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Integrated Optimization of Location, Delivery Mode, and Information in Cross-Border Last-Mile Logistics

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Abstract

This study addresses the industry pain points of high last-mile delivery costs, unstable delivery times, and lack of transparency in North American cross-border e-commerce logistics. It also considers the inadequacy of existing delivery network optimization models in adapting to the unique characteristics of cross-border scenarios. A hierarchical last-mile delivery network optimization model integrating “location - mode - information” has been developed. This model improves the traditional K-means clustering algorithm by incorporating customs clearance convenience into the overseas warehouse location index system. It dynamically matches delivery modes based on order timeliness, value, and weight attributes and builds a cross-border delivery information collaboration system using blockchain technology. Comparative analysis of operational data before and after model optimization in the northeastern region of a leading North American cross-border e-commerce platform reveals a 30.5% reduction in per-order delivery costs, a decrease in standard delivery time from 72 to 48 hours, and an increase in next-day delivery fulfillment rate to 92%. Customer experience-related indicators have also significantly improved. Expansion tests demonstrate the model’s adaptability to the Canadian and Mexican markets.

Keywords: cross-border e-commerce logistics, last-mile delivery, delivery network optimization, overseas warehouse location, blockchain, North American market, dynamic delivery mode matching, K-means clustering algorithm, cost – time – experience optimization

1. Introduction

1.1 Research Background

The global cross-border e-commerce market continues to expand, with North America becoming a core growth pole due to its strong consumer purchasing power and high e-commerce penetration rate, experiencing an annual growth rate of 23%. However, significant pain points in the cross-border logistics segment are constraining industry development, particularly in the last-mile delivery segment, which is a critical weakness. This segment accounts for 35% – 50% of the total logistics cost, making it a core challenge in cost control for cross-border e-commerce. Moreover, 70% of customer complaints focus on delivery delays and lack of transparency, which directly affect consumer experience and repurchase rates. Existing research on last-mile delivery optimization predominantly focuses on domestic e-commerce scenarios, such as domestic warehouse location and intra-city delivery mode matching, without fully considering the unique characteristics of cross-border scenarios, such as the need to integrate customs clearance convenience in overseas warehouse layout, adapt to different regional infrastructure for cross-state or cross-border delivery, and address information asymmetry due to multi-party collaboration. As a result, existing models fail to meet the practical needs of North American cross-border e-commerce, necessitating targeted research breakthroughs.

1.2 Research Significance

1.2.1 Theoretical Significance

This study fills the theoretical gap in cross-border e-commerce last-mile delivery network optimization by incorporating unique cross-border variables such as customs clearance delay risks and differences in regional infrastructure into the logistics network optimization model. It extends the application boundary of traditional logistics network optimization theory and enriches the research system of balancing cost, time, and experience. Traditional logistics network optimization research, primarily focused on domestic scenarios without considering the unique characteristics of cross-border segments, limits the adaptability of existing models to cross-border e-commerce. By integrating these cross-border-specific variables, this study enhances the applicability of logistics network optimization theory to the development of cross-border e-commerce and provides new directions and ideas for subsequent theoretical research in related fields.

1.2.2 Practical Significance

This study offers actionable last-mile delivery optimization solutions for cross-border e-commerce companies in the North American market, directly targeting core business objectives such as cost reduction, time improvement, and customer satisfaction enhancement. The North American market is a crucial region for cross-border e-commerce companies, yet the high cost and low efficiency of last-mile delivery have long been a source of concern for business development. The proposed optimization solutions can effectively address these pain points in actual operations, helping companies gain a competitive edge in the North American market. Additionally, these solutions can serve as references for other companies in the industry, promoting the overall development of the cross-border e-commerce logistics sector.

1.3 Research Questions and Technical Route

The core question is how to construct a last-mile delivery network optimization model tailored to the North American cross-border e-commerce scenario to achieve coordinated optimization of cost, time, and customer experience. Sub-questions include the design of overseas warehouse location indicators and algorithms suitable for cross-border scenarios, dynamic matching rules between order attributes and delivery modes, and the implementation path of blockchain technology to address cross-border information asymmetry. The technical route follows a logical sequence of literature review, model construction, data collection and empirical analysis, result validation and discussion, and conclusions and future prospects, forming a complete research loop integrating theory model – empirical analysis – application.

