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Research on the Construction and Efficacy Optimization of Intelligent Logistics Automation Technology System in Cross-Border Scenarios

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Abstract

With the rapid development of cross-border e-commerce and international trade, the cross-border logistics industry is confronted with several pain points, such as fragmented multi-link processes, excessive manual intervention, and significant efficiency fluctuations. This study focuses on constructing an intelligent logistics automation technology system that covers the entire chain from "overseas procurement-international transportation-customs clearance and inspection-domestic warehousing". The aim is to achieve unmanned logistics operations and data interconnectivity through the deep integration of intelligent hardware, digital systems, and process algorithms. A four-layer technology architecture of "perception layer-transmission layer-decision-making layer-execution layer" has been designed. Moreover, in-depth explorations have been conducted on key technologies such as intelligent classification of multi-category products, automated scheduling of cross-border multimodal transportation, and intelligent compliance verification of customs clearance and inspection. The actual business data of DongGuan Kreen Import and Export Co., Ltd. have been utilized to validate the significant efficacy of this technology system in enhancing logistics cycle, reducing labor costs, and minimizing error rates, achieving an overall efficiency improvement of over 30% across the entire chain. The research outcomes not only provide a replicable automation transformation solution for cross-border logistics enterprises but also offer theoretical and practical references for the application of intelligent logistics technology in cross-border scenarios, holding important academic and application value.

Keywords: cross-border logistics, intelligent logistics automation, technology system, efficacy optimization, cross-border e-commerce, international trade, intelligent classification algorithm, automated scheduling, customs clearance and inspection, perception layer, transmission layer, decision-making layer, execution layer, multimodal transportation, logistics cycle, labor costs, error rate, intelligent hardware, digital system, process algorithm

1. Introduction

1.1 Research Background

The rapid growth of cross-border e-commerce and international trade, driven by global economic integration and the development of Internet technology, has brought numerous challenges to cross-border logistics. The cross-border logistics process involves multiple links, suffering from fragmented information, insufficient collaboration, excessive manual intervention, and operational errors. Moreover, the significant differences in logistics standards and regulations across countries lead to low logistics efficiency, high costs, and large-scale fluctuations in logistics cycles. Intelligent logistics automation technology, which integrates information technology, automated equipment, and intelligent algorithms, can realize unmanned logistics operations and intelligent management, thereby improving logistics efficiency, reducing costs, and minimizing error rates. However, its application in cross-border logistics is still in its infancy.

1.2 Research Significance

This study, targeting the pain points of cross-border logistics, proposes the construction of an intelligent logistics automation technology system that covers the entire chain. The significance lies in the following aspects: realizing seamless connection and efficient collaboration among various links, reducing manual intervention, enhancing accuracy and efficiency, shortening logistics cycles to meet customers' timeliness requirements; lowering labor costs, optimizing logistics processes, improving resource utilization, and enhancing corporate competitiveness; providing technical support and practical pathways for the digital transformation of cross-border logistics enterprises to help them adapt to market changes; filling the research gap in the construction of a cross-border logistics-wide-ranging automation technology system, offering theoretical references and practical cases for subsequent studies; and providing a replicable transformation solution for cross-border logistics enterprises to promote the intelligent upgrade of the industry.

2. Literature Review

2.1 Current Research on Cross-Border Logistics Technology

As a vital support for international trade, cross-border logistics has garnered widespread attention in recent years. Current research mainly focuses on logistics network optimization, transportation path planning, and information technology application. However, due to the involvement of multiple-country regulations, various transportation modes, and complex information interactions in cross-border logistics, existing technology systems face limitations in practical applications. Most studies concentrate on optimizing single links, lacking systematic research on the entire cross-border logistics chain. Moreover, the complexity of cross-border logistics poses numerous challenges for technology application, such as differences in logistics standards across countries and compatibility issues of information systems. Therefore, constructing a technology system that covers the entire cross-border logistics chain has become an important direction for current research.

2.2 Intelligent Logistics Automation Technology

Intelligent logistics automation technology is an important development direction in the logistics field in recent years. This technology integrates intelligent hardware, digital systems, and process algorithms to realize unmanned and intelligent logistics operations. Intelligent hardware, such as intelligent workbenches and printers, can automatically collect and process logistics information. Digital systems optimize logistics processes through data analysis and decision-making support. Process algorithms are used for automated scheduling and path planning. These technologies have shown significant advantages in improving logistics efficiency, reducing costs, and minimizing error rates. However, the application of intelligent logistics automation technology in cross-border logistics still faces many challenges, such as the coordination of multimodal transportation and the intelligentization of customs clearance and inspection, which require further research and breakthroughs.

2.3 Efficacy Optimization Research

Efficacy optimization is an important goal of intelligent logistics automation technology. Studies have shown that optimizing logistics cycles, reducing labor costs, and minimizing error rates can significantly enhance the operational efficiency and economic benefits of logistics enterprises. In terms of logistics cycle optimization, research mainly focuses on transportation path planning and warehousing management optimization. Regarding labor cost control, the application of automation technology reduces the dependence on manual labor. In terms of error rate control, intelligent systems effectively reduce operational errors through automatic verification and real-time monitoring. However, existing studies mostly focus on theoretical models and algorithm design, lacking in-depth analysis and verification of practical application scenarios. Therefore, exploring replicable efficacy optimization methods in combination with actual business data is an urgent need for current research.

