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Symbiotic Development System of Reverse Logistics and Forward Logistics in Rural Guangxi Based on Blockchain under the Background of Rural Revitalization

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Abstract: The rural revitalization strategy in Guangxi, China, underscores the significance of a robust rural logistics system for economic growth and agricultural product competitiveness. This paper addresses the critical issue of uneven benefit distribution within the integrated reverse and forward logistics system in rural Guangxi. It explores the transformative potential of blockchain technology in rectifying these disparities and enhancing overall logistics efficiency. By leveraging blockchain's distributed ledger and smart contract capabilities, the research proposes a transparent and automated logistics ecosystem that fosters trust and efficiency. The integration of Internet of Things (IoT) technology further optimizes the logistics process through real-time data collection and monitoring. The study's findings indicate that blockchain technology significantly improves logistics timeliness, with the on-time order completion rate increasing from 90.74% to 96.47%. Moreover, the application of blockchain technology is evaluated using the Shapley value method, demonstrating its efficacy in promoting equitable benefit distribution among stakeholders. This paper contributes to the discourse on rural development by highlighting the socio-economic benefits of blockchain technology in enhancing rural logistics and supporting the broader goals of rural revitalization.

1. Introduction

Driven by China's rural revitalization strategy, rural areas in Guangxi are entering a critical period of economic transformation and upgrading. As a bridge connecting agricultural production and market consumption, the efficiency and effectiveness of the rural logistics system are directly related to the market competitiveness of agricultural products and the economic well-being of farmers. However, the current rural logistics system in Guangxi is facing the dual challenges of unbalanced benefit distribution and low logistics distribution efficiency. The inefficiency of reverse logistics leads to waste of resources, while the poor forward logistics affects the timely sales of agricultural products. The existence of these problems has seriously restricted the healthy development of the rural economy. Therefore, exploring a new technical solution that can effectively integrate reverse logistics and forward logistics and improve overall logistics efficiency is of great practical significance for promoting rural revitalization in Guangxi and even the whole country.

In order to provide a theoretical basis for the implementation of the Central Document No. 1, which proposed "using modern scientific and technological means to innovate new paths for rural logistics development", the research team visited rural e-commerce and logistics leading enterprises and found that in addition to the backward construction of logistics infrastructure and insufficient logistics talent support, all enterprises are facing two major difficulties in their development: one is that it is difficult and expensive for enterprises to obtain financing, which needs to be solved urgently. Since rural e-commerce enterprises started late and have not yet formed a relatively mature market model and systematic industry norms, the scale of enterprises is uneven, and the low industry entry threshold has further aggravated this situation. Some self-employed households can engage in rural logistics by buying a transport vehicle. Due to the uneven quality of the business, it is very difficult to seek financial support from banks and other financial institutions. The second is the difficulty in establishing a brand, and mutual trust between supply and demand has become a problem that needs to be solved urgently. On the one hand, due to the non-standard nature of agricultural products, if a certain type of agricultural products is sought after by consumers, other businesses will soon launch similar products to imitate or even engage in vicious competition, and finally there will even be a phenomenon of bad money driving out good money, which greatly weakens the motivation of enterprises to build high-quality brands; on the other hand, in recent years, food safety issues have occurred frequently, and issues such as pesticide residues and whether they are truly green and pollution-free have become the primary concerns of consumers. The trust issue between supply and demand has become a major obstacle to the development of rural e-commerce companies. This article will focus on the application of blockchain technology in Guangxi's rural logistics system and explore its potential and practical path in solving the above problems.

The main contribution of this paper is to propose a construction plan for the symbiotic development system of reverse logistics and forward logistics in rural Guangxi based on blockchain technology. Through the distributed storage and smart contract technology of blockchain, this paper aims to achieve transparent sharing of logistics information, automatic execution of contract terms, and optimization of logistics distribution process. These technological solutions can not only solve the problem of uneven distribution of benefits, but also significantly improve the efficiency and transparency of logistics and distribution. The innovation of this paper lies in combining blockchain technology with IoT technology to achieve real-time information collection and monitoring of items, equipment, and vehicles in the logistics distribution process, as well as integrating rural logistics resources through blockchain to build an efficient logistics support system.