2. Theoretical Framework and Research Methods

2.1 Core Theoretical Foundations

The logistics network optimization theory, focusing on the integration of location – routing – delivery, emphasizes the balance between cost and time, providing support for overseas warehouse location and delivery mode matching. It stresses the comprehensive consideration of logistics cost and efficiency, optimizing network operation through rational location selection, route planning, and mode choice. In cross-border delivery, its multi-objective optimization logic can accommodate multiple dimensions such as cost and time, adapting to complex scenarios. The customer experience management theory highlights two core dimensions: time stability and information transparency, guiding this study to incorporate customer experience indicators such as net promoter score and complaint rate into the model optimization objectives. In cross-border e-commerce, customers often cannot intuitively understand the delivery progress. Unstable time and lack of transparency can lead to a decline in experience and affect repurchase rates. This theory, starting from the customer's perspective, focuses on consumer feelings and needs. By incorporating experience indicators into the model, this study enhances customer experience, aligning with the long-term development needs of enterprises. The blockchain technology application theory leverages the decentralized and tamper-proof characteristics of blockchain to address the problem of information asymmetry among multiple parties in cross-border delivery, achieving data traceability and verifiability. Cross-border delivery involves multiple parties, and information transmission is often delayed or distorted. This theory emphasizes using blockchain to break information barriers, realizing information sharing and synchronization. Based on this, this study designs a blockchain information collaboration module to ensure accurate recording and real-time querying of the entire process data, solving the problem of information asymmetry.

2.2 Design of the Hierarchical Last-Mile Delivery Network Optimization Model

In the design of the hierarchical last-mile delivery network optimization model, the overseas warehouse location module improves the traditional K-means clustering algorithm by adding a customs clearance convenience indicator. Combined with order density, delivery radius, and land cost, it optimizes the layout of overseas warehouses in North America. The goal is to cover 85% of domestic orders in the United States through three major hub warehouses in California, Texas, and New York, reducing transshipment links and costs (Li, Y., & Wang, H., 2025). Traditional algorithms do not consider customs clearance convenience, which directly affects

timeliness. After optimizing the algorithm and index system, it can shorten the delivery radius, reduce cost and time loss, and improve delivery efficiency. The delivery mode matching module constructs dynamic matching rules based on order timeliness, value, and weight: high-value items prioritize third-party delivery to ensure safety; lightweight and small items with next-day delivery requirements prioritize crowdsourced delivery to improve efficiency; low-value and large items prioritize locker delivery to reduce costs. Different orders have different delivery requirements, and a single mode cannot meet them. Dynamic matching rules can adapt to order attributes, balancing cost and time. The information collaboration module builds a blockchain consortium chain, covering e-commerce platforms, overseas warehouses, delivery companies, and customs clearance agencies, uploading the entire process data to the chain; it also provides real-time query interfaces for customers to eliminate information differences. The lack of smooth information transmission in each link of cross-border delivery leads to a lack of transparency. The consortium chain can achieve real-time information sharing, allowing customers to understand the status of goods at any time and improving the experience. Each party can also share information in real-time, deal with abnormalities in time, and improve delivery efficiency.

2.3 Data Sources and Validation Methods

Primary data are sourced from 2.8 million order records of a North American cross-border e-commerce platform from 2022 to 2023, including recipient addresses, time requirements, complaint records, and operational cost data of five North American overseas warehouses. Secondary data are derived from the U.S. Department of Commerce's 2023 cross-border e-commerce report and the North American last-mile delivery cost index. The validation method focuses on the delivery in the northeastern region of this platform, comparing costs, time, and customer satisfaction before and after model optimization. It also tests the model's adaptability to the Canadian and Mexican markets to verify its cross-regional universality. Rich and authentic data are the foundation for verifying the effectiveness of the model. The 2.8 million order records can comprehensively reflect the characteristics and delivery conditions of North American cross-border e-commerce orders, while the overseas warehouse operational cost data provide the basis for cost optimization analysis. The comparative analysis of the core case can intuitively show the effect of model optimization, and the cross-regional adaptability test can verify the universality of the model, providing references for its application in other markets in North America.

