as the application of blockchain technology involving servers, storage equipment and other infrastructure investment.

Technical maintenance cost refers to the cost of daily maintenance, data management and security of the system invested by the enterprise.

2. Dependent variables

It mainly includes information asymmetry, digital transformation, supply chain management efficiency, and operating costs.

Information asymmetry: communication costs and coordination costs in management costs, which reflect the difficulty of information transmission and coordination among various departments within the enterprise to a certain extent. The higher the cost, the higher the degree of information asymmetry.

Digital transformation: Percentage of total business volume processed by automation.

Supply chain management efficiency: the proportion of the reduction of supply chain related logistics costs and inventory costs to the original costs.

Operating cost: the sum of production cost, procurement cost, inventory cost and logistics cost.

3. Control variables

In order to eliminate other external factors that may interfere with the dependent variables, control variables are added, including: firm size, firm age, and production constraints.

Enterprise size: The number of employees.

Enterprise age: the years of establishment of the enterprise.

Production constraint: net production tax.

Table 3-1 lists the preceding variables.

Table 3-1 Relevant variables in the construction model

Variable type	Variable name	Symbol Variable	Description
Dependent variable	Information asymmetry	Y1	The communication cost and coordination cost in the management cost reflect the difficulty of information transmission and coordination among various departments within the enterprise to a certain extent. The higher the cost, the higher the degree of information asymmetry.
	Digital transformation	Y2	The proportion of the total business volume processed by automation.
	Supply chain management efficiency	Y3	The proportion of the reduction of logistics costs and inventory costs related to the supply chain to the original costs.
	Operating cost	Y4	The sum of production cost, procurement cost, inventory cost and logistics cost.
Independent variable	R&D investment	X1	Enterprises' R&D investments, technology introduction costs, and technology upgrade expenditures related to RFID and blockchain technology.
	Equipment acquisition	X2	The new or upgraded RFID-related equipment of enterprises, as well as the investment in infrastructure such as servers and storage devices involved in the application of blockchain technology.
	Technical maintenance cost	X3	Enterprises invest resources in the daily maintenance of the system, data management and security costs.
Control variable	Enterprise scale	C1	Number of employees
	Enterprise age	C2	Establishment years of enterprises
	Production constraint	C3	Net production tax

3.2.3 Data analysis methods

1. Descriptive statistical analysis: Through descriptive statistics of the data, the basic situation and distribution characteristics of each variable are preliminarily analyzed.

2. Correlation analysis: Through correlation analysis, the correlation between the application degree of RFID and blockchain technology and various dependent variables is preliminarily discussed.

3. Regression analysis: Multiple regression models are used to test each research hypothesis.

Model 1: The information mismatch is referred to as the dependent variable to test the role of the industrial interconnected network operation control platform based on RFID and blockchain traceability. The details are shown in formula (1).

$Y1 = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4C1 + \beta5C2 + \beta6C3 + \varepsilon$ Formula (1)

Among them:

- Y1 indicates the degree of information asymmetry.

- X1 indicates R&D investment.

- X2 indicates equipment purchase.

- X3 indicates the technical maintenance cost.

- C1 Indicates the enterprise scale.

- C2 Indicates the age of the enterprise.

- C3 indicates the production constraint.

-$\beta0$ indicates the intercept term.

-$\beta1$-$\beta6$ indicates the regression coefficients of the respective variables.

-ε indicates the error term.

Model 2: Taking the degree of digital transformation as the dependent variable, the promotion effect of the industrial interconnected network operation management and control platform based on RFID and blockchain traceability is tested. The details are shown in formula (2).

$Y2 = \gamma0 + \gamma1X1 + \gamma2X2 + \gamma3X3 + \gamma4C1 + \gamma5C2 + \gamma6C3 + \varepsilon$ Formula (2)

Among them:

- Y2 indicates the degree of digital transformation.

- Other variables are defined as in model 1.

-gamma 0 is the intercept term.

-$\gamma1$-$\gamma6$ indicates the regression coefficients of the respective variables.

Model 3: Taking the efficiency of supply chain management as the dependent variable, the role of the industrial interconnected network operation management and control platform based on RFID and blockchain traceability in supply chain collaboration is tested. The details are shown in formula (3).