The structure of the paper is as follows: first, the research background and current status are introduced, and the necessity and urgency of the research are clarified; secondly, the application framework and implementation plan of blockchain technology in Guangxi’s rural logistics system are elaborated in detail; then, how this technical solution solves existing problems is analyzed, and its potential impact on the rural revitalization strategy is explored; finally, the full paper is summarized and future research directions are proposed.

2. Related Works

Under the background of rural revitalization strategy, the symbiotic development system of reverse logistics and forward logistics in rural Guangxi is crucial to improving regional economy and achieving sustainable development. Hennequin[1] studied the production policy based on hierarchical inventory through the IPA method, providing a new perspective on reverse logistics and industrial symbiosis. Shamsuddoha et al.[2] used system dynamics to conduct a case study on the reverse logistics cycle in the poultry supply chain, emphasizing the importance of environmental sustainability. Rajput and Singh[3] proposed an Industry 4.0 model for integrating the circular economy and reverse logistics networks. Mishra et al.[4] explored the implementation and realization of reverse logistics and closed-loop supply chains in the circular economy through a systematic literature review, covering different concepts such as cost savings, network design, sustainable reverse logistics, waste management, and extended producer responsibility. Shahidzadeh and Shokouhyar[5] used social media analysis to reveal the application of real-time decision support systems in reverse logistics resource recovery. Wahab et al.[6] compared the cross-border reverse logistics of fast fashion brands in China. Xu and He[7] reviewed the application of blockchain in modern logistics information sharing and conducted a case study analysis. Liu et al.[8] proposed a new method for privacy protection of logistics data based on blockchain. Nanda et al.[9] integrated blockchain and IoT into the medical supply chain to track the logistics of medical products. Fu et al.[10] proposed a blockchain-based supply chain finance solution for logistics companies. These studies used different methods, including case studies, system dynamics, and model building, and the results showed that reverse logistics plays an important role in improving resource efficiency and environmental sustainability.

At present, scholars' research on the synergy and symbiotic development of rural reverse logistics and forward logistics is basically focused on the synergistic development model of the two under the circular economy, while the construction and feasibility of the specific mutually beneficial symbiotic model for the value chain of the two are slightly insufficient, and there is no substantial discussion on how to construct the mutually beneficial symbiotic model of the two. Therefore, it has not been able to effectively solve the problems of information security and sharing, efficient flow of resources, etc. faced by the development of reverse logistics and forward logistics. The introduction of blockchain technology can just fill the gap of the symbiotic system and complement the symbiotic system. Therefore, based on the perspective of blockchain technology characteristics, combined with the composition of the value chain of reverse logistics and forward logistics, the construction of the symbiotic development system of the two is explored and analyzed. To this end, this paper first sorts out and analyzes the relevant theoretical research results of blockchain technology, reverse logistics, forward logistics and symbiotic concepts at home and abroad, and then proposes to reconstruct the value chain between reverse logistics and forward logistics, and analyzes the basic composition of the value chain, the structural integration of the system to resources, etc. in detail, and analyzes the feasibility of the reconstruction of the value chain of the symbiotic system through the agglomeration effect of shared resources. Through the self-organization of the organizational space where the two are located and the two-sided analysis of the symbiotic system, the sustainable development of the symbiotic system is guaranteed. Then the compatibility of the introduction of blockchain technology into the reverse logistics and forward logistics value chains is analyzed.

3. Methods

3.1 Data Collection

In rural areas of Guangxi, this paper will take a series of detailed and specific measures to collect data to ensure the comprehensiveness and accuracy of the research. First, on-site inspections will be conducted at logistics distribution centers and village-level express logistics integrated service stations to gain an in-depth understanding of their operating conditions and existing problems. These inspections will include a detailed analysis of the operating efficiency, service coverage, and challenges faced by county-level logistics distribution centers, township express logistics transfer stations, and village-level express logistics integrated service stations. Secondly, through in-depth interviews, we will collect opinions and feedback from logistics company managers, farmers, experts and scholars to obtain first-hand qualitative data. The interviews will explore their views on the current logistics system, their understanding and needs of blockchain technology, and their evaluation of logistics efficiency and service quality.