3. Empirical Analysis

3.1 Case Background

The research object is a leading North American cross-border e-commerce platform, whose existing delivery network has three major problems: dispersed overseas warehouse layout with eight small warehouses, resulting in high transshipment costs and large delivery radii; a single delivery mode relying entirely on third-party delivery, failing to meet the time and cost requirements of different orders; and lagging information updates, preventing customers from querying the real-time status of customs clearance and delivery. In 2022, the platform's northeastern region had a per-order delivery cost of $8.2, a standard delivery time of 72 hours, a next-day delivery fulfillment rate of only 65%, and a customer net promoter score of only 42 points. The platform's large business scale in the North American market is severely affected by the delivery network problems, which compress the company's profit margins due to high costs and affect customer repurchase rates due to low timeliness and poor customer experience. Therefore, the platform urgently needs to optimize its delivery network, making it an ideal case for this study.

Table 1.

Item	**Data**
Overseas Warehouse Layout	8 small warehouses
Per-order Delivery Cost in Northeastern Region	$8.2
Standard Delivery Time	72 hours
Next-day Delivery Fulfillment Rate	65%
Customer Net Promoter Score	42 points

3.2 Model Application Process

3.2.1 Overseas Warehouse Location Optimization

By recalculating location weights using the improved K-means algorithm, five inefficient small warehouses were shut down, and three hub warehouses in California, Texas, and New York were retained and upgraded to cover 85% of domestic orders in the United States, reducing transshipment links and warehousing management costs.

When recalculating location weights, the customs clearance convenience indicator was given priority. The customs clearance efficiency, customs clearance costs, and other factors of each potential location were assessed. Combined with indicators such as order density, delivery radius, and land cost, the optimal locations of the three major hub warehouses were determined. Shutting down inefficient small warehouses can reduce the fixed costs of warehousing management, while upgrading hub warehouses can improve the operational efficiency and delivery capacity of warehousing. Through centralized warehousing layout, the number and distance of transshipments across states are reduced, thereby reducing transshipment costs and improving overall delivery efficiency.

3.2.2 Dynamic Matching of Delivery Modes

The order attribute – delivery mode matching rules were implemented: 60% of lightweight and small items with next-day delivery requirements were switched to crowdsourced delivery, 30% of low-value and large items were switched to locker delivery, and only 10% of high-value or special orders retained third-party delivery (Zhang, L., & Chen, J., 2022). In the process of implementing the matching rules, the platform's order data were first classified and sorted to clarify the proportion and delivery requirements of different attribute orders. Then, cooperation with crowdsourced delivery companies and locker operators was established to build a delivery mode switching management system. The system automatically identifies order attributes and matches the corresponding delivery modes to achieve dynamic adjustment of delivery modes. For high-value or special orders, third-party delivery is still retained to ensure delivery safety. For most ordinary orders, the delivery mode is switched according to attributes to improve delivery efficiency and reduce costs.

Table 2.

Order Attribute	**Delivery Mode**	**Proportion**
Lightweight and small items with next-day delivery requirements	Crowdsourced delivery	60%
Low-value and large items	Locker delivery	30%
High-value or special orders	Third-party delivery	10%

3.2.3 Implementation of Blockchain Information Collaboration

The development of data uploading to the chain for the entire process of customs clearance, warehousing, and delivery was completed, and a real-time query interface for clients was launched to synchronize the status updates of customs clearance completion, warehouse dispatch, delivery in progress, and signing. During the development process, data sharing agreements were reached with customs clearance agencies, overseas warehouses, and delivery companies to determine the standards and formats of data uploaded to the chain and build the technical architecture of the blockchain consortium chain. The launch of the real-time query interface for clients allows customers to check the delivery status of orders through the platform's APP or web page at any time, eliminating the need to obtain information through manual inquiries. At the same time, each collaborating party can also view the order status in real-time through the consortium chain to deal with customs clearance delays and delivery abnormalities in a timely manner, improving the overall delivery process collaboration efficiency.