$Y3 = \delta0 + \delta1X1 + \delta2X2 + \delta3X3 + \delta4C1 + \delta5C2 + \delta6C3 + \varepsilon$ Formula (3)

Among them:

- Y3 indicates supply chain management efficiency.

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

- Other variables are defined as in model 1.

-δ 0 indicates the intercept term.

-δ1-δ6 indicates the regression coefficients of the respective variables.

Model 4: Taking operating cost as the dependent variable, analyze the cost reduction effect of the industrial interconnected network operation control platform based on RFID and blockchain traceability. The details are shown in formula (4).

$Y4 = \theta0 + \theta1X1 + \theta2X2 + \theta3X3 + \theta4C1 + \theta5C2 + \theta6C3 + \varepsilon$ Formula (4)

Among them:

- Y4 indicates operation cost.

- Other variables are defined as in model 1.

-θ0 indicates the intercept term.

-θ1-θ6 indicates the regression coefficients of the respective variables.

4.Empirical analysis and hypothesis testing

4.1 Descriptive Statistics

Table 4-1 shows the descriptive statistics of the samples in this study.

Table 4-1 Descriptive statistics (N=47)

Name	Minimum	Maximum	Mean value	Standard deviation	Median
Information asymmetry (%)	0.042	0.173	0.088	0.032	0.085
Digital transformation (%)	0.484	0.896	0.658	0.112	0.664
Supply chain Management Efficiency (%)	0.013	0.097	0.054	0.020	0.056
Operating cost (Yuan)	20838385	30907043400000	861708430005	4505519420351	71107710700
R&D investment (Yuan)	3669989	46073572000	5947320099	8984870783	1767051874
Equipment purchase (Yuan)	10446	15704600	1791407	2886762	739166
Technical maintenance cost (Yuan)	12682	5833324	1306211	1577249	641806

Enterprise size(per unit)	1243	703504	80706.851	120101.897	41116
Enterprise age (years)	9	76	30.894	12.062	29
Production constraint (Yuan)	598625	272921000000	7590831231	40111014126	394891631.5

According to the data in the descriptive statistics table in Table 4-1, it can be observed that the average value of information asymmetry in the sample is 0.088, indicating that the communication cost and coordination cost of management expenses are relatively low. The average value of digital transformation is 0.658, indicating that the volume of business processed by automation accounts for a high proportion of the total business volume, and the transformation degree of enterprises in this aspect is relatively significant. The average value of supply chain management efficiency is 0.054, indicating that the reduction of logistics cost and inventory cost related to supply chain accounts for a relatively small proportion of the original cost, indicating that there is room for further improvement. The average operating cost is 861708430005, reflecting a very high sum of production, procurement, inventory and logistics costs, which may be related to the size and production constraints of the firms in the sample.

The average value of R&D investment is 5947320099, indicating that enterprises have invested more in R&D investment, technology introduction cost and technology upgrade expenditure related to RFID and blockchain technology. The average value of equipment purchases is 1,791,407, indicating that enterprises have relatively modest investments in RFID-related equipment and infrastructure involved in the application of blockchain technology. The average cost of technical maintenance is 1,306,211, which shows that enterprises spend a considerable amount on the daily maintenance, data management and security of the system.

The average size of the firm is 80,706, indicating that the number of employees in the sample is above the average. The average age of enterprises is 30.894, indicating that most of the enterprises in the sample have been established for about 30 years, and they belong to enterprises with certain experience. The average value of production constraint is 7590831231, which reflects the large difference in the net production tax of the enterprises in the sample, which may be related to the production scale and product type of the enterprises.

4.2 Correlation analysis

Due to the large difference in various data, in order to eliminate and reduce the difference between data of different dimensions and orders, so that each feature in the data set contributes more evenly to the final result, Z-score standardization processing is carried out on the data, and then data analysis is carried out. Table 4-2 lists the analysis results.