In addition, a questionnaire survey will be designed and implemented, including rural logistics practitioners, farmers, consumers, etc., to collect their satisfaction with the current logistics system, their understanding and demand for blockchain technology, and their evaluation of logistics efficiency and service quality. The questionnaire will cover a wide range of participants to ensure the representativeness and diversity of the data. At the same time, we collect data on the application of IoT technology in logistics and distribution, including the application of RFID tags, vehicle positioning and real-time monitoring, and distribution route optimization, so as to evaluate the impact of IoT technology on improving logistics and distribution efficiency. Especially in the field of warehousing and logistics, RFID technology can realize the rapid and accurate identification of goods, effectively improving the efficiency of warehousing and logistics.

We will focus on the application of Internet of Things technology in the distribution process, including that after the staff enters the waybill into the transportation scheduling system, the system will generate the best scheduling route and optimize the vehicle loading. The system will calculate the time for the goods to arrive at the delivery location based on the final selected delivery plan, and notify the consignee in advance to receive the goods. When the delivery vehicle leaves the distribution center, the staff uses the reader to read the RFID tag information of all the goods on the vehicle, upload and update the delivery information, determine the location of the delivery vehicle through the on-board receiver, and transmit the location and other information to the dispatch center through the on-board communication system [11-12].

3.2 System Dynamics Model

As rural settlements are generally dispersed and cross-regional, it is proposed to establish a multi-center, multi-level rural logistics network system consisting of two subsystems, forward logistics and reverse logistics, to achieve cross-regional coordination of rural logistics operations and better and more rational use of logistics resources from all parties. In this paper, the construction of the system dynamics model aims to deeply understand and analyze the dynamic changes and complexity of the symbiotic development system of reverse logistics and forward logistics in rural Guangxi. The model is based on feedback control theory and reveals the evolution of system behavior over time by simulating the interaction between stocks, flows, and feedback loops [13]. The stock represents the measure of the system state at a certain moment, while the flow represents the rate at which the stock changes over time. This can be expressed by the following basic formula:

$$\frac{dS}{dt} = I - O \tag{1}$$

Among them, S represents stock, I represents inflow, O represents outflow, and t represents time. The feedback loop in system dynamics describes the cause-effect chain in the system. The dynamics of the feedback loop can be expressed by the following formula:

$$\frac{dS}{dt} = k(R - S) \tag{2}$$

Among them, k is the feedback constant, R is the reference value or target stock, and S is the actual stock. The construction process of the model first determines the research object and boundaries, clarifies the symbiotic system of reverse logistics and forward logistics in rural Guangxi, and defines the boundaries and elements of the system. Next, the system structure diagram is drawn, including the various elements of the system and the relationships between them, usually represented in the form of flow charts, block diagrams, etc. On this basis, the variables and parameters of the system are determined. Variables describe the factors of system status and behavior, including logistics efficiency, cost, service quality, etc., while parameters are constants or functions that affect the dynamic changes of the system, including market demand growth rate, technological progress rate, etc. The impact of technological progress on logistics efficiency can be expressed by the following formula:

$$T = T_0 e^{rt} \tag{3}$$

Among them, T represents the technology level at time t, T_0 represents the initial technology level, r represents the technology advancement rate, and t represents time. Subsequently, according to the system structure diagram and the determined variables and parameters, a dynamic equation is established to describe the interaction and change law between the various variables in the system, which is usually expressed in the form of differential equations or difference equations. In order to simulate the dynamic change process of the system, it is necessary to determine the initial conditions and boundary conditions. The initial conditions are the state of the system at the initial point in time, and the boundary conditions are the interaction conditions between the system and the external environment. After the model is established, it is verified and revised through comparison with historical data, expert review, etc. to ensure the accuracy and reliability of the model. After that, the model is run through computer simulation to observe the behavior of the system evolving over time, and the effects of different strategies are evaluated by changing parameters and scenarios. Finally, the research results are presented in a visual form to facilitate stakeholders' understanding and decision-making, and provide decision-making support for the optimization of the logistics system in the context of rural revitalization.