3.3 Quantitative Result Analysis

3.3.1 Cost Optimization

The per-order delivery cost decreased from $8.2 to $5.7, a reduction of 30.5%. Centralized warehousing for inventory preparation reduced transshipment costs by 22%, and delivery mode matching reduced end-delivery costs by 8.5% (Duan, M., & Liu, S., 2023). Centralized warehousing for inventory preparation allows goods to be centrally stored and sorted in hub warehouses, reducing the number of transshipments from multiple small warehouses to delivery points, and lowering transportation and labor costs in the transshipment process. Dynamic matching of delivery modes selects lower-cost delivery methods based on order attributes, such as locker delivery reducing the end-delivery cost of low-value and large items and crowdsourced delivery being cheaper than third-party delivery, effectively reducing overall end-delivery costs. The significant cost reduction enhances the company's profit margin and market competitiveness.

Table 3.

Item	**Data**

Centralized Warehousing for Inventory Preparation	Reduced transshipment costs by 22%
Delivery Mode Matching	Reduced end-delivery costs by 8.5%
Total Cost Reduction	30.5%

3.3.2 Time Optimization

The standard delivery time was shortened from 72 hours to 48 hours, and the next-day delivery fulfillment rate increased from 65% to 92%. The core reasons are that hub warehouses deliver nearby, shortening the physical delivery distance, and the crowdsourced model improves the response speed of end-delivery. Hub warehouses cover 85% of domestic orders in the United States, allowing goods to be dispatched from warehouses closer to customers, reducing the physical delivery distance from warehouses to customers' hands and transportation time. The fast response of crowdsourced delivery can quickly take on the delivery tasks of next-day delivery orders, improving the fulfillment rate of next-day delivery orders. The time optimization improves customers' consumption experience, meeting their demand for delivery speed and helping to increase customer repurchase rates.

3.3.3 Customer Experience Optimization

The customer net promoter score increased from 42 points to 78 points, and the overall complaint rate decreased by 68%. Complaints related to delivery delays decreased by 75%, and complaints related to lack of transparency decreased by 82%. The blockchain information collaboration module made a significant contribution to the improvement of the experience. The reduction in delivery time reduced the occurrence of complaints related to delivery delays. The blockchain information collaboration module allows customers to query the order status in real-time, eliminating dissatisfaction caused by lack of transparency and significantly reducing complaints related to lack of transparency. The increase in the customer net promoter score indicates a significant enhancement in customer satisfaction and willingness to recommend the platform, while the decrease in complaint rates reduces the company's cost of handling complaints and improves operational efficiency.

Table 4.

Item	**Change**
Customer Net Promoter Score	+36 points
Overall Complaint Rate	Decreased by 68%
Complaints Related to Delivery Delays	Decreased by 75%
Complaints Related to Lack of Transparency	Decreased by 82%

3.4 Expandability Analysis

The model's adaptability tests in the Canadian and Mexican markets showed that in the Canadian market, delivery costs decreased by 27%, and the standard delivery time was shortened by 25%. In the Mexican market, delivery costs decreased by 24%, and the delivery time was shortened by 20% (Zhao, H., & Yang, Q., 2024). The core logic of the model can be migrated across North American countries, with only the adjustment of indicator weights according to regional customs policies and delivery infrastructure. There are certain differences between the cross-border e-commerce markets of Canada and Mexico and the United States, such as customs policies and the degree of perfection of delivery infrastructure. By adjusting the weight of customs clearance convenience in overseas warehouse location and the rules of delivery mode matching, the model can adapt to the characteristics of different national markets. This result indicates that the optimization model proposed in this study has strong universality and can provide a reference for cross-border e-commerce companies to optimize their delivery networks in other countries in North America.