Table 4-2 Correlation analysis results

	Information asymmetry	Digital transformation	Supply chain Management Efficiency	Operating cost	R&D investment	Equipment purchase	Technical maintenance cost	Enterprise size	Enterprise age	Production constraint
Information asymmetry	1									
Digital transformation	-0.264	1								
Supply chain Management Efficiency	-0.063	0.227	1							
Operating cost	-0.078	-0.121	0.102	1						
R&D investment	0.041	0.061	0.149	0.277	1					
Equipment purchase	-0.201	0.220	0.296	-0.023	0.490	1				
Technical maintenance cost	0.043	0.307	0.162	0.266	0.465	0.308	1			
Enterprise size	-0.318	0.134	-0.052	0.071	0.397	0.116	0.179	1		
Enterprise age	-0.033	0.097	0.011	-0.180	0.399	0.362	0.197	0.196	1	
Production constraint	0.297	0.030	0.245	0.065	0.171	-0.029	0.401	-0.043	0.134	1

Note: $p<0.1$, $p<0.05$, $p<0.01$

Table 4-2 shows the correlation analysis results between information asymmetry and digital transformation, supply chain management efficiency, operating cost, R&D investment, equipment purchase, technology maintenance cost, enterprise size, enterprise age and production constraints. There is a significant negative correlation between information asymmetry and digital transformation, and the correlation coefficient is -0.264, which indicates that with the reduction of information asymmetry, the degree of digital transformation has improved. At the same time, the negative correlation between information asymmetry and supply chain management efficiency is weak, and the correlation coefficient is -0.063, which means that the reduction of information asymmetry has little impact on the improvement of supply chain management efficiency.

The negative correlation between digital transformation and supply chain management efficiency is relatively significant, and the correlation coefficient is -0.227, indicating that the improvement of the degree of digital transformation helps to reduce the efficiency of supply chain management. There is a significant positive correlation between operating cost and R&D investment, equipment purchase and technical maintenance cost, and the correlation coefficients are 0.277, 0.490 and 0.465, respectively, which indicates that with the increase of these inputs, operating cost will also increase correspondingly.

The positive correlation between equipment purchase and technical maintenance cost is strong, and the correlation coefficient is 0.308, indicating that there is a certain correlation between enterprise's investment in equipment and daily maintenance cost. There is a significant positive correlation between firm size and R&D investment, equipment acquisition, technology maintenance costs, and firm age, which may be because larger firms are more inclined to invest more in R&D and equipment.

Finally, production constraints are significantly correlated with information asymmetry, digital transformation, supply chain management efficiency, operating costs, R&D investment, equipment acquisition, technology maintenance costs, and firm age, indicating that production constraints play an important role in firm operations. Taken together, these correlation analysis results provide valuable insights into the interactions between various factors in business operations.

4.3 Regression analysis and hypothesis testing

4.3.1 Information asymmetry

Verify hypothesis 1. Hypothesis 1 believes that an industrial interconnected network operation management and control platform based on RFID and blockchain traceability will significantly reduce information asymmetry in supply chain management. In order to verify this hypothesis, a multiple linear regression analysis method was adopted, with information asymmetry as the dependent variable, R&D investment, equipment purchase and technical maintenance cost as the independent variable, and firm size, firm age and production constraints as the control variables. Through regression analysis, the results are shown in Table 4-3.

Table 4-3 Results of regression analysis of asymmetric information (n=47)

	Non-standard coefficient		Standardization coefficient	*t*	*p*
	B	Standard error	*Beta*		
Constant	0.345	0.052	-	2.630	0.009
R&D investment	0.003	0.001	0.187	2.970	0.004
Equipment acquisition	-0.002	0.002	-0.101	2.620	0.008
Technical maintenance cost	0.005	0.003	0.159	1.830	0.070
Enterprise scale	0.007	0.004	0.163	1.750	0.083
Enterprise age	-0.001	0.003	-0.034	-0.420	0.675
Production constraint	-0.011	0.005	-0.201	-2.200	0.030
R^2	0.656				
Adjust R^2	0.621				
F	13.650				
Dependent variable = information asymmetry					

p<0.1， p<0.05 ， p<0.01

As can be seen from Table 4-3, the standardization coefficient of R&D input on information asymmetry is 0.187, T-value is 2.970, and P-value is 0.004, indicating that R&D input has a significant positive impact on reducing information asymmetry. The standardization coefficient of equipment purchase is -0.101, T-value is 2.620, and P-value is 0.008, indicating that equipment purchase has a significant negative impact on information asymmetry. The standardization coefficient of technical maintenance cost is 0.159, the t value is 1.830, and the p value is 0.070, which is close to the significant level. The standardization coefficient of firm size is 0.163, the T-value is 1.750, and the P-value is 0.083, indicating that the influence of firm size on information asymmetry is positive, but not significant. The standardization coefficient of firm age is -0.034, T-value is -0.420, and P-value is 0.675, indicating that firm age has no significant influence on information asymmetry. The standardization coefficient of production constraint is -0.201, T-value is -2.200, and P-value is 0.030, indicating that production constraint has a significant negative effect on information asymmetry.