This paper builds a multi-center and multi-level rural logistics information network. In this study, production logistics and household logistics with opposite directions but overlapping routes are combined to form a two-way logistics network, a reverse logistics system of recycling and waste logistics, and a composite rural logistics system with e-commerce logistics service platform. The three subsystems in the system share information with each other through computer network technology, so as to effectively coordinate resources and avoid the waste of logistics resources. Through the construction of this system, the physical structure should be composite, so that the urban and rural logistics systems can be effectively connected, and the coordinated development of urban and rural economies can be further promoted.

Based on this "circular logistics system", it is proposed to establish logistics centers in towns with good economic conditions, concentrated sources of goods, and convenient transportation, connecting to large-scale county-level logistics distribution centers, and connecting to village-level logistics stations, while taking into account the radiation of other towns with fewer surrounding enterprises and immature conditions, so as to achieve blind spot coverage of township-level logistics centers in different regions. For the construction of village-level logistics stations, according to their geographical distribution and traffic conditions, logistics distribution stations are established in villages with important traffic locations, and logistics transfer stations are established in villages that are not transportation hubs to carry out services such as receiving and sending. This paper studies how to realize the effective connection from logistics center to large hub and then to small and micro transit nodes in the network system to form a multi-center and multi-level physical structure. In order to build a theoretical framework for the subsequent research, the co-development system of reverse logistics and forward logistics in rural Guangxi is taken as an example.

3.3 Product Information Traceability Model and Information Anti-counterfeiting and Supervision Model

Based on blockchain technology, the model and strategy of the symbiotic development system of rural reverse logistics and forward logistics are studied, and a product information traceability model and information anti-counterfeiting and supervision model based on blockchain are constructed. The construction idea is shown in Figure 1.

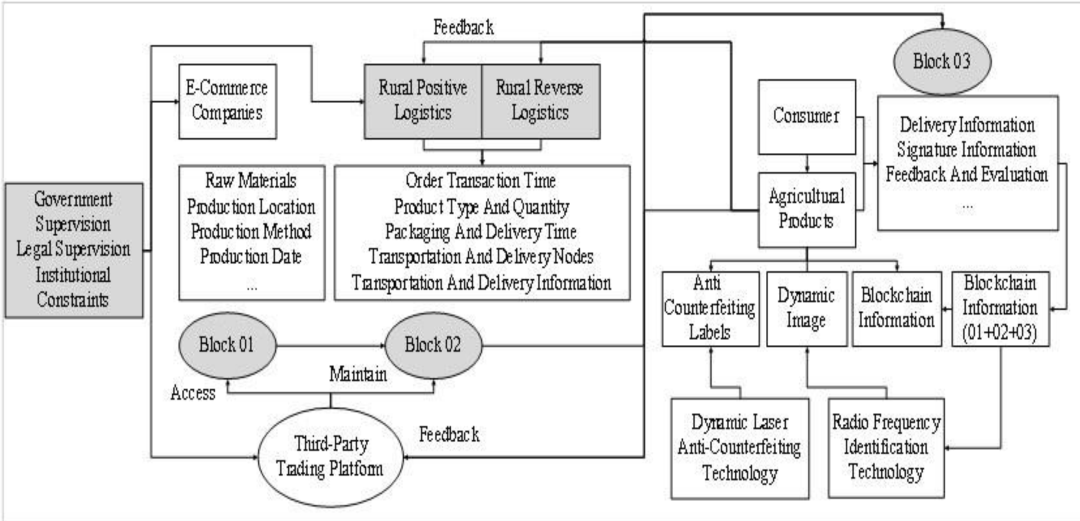

Figure 1: Blockchain-based product information traceability model and information anti-counterfeiting and supervision model construction ideas

The blockchain-based product information traceability model and information anti-counterfeiting and supervision model construction ideas aim to improve the transparency and security of the entire supply chain of agricultural products from production to consumption by integrating advanced information technology. The model uses the tamper-proof characteristics of blockchain to create a unique digital identity for each product and record the information of each key node in its entire life cycle, including production, processing, transportation, and sales. In addition, the model also covers the development model of rural reverse logistics, the design of information systems, and a comprehensive performance evaluation model based on a green indicator system, providing a comprehensive and systematic evaluation and improvement method for the rural logistics system. [14-15].