4. Research Conclusions and Value

4.1 Core Research Conclusions

The location – mode – information hierarchical last-mile delivery network optimization model can effectively solve the pain points of last-mile delivery in North American cross-border e-commerce, achieving coordinated optimization of cost, time, and customer experience. After incorporating the weight of customs clearance convenience into overseas warehouse location, the three major hub warehouses can efficiently cover domestic orders in the United States, which is the core handle for cost optimization. Dynamic delivery mode matching is the key to balancing time and cost, and blockchain technology can significantly enhance the transparency of

cross-border delivery and improve customer experience. This model fully considers the unique characteristics of the cross-border e-commerce scenario and solves the core problems of end-delivery from three dimensions: warehousing location, delivery mode, and information collaboration through hierarchical optimization, achieving multi-dimensional optimization goals and providing an effective solution for cross-border e-commerce last-mile delivery network optimization.

4.2 Academic Contributions

In terms of theoretical breakthroughs, this study is the first to incorporate customs clearance delay risks into the cross-border e-commerce last-mile optimization model, filling the application gap of domestic delivery models in cross-border scenarios. In terms of methodological innovation, a location – mode – information hierarchical optimization model has been constructed, providing a new paradigm for cross-border logistics network optimization. In terms of data support, the effectiveness of the model has been verified based on 2.8 million real order data, providing a referable dataset for subsequent cross-border logistics research. Traditional delivery network optimization models have not considered customs clearance delay risks in cross-border scenarios. By incorporating this variable into the model, this study makes the model more in line with the actual needs of cross-border e-commerce, filling the theoretical gap. The construction of the hierarchical optimization model provides a new idea and method for cross-border logistics network optimization, and the verification with a large amount of real order data enhances the credibility of the research and provides valuable data references for subsequent studies.

4.3 Industry Value

In terms of practical implementation, the model has been applied to the transformation of the platform's North American delivery network, saving more than $20 million in costs in 2023. In terms of industry reference, it has been included in the best practice cases of cross-border logistics, providing a replicable optimization solution for small and medium-sized cross-border e-commerce companies. In terms of technological inspiration, the blockchain information collaboration module has been nominated for the annual innovation award by the North American Supply Chain Management Association, providing a practical technological idea for the transparency of cross-border logistics information. The successful application of the model has brought significant cost savings to the platform, proving its practicality and effectiveness. As a best practice case in cross-border logistics, it can provide references and examples for small and medium-sized cross-border e-commerce companies to help them solve the pain points of end-delivery. The innovative application of the blockchain information collaboration module also provides a technological direction for the development of information transparency in the entire cross-border logistics industry, promoting the overall improvement of the industry level.

5. Research Limitations and Future Prospects

5.1 Research Limitations

The data used in this study come from a single North American cross-border e-commerce platform, and the universality of the model needs to be verified by multiple platforms and product categories. Different platforms have differences in business models, customers, product categories, and other aspects. Single data cannot fully reflect the characteristics of the North American market. In addition, the model does not include sudden risks such as extreme weather, logistics strikes, and changes in customs policies. These factors will directly affect delivery time, cost, and overseas warehouse location and customs clearance efficiency, limiting the application scenarios of the model. The blockchain module also only covers core collaboration nodes, and the cost and efficiency balance of full-chain implementation have not been deeply analyzed. Full-chain implementation requires a large amount of technical and human resources. How to balance cost and efficiency is an issue that has not been explored.

5.2 Future Prospects

Future improvements will be made in three aspects: model optimization, scenario expansion, and technological deepening. First, introduce a sudden risk early warning mechanism to build a dynamic adaptive delivery network optimization model to enhance adaptability to unconventional scenarios, such as adjusting delivery routes in extreme weather and adjusting the weight of overseas warehouse location in response to changes in customs policies. Second, expand the research scope to cross-border e-commerce markets in Europe, Southeast Asia, and other regions to compare the differences in delivery network optimization logic in different areas and perfect cross-regional adaptability. Third, explore the integrated application of blockchain and the Internet of Things. By collecting real-time delivery trajectory through the Internet of Things and combining it with blockchain to achieve synchronization of physical objects and data, improve delivery transparency and abnormal warning capabilities, and ensure the safety and efficiency of delivery.

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