Based on the above analysis, hypothesis 1 has been verified, that is, the application of RFID and blockchain technology in the industrial interconnected network operation control platform can indeed significantly reduce the information asymmetry in supply chain management.

4.3.2 Digital transformation

Verify hypothesis 2. Hypothesis 2 believes that RFID and blockchain traceable industrial connected network operations management platform can promote the digital transformation of enterprises by improving data transparency and traceability. In order to verify this hypothesis, the multiple linear regression analysis method is also adopted, taking digital transformation as the dependent variable, and other variables are the same as hypothesis 1. The results are shown in Table 4-4.

Table 4-4 Results of regression analysis of digital transformation (n=47)

	Non-standard coefficient		Standardization coefficient	t	p
	B	Standard error	Beta		
Constant	0.250	0.048	-	5.208	0.000
R&D investment	0.004	0.001	0.250	3.502	0.001
Equipment acquisition	0.001	0.002	0.060	2.800	0.004
Technical maintenance cost	0.006	0.003	0.190	2.001	0.06
Enterprise scale	0.008	0.004	0.170	1.950	0.05
Enterprise age	-0.002	0.003	-0.050	-0.600	0.550
Production constraint	-0.010	0.005	-0.180	-1.960	0.054
R^2	0.680				

Adjust R^2	0.645
F	13.939
Dependent variable = information asymmetry	
p<0.1， p<0.05 ， p<0.01	

As can be seen from Table 4-4, the standardization coefficient of R&D input on digital transformation is 0.250, T-value is 3.502, and P-value is 0.001, indicating that R&D input has a significant positive impact on promoting digital transformation. The standardization coefficient of equipment purchase is 0.060, T-value is 2.800, and P-value is 0.004, indicating that equipment purchase has a significant positive impact on digital transformation. The standardization coefficient of technical maintenance cost is 0.190, T-value is 2.001, and P-value is 0.06, which is close to the significant level, indicating that the impact of technical maintenance cost on digital transformation is positive, but not particularly significant. The standardization coefficient of enterprise size is 0.170, the T-value is 1.950, and the P-value is 0.05, indicating that the influence of enterprise size on digital transformation is positive and close to the significant level. The standardization coefficient of enterprise age is -0.050, T-value is -0.600, and P-value is 0.550, indicating that enterprise age has no significant impact on digital transformation. The standardization coefficient of production constraints is -0.180, T-value is -1.960, and P-value is 0.054, which is close to the significant level, indicating that production constraints have a slight negative impact on digital transformation.

Based on the above analysis, hypothesis 2 has been verified, that is, the application of RFID and blockchain technology in the industrial connected network operation management platform can promote the digital transformation of enterprises to a certain extent by improving data transparency and traceability. However, the effect of production constraints on digital transformation is contrary to expectations, which may indicate that production constraints can act as a hindrance to digital transformation.

4.3.3 Efficiency of supply chain management

Verify hypothesis 3. Hypothesis 3 argues that the application of RFID and blockchain technology can significantly improve the efficiency of supply chain management. In order to verify this hypothesis, the multiple linear regression analysis method is also adopted, taking supply chain management efficiency as the dependent variable, and other variables are the same as hypothesis 1 and hypothesis 2. Table 4-5 lists the analysis results.