3.4 Construction of an Aural Logistics Network System with Both Production and Life as the Core

With the vigorous promotion of the national "rural revitalization" strategy, the improvement of rural economy and people's living standards, and the increase in demand for production and living materials, rural logistics volume continues to increase. This paper proposes to build a dual-positive rural logistics system for production and life based on a dual-positive logistics network to simultaneously realize the transportation of production and living materials from cities to rural areas, and agricultural products from rural areas to cities. These two logistics modes, which are in opposite directions but overlap in paths, serve farmers' production and life, effectively reduce the empty load rate of vehicles, improve the efficiency of rural logistics operations, and save and reasonably allocate logistics resources.

In terms of implementation strategy, DLT technology will support the establishment of a rural logistics information service platform for the entire region, integrating the information systems of postal, supply and marketing, logistics, express delivery, agricultural materials and agricultural products distribution and other enterprises and intermediary institutions, and building a "one network" for rural logistics information services in the entire region. This will include functions such as logistics information query, warehousing and cold storage resource management, product traceability, vehicle and cargo matching, track tracking, safety supervision, online matchmaking transactions and supply chain finance, to achieve the digitization, informatization and visualization of logistics information. Finally, the application of DLT technology will also strengthen rural logistics financial services, open up green credit channels, increase credit supply to rural express logistics, cold chain logistics, and e-commerce system construction, and meet the effective credit needs of leading logistics companies and upstream and downstream companies.

4. Results and Discussion

4.1 Experimental Design

In the experimental design of this paper, the advantages and disadvantages of the symbiotic development system of reverse logistics and forward logistics in rural Guangxi will be evaluated by comparing blockchain technology with the traditional logistics system. The traditional logistics system includes manual delivery and route planning, supply chain financial services and traditional warehouse management. In order to collect comparative data and conduct evaluation, order tracking information will be exported from the logistics company's own transportation management system, and time data will be collected from various logistics nodes, including the time of order placement, collection, receipt, receipt, etc., and the time spent in each stage will be calculated using formulas for timeliness analysis. The quality level of third-party logistics services is measured from two aspects: order processing accuracy and customer effective complaint handling and settlement rate, and the Shapley value method is used to evaluate the balance of benefit distribution.

4.2 Timeliness

This paper will evaluate the effect of blockchain technology in improving logistics efficiency by comparing the logistics timeliness before and after the application of blockchain technology. The timeliness data before and after are shown in Table 1.

In the study of the symbiotic development system of reverse logistics and forward logistics in rural Guangxi, we conducted a detailed analysis by comparing the logistics timeliness data before and after the application of blockchain technology. Table 1 shows the results of the timeliness study, in which blockchain technology significantly reduces the response time from order placement to collection, delivery time from collection to receipt, and return time from signature to receipt. Specifically, the response time from placing an order to collection is shortened from 24.19 hours to 13.75 hours, an increase of 43.16%; the time from collection to signature and delivery is shortened from 49.63 hours to 28.49 hours, an increase of 42.6%; the time from signature to return of the receipt is shortened from 26.48 hours to 11.84 hours, an increase of 55.29%. In addition, the order completion rate on time increases from 90.74% to 96.47%, an increase of 6.31 percentage points; the cargo difference rate and cargo damage rate decreases by 62.1% and 79.23% respectively, showing a significant reduction in cargo losses and errors during the logistics process; the information transmission accuracy rate and information transmission timeliness rate have also been significantly improved, from 95.49% and 90.91% to 98.14% and 94.51% respectively. These improvements show that blockchain technology plays an important role in improving the timeliness of logistics. By optimizing delivery routes, reducing intermediate links and improving information transparency, it effectively improves the efficiency and service quality of the entire logistics system.