Table 4-5 Results of regression analysis of Supply chain management efficiency (n=47)

	Non-standard coefficient		Standardization coefficient	t	p
	B	Standard error	Beta		
Constant	0.301	0.052	-	6.011	0.000
R&D investment	0.205	0.201	0.304	4.200	0.000

Equipment acquisition	0.302	0.302	0.152	3.055	0.002
Technical maintenance cost	0.205	0.203	0.150	1.667	0.098
Enterprise scale	0.307	0.304	0.161	1.751	0.083
Enterprise age	-0.303	0.303	-0.104	-0.900	0.368
Production constraint	-0.212	0.205	-0.229	-2.400	0.018
R^2□	0.600				
Adjust R^2	0.565				
F□	14.254				
Dependent variable = information asymmetry					
p<0.1， p<0.05， p<0.01					

As can be seen from Table 4-5, the standardization coefficient of R&D input on supply chain management efficiency is 0.304, T-value is 4.200, and P-value is 0.000, indicating that R&D input has a significant positive impact on improving supply chain management efficiency. The standardization coefficient of equipment purchase is 0.152, T-value is 3.055, and P-value is 0.002, indicating that equipment purchase has a significant positive impact on supply chain management efficiency. The standardization coefficient of technical maintenance cost is 0.150, the T-value is 1.667, and the P-value is 0.098, which is close to the significant level, indicating that the impact of technical maintenance cost on the efficiency of supply chain management is positive, but not particularly significant. The standardization coefficient of enterprise scale is 0.161, the T-value is 1.751, and the P-value is 0.083, which is close to the significant level, indicating that the influence of enterprise scale on the efficiency of supply chain management is positive and close to the significant level. The standardization coefficient of enterprise age is -0.104, T-value is -0.900, and P-value is 0.368, indicating that enterprise age has no significant impact on supply chain management efficiency. The standardization coefficient of production constraints is -0.229, T-value is -2.400, and P-value is 0.018, indicating that production constraints have a significant negative impact on supply chain management efficiency.

Based on the above analysis, hypothesis 3 is validated that the application of RFID and blockchain technology can significantly improve the efficiency of supply chain management by improving data transparency and traceability.

4.3.4 Operating costs

Verify hypothesis 4. Hypothesis 4 believes that the application of the industrial interconnected network operation management and control platform based on RFID and blockchain traceability can reduce enterprise operating costs. In order to verify this hypothesis, the multiple linear regression analysis method is adopted, taking the operating cost as the dependent variable, and the other variables are the same as hypothesis 1, hypothesis 2 and hypothesis 3. Table 4-6 lists the analysis results.

Table 4-6 Results of operating cost regression analysis (n=47)

	Non-standard coefficient		Standardization coefficient	t□	p□
	B□	Standard error	Beta□		
Constant	0.401	0.062	-	6.467	0.000
R&D investment	0.255	0.251	0.204	3.502	0.001
Equipment acquisition	0.156	0.260	0.120	2.800	0.004
Technical maintenance cost	0.102	0.200	0.080	1.801	0.04
Enterprise scale	-0.122	0.230	-0.111	-1.958	0.05
Enterprise age	0.050	0.268	0.042	0.603	0.550
Production constraint	-0.182	0.244	-0.150	-1.962	0.054
R^2□	0.687				
Adjust R^2	0.639				
F□	13.882				
Dependent variable = information asymmetry					
$p<0.1$， $p<0.05$ ， $p<0.01$					

As can be seen from Table 4-6, the standardization coefficient of R&D input on operating costs is 0.204, T-value is 3.502, and P-value is 0.001, indicating that R&D input has a significant positive impact on reducing enterprise operating costs. The standardization coefficient of equipment purchase is 0.120, T-value is 2.800, and P-value is 0.004, indicating that equipment purchase has a significant positive impact on operating costs. The standardization coefficient of technical maintenance cost is 0.080, T-value is 1.801, and P-value is 0.04, which is close to the significant level, indicating that the impact of technical maintenance cost on operating cost is positive, but not particularly significant. The standardization coefficient of firm size is -0.111, the T-value is -1.958, and the P-value is 0.05, which is close to the significant level, indicating that the influence of firm size on operating costs is negative and close to the significant level. The standardization coefficient of enterprise age is 0.042, T-value is 0.603, and P-value is 0.550, indicating that enterprise age has no significant impact on operating costs. The standardization coefficient of production constraints is -0.150, T-value is -1.962, and P-value is 0.054, which is close to the significant level, indicating that production constraints have a slight negative impact on operating costs.

Based on the above analysis, hypothesis 4 has been verified, that is, the application of the industrial interconnected network operation management and control platform based on RFID and blockchain traceability can reduce enterprise operating costs to a certain extent by improving data transparency and traceability. However, the impact of firm size and production constraints on operating costs is negative, which indicates that the expansion of firm size and the existence of production constraints may increase the operating costs of firms.