Table 1: Results of time-effectiveness study

Index	Traditional logistics system	After blockchain application	Improvement percentage (%)
Response time from order placement to collection (hours)	24.19	13.75	43.16
Time from collection to signing for delivery (hours)	49.63	28.49	42.6
Time from receipt to receipt (hours)	26.48	11.84	55.29
Order completion rate on time (%)	90.74	96.47	6.31
Cargo difference rate (%)	2.48	0.94	62.1
Cargo damage rate (%)	1.83	0.38	79.23
Information transmission accuracy (%)	95.49	98.14	2.78
Timely rate of information transmission (%)	90.91	94.51	3.96

4.3 Service Quality

In order to evaluate service quality, this paper collects the order processing accuracy and customer effective complaint handling rate under different methods to evaluate service quality. The order processing accuracy data is shown in Figure 2:

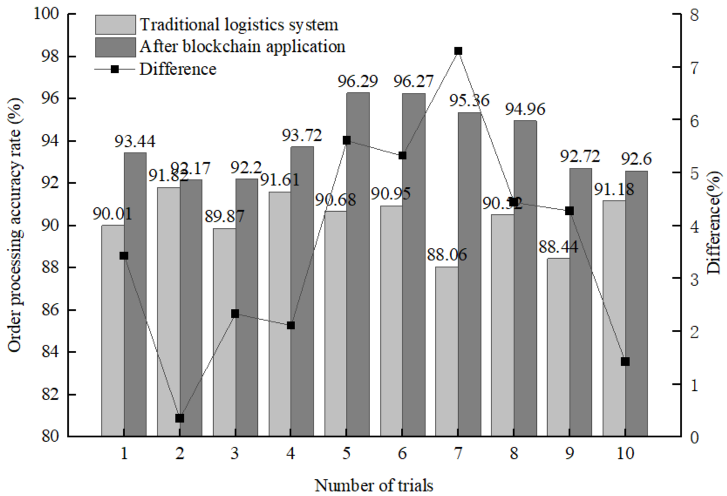

Figure 2: Order processing accuracy

In this paper, through a detailed analysis of the order processing accuracy before and after applying blockchain technology to Guangxi's rural logistics system, we found that blockchain technology significantly improves the accuracy of order processing. It can be seen from the data provided that the order processing accuracy of the traditional logistics system fluctuates to a certain extent, with the lowest being 88.06% and the highest being 91.82%. After applying blockchain technology, the order processing accuracy rate has been significantly improved, with the lowest being 92.17% and the highest being 96.29%. This significant improvement is mainly attributed to the automation and intelligence of blockchain technology in order processing, which reduces human errors and improves the speed and accuracy of data processing. Especially in the order processing process, the immutability and transparency of blockchain ensure the authenticity and integrity of order information, thereby greatly improving service quality. In addition, the introduction of blockchain technology has also improved customers' perception of logistics service satisfaction and further enhanced the comprehensive evaluation of service quality. Figure 3 shows the effective customer complaint handling rate data:

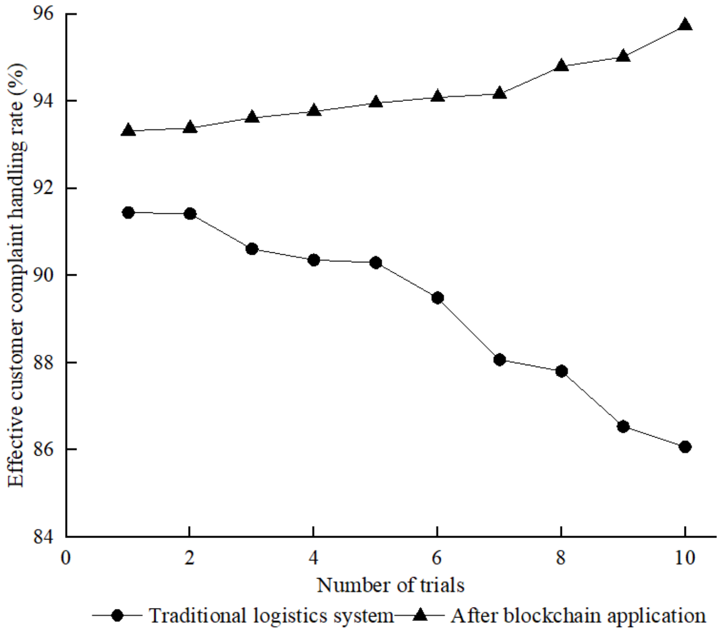

Figure 3: Effective customer complaint handling rate

In this paper, a comparative analysis is conducted on the effective customer complaint handling rates before and after the application of blockchain technology in Guangxi's rural logistics system. Data show that the effective settlement rate of customer complaints in the traditional logistics system fluctuates to a certain extent, with the lowest being 86.07%, the highest being 91.45%, and the average settlement rate being 90.3%. After applying blockchain technology, the effective settlement rate of customer complaints has been significantly improved, with the lowest being 93.32%, the highest being 95.74%, and the average settlement rate increasing to 94.09%. This significant improvement shows that blockchain technology plays an important role in improving customer service response speed, processing efficiency and settlement quality. The real-time data sharing and smart contract automatic execution features of the blockchain reduce manual processing, reduce errors and delays, thereby improving customer satisfaction and service quality. In addition, blockchain technology improves the transparency of logistics services, allowing customers to more clearly understand the progress of complaint handling, further enhancing customers' trust in logistics service providers.

4.4 Balanced Distribution of Benefits

In this paper, we introduced blockchain technology to conduct an in-depth evaluation of the balance of benefits distribution in the symbiotic development system of reverse logistics and forward logistics in rural Guangxi. Table 2 shows the comparison of benefit distribution indicators before and after blockchain application, including logistics cost savings, customer satisfaction, risk management efficiency and capital liquidity.

Table 2: Benefit distribution balance assessment

Benefit distribution indicators	Traditional logistics system		After blockchain application	
	Profit distribution	Shapley	Profit distribution	Shapley
Logistics cost savings (%)	5.74	0.2	11.49	0.25
Customer satisfaction (%)	84.69	0.1	92.44	0.05
Risk management efficiency (%)	86.42	0.08	94.51	0.02
Liquidity of funds (%)	61.29	0.15	79.46	0.3

According to the data in Figure 2, logistics cost savings increases from 5.74% to 11.49%, customer satisfaction increases from 84.69% to 92.44%, risk management efficiency increases from 86.42% to 94.51%, and capital liquidity increases from 61.29% to 79.46%. These improvements not only reflect the potential of blockchain technology in improving logistics efficiency, reducing costs, enhancing risk management and improving capital liquidity, but also show its advantages in achieving balanced distribution of benefits. The improvement in the Shapley value shows that blockchain technology plays an important role in promoting the balance of benefit distribution and brings greater value to all participants.

5. Conclusion

This paper proposes an innovative solution to the problems of unbalanced benefit distribution and low efficiency of logistics distribution in the symbiotic development system of reverse logistics and forward logistics in rural Guangxi by introducing blockchain technology. Research shows that blockchain technology can significantly improve logistics timeliness, reduce operating costs, improve customer satisfaction, and enhance risk management efficiency and capital liquidity. Especially in terms of order processing accuracy and effective customer complaint handling rate, the application of blockchain technology has significantly improved service quality. In addition, the calculation of the Shapley value further confirms the advantages of blockchain technology in promoting the balance of benefit distribution. These results show that blockchain technology has great potential in promoting the modernization of Guangxi's rural logistics system and rural revitalization. However, the study also has certain limitations. For example, the scope and depth of data collection may limit the generalizability of the results, and the actual application effect of blockchain technology needs to be further verified in a larger-scale environment. Future research can explore the combination of blockchain technology with other emerging technologies, such as artificial intelligence and big data analysis, to further improve the efficiency and fairness of the logistics system. In addition, policymakers and industry practitioners should pay attention to the application of blockchain technology in the field of logistics and formulate corresponding supporting policies and standards to promote its implementation in a wider range of fields. Through these efforts, blockchain technology is expected to provide strong technical support for rural revitalization and logistics system optimization in Guangxi and even the whole country.

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