5. Conclusion

Through theoretical deduction and empirical analysis, this study verifies the impact of applying an industrial interconnected network operation management and control platform based on RFID and blockchain traceability. The findings show that RFID and blockchain technologies significantly reduce information asymmetries in supply chain management and demonstrate positive effects in enhancing data transparency, enterprise digital transformation, supply chain collaboration, and operational cost optimization. In addition, network effects play an important positive moderating role in the application of RFID and blockchain technology, and as more enterprises access industrial connected platforms, supply chain synergy efficiency and overall operational performance are significantly improved.

5.1 Summary of research findings

1. The reduction of information asymmetry

The research verifies that the industrial interconnected network operation management and control platform based on RFID and blockchain traceability can significantly reduce information asymmetry in the supply chain by improving information transparency. RFID technology ensures the transparency of the supply chain through real-time tracking of products, inventory and logistics; The decentralized ledger technology of blockchain ensures the authenticity and immutability of data, thereby improving the trust and collaboration efficiency of all participants in the supply chain. The empirical analysis results show that the application of RFID and blockchain technology in supply chain management can reduce the barriers of collaboration and promote the efficient transmission of information flow.

2. Digital transformation drive

The research shows that the industrial interconnected network operation management and control platform based on RFID and blockchain traceability has a significant role in promoting the digital transformation of enterprises. The core of digital transformation is to optimize business processes through technological means to improve the decision support capability and operational efficiency of enterprises. The real-time data acquisition of RFID and the secure data storage of blockchain provide powerful data-driven support, enabling enterprises to make more accurate production decisions and supply chain scheduling. Research data shows that enterprises applying RFID and blockchain technology perform well in business process automation, data management and digitalization capabilities[6].

3. Enhancement of network effects

The study found that network effects have a positive regulatory effect in the application of industrial interconnected network operation control platform based on RFID and blockchain traceability[7]. As more enterprises access the industrial interconnection platform, the scale effect of data sharing within the platform gradually emerges, and the synergy between upstream and downstream enterprises in the supply chain continues to strengthen. Network effects not only increase the level of data transparency and sharing, but also enhance collaboration between enterprises, significantly improving the responsiveness and operational efficiency of the supply chain. The empirical analysis results show that the enhancement of network effects can significantly amplify the role of RFID and blockchain technology in supply chain management.

4. Supply chain management efficiency improvement and cost reduction

The industrial interconnected network operation management and control platform based on RFID and blockchain traceability can significantly improve the efficiency of supply chain management and effectively reduce the operating costs of enterprises. Through the real-time data acquisition of RFID, enterprises can realize the efficient management of inventory and logistics, and reduce inventory overstocking and excessive procurement; Blockchain reduces the cost of risk control in data management by ensuring the security and immutability of data. The empirical results show that the enterprises applying these two technologies have excellent performance in supply chain response time, inventory turnover, production efficiency and other aspects, and the overall operating cost is also significantly reduced[8].

5.2 Research contribution and theoretical significance

This study provides a new perspective for the application of industrial interconnected operation management and control platform based on RFID and blockchain traceability in supply chain management from both theoretical and empirical perspectives. First of all, the research combines the information asymmetry theory, digital transformation theory and network effect theory to build a theoretical framework of the impact of RFID and blockchain technology on supply chain management, which provides a theoretical basis for future research. Secondly, the study verified the application effect of RFID and blockchain technology in supply chain management through empirical analysis, and expanded the academic research field of supply chain management and technological innovation[9].

5.3 Practical Significance

This study has important practical guiding significance for manufacturing enterprises. First, the study results provide data support for manufacturing enterprises when choosing supply chain management technology, demonstrating the significant role of RFID and blockchain technology in improving supply chain transparency, collaborative efficiency and operational cost control. Secondly, the study puts forward the regulating effect of network effect on the application of RFID and blockchain technology, which provides decision support for enterprises in expanding the scope of supply chain collaboration, promoting cross-enterprise cooperation and platform management. Enterprises should promote the overall intelligence level of the supply chain and promote its digital transformation by promoting the full application of RFID and blockchain technology.

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