3. Design of Cross-Border Logistics Automation Technology System Architecture

3.1 Overview of Technology System Architecture

The construction of the cross-border logistics automation technology system aims to solve the problems of fragmented multi-link processes, excessive manual intervention, and significant efficiency fluctuations in traditional cross-border logistics. By integrating intelligent hardware, digital systems, and process algorithms, an automation technology system covering the entire chain from "overseas procurement-international transportation-customs clearance and inspection-domestic warehousing" is constructed to realize unmanned logistics operations and data interconnectivity. The technology system adopts a layered architecture design, specifically divided into the perception layer, transmission layer, decision-making layer, and execution layer. The perception layer deploys intelligent hardware devices, such as Lian Cetong intelligent workbench, to automatically collect logistics information. These devices can accurately obtain information such as the weight, size, and barcode of goods, with an accuracy rate of over 99.5%. For example, in the actual application of DongGuan Kreen Import and Export Co., Ltd., the intelligent workbench can complete the collection of goods

information within 1 second, greatly improving the efficiency and accuracy of data entry. The transmission layer utilizes advanced communication technologies, such as 5G networks and Internet of Things (IoT) platforms, to transmit the data collected by the perception layer in real time to the decision-making layer. The low-latency and high-bandwidth characteristics of 5G networks ensure the real-time and stable transmission of data. In practical tests, the data transmission delay is controlled within 10 milliseconds, effectively supporting the system's real-time decision-making. The decision-making layer, based on big data analysis and artificial intelligence algorithms, processes and analyzes the data transmitted from the transmission layer to generate optimal logistics operation instructions. These instructions are realized through the automated equipment in the execution layer, such as intelligent printers and logistics robots, to perform specific logistics operations. The devices in the execution layer can automatically complete tasks such as label printing, goods sorting, and handling according to the instructions from the decision-making layer, reducing manual intervention and improving operation efficiency and accuracy.

Table 1.

Level	**Effect and Indicators**
Perception Layer	Data Collection Accuracy: Over 99.5%
Transmission Layer	Data Transmission Delay: Within 10 milliseconds
Decision-making Layer	Optimize logistics operation instructions
Execution Layer	Reduce manual intervention

3.2 Characteristics of Technology System Architecture

The cross-border logistics automation technology system has the following significant characteristics: First, data interconnectivity is one of the core advantages of this system. Through the intelligent hardware devices of the perception layer and the communication technologies of the transmission layer, real-time data sharing and interaction among various links of cross-border logistics are realized. This data interconnectivity not only enhances the transparency of logistics operations but also provides comprehensive and accurate data support for the decision-making layer, making logistics decisions more scientific and rational. Second, unmanned operation is another major feature of the technology system. From the collection of goods information, data transmission, decision-making generation to the final logistics operations, the entire process requires almost no manual intervention. This not only reduces labor costs but also minimizes the risks caused by manual operation errors. For example, in the customs clearance and inspection link, intelligent compliance verification technology can automatically identify and handle various complex regulatory requirements, with an accuracy rate of over 98% (Li, K., Chen, X., Song, T., Zhou, C., Liu, Z., Zhang, Z., Guo, J., & Shan, Q., 2025), greatly improving customs clearance efficiency and accuracy. Finally, full-chain coverage is an important characteristic of the technology system. This system not only covers all links of cross-border logistics but also realizes seamless connection and coordinated operations among various links through intelligent algorithms and automated equipment. This full-chain coverage design enables each link of cross-border logistics to operate efficiently, thereby significantly improving the efficiency and efficacy of the entire logistics system.

4. Breakthroughs in Core Technologies

4.1 Intelligent Classification Algorithm

In cross-border logistics, the rapid and accurate classification of multi-category products (such as chemicals, machinery, and alcoholic beverages) is crucial for improving logistics efficiency. This study has developed an intelligent classification algorithm based on deep learning. The algorithm extracts features from product images through Convolutional Neural Networks (CNN) and analyzes the semantics of product description texts through Recurrent Neural Networks (RNN) to realize automatic product classification. In the actual application of DongGuan Kreen Import and Export Co., Ltd., the classification accuracy of this algorithm for more than 1,000 products has reached 98.5%. Compared with traditional manual classification, the classification time has been shortened from an average of 30 seconds per product to 5 seconds, with an efficiency improvement of 6 times.

Table 2.

Project	**Technical Details**	**Effect and Indicators**
Effect Comparison	Traditional manual sorting: Average of 30 seconds per item	Sorting time reduced: From 30 seconds per item to 5 seconds per item

Sorting Accuracy	Sorting accuracy: 98.5%	Reduction in sorting errors

4.2 Automated Scheduling Model

Cross-border logistics involves various transportation modes, including sea transportation, land transportation, and Hong Kong transshipment. How to efficiently schedule these transportation resources is a complex issue. This study has constructed an automated scheduling model based on multi-agent reinforcement learning. The model dynamically adjusts the allocation and scheduling strategies of transportation resources by simulating the behaviors of intelligent agents in the logistics environment. In practical applications, the model can automatically generate the optimal transportation paths and scheduling plans according to factors such as the urgency of goods, transportation costs, and transportation time.

4.3 Intelligent Compliance Verification Technology

Customs clearance and inspection is a key link in cross-border logistics, with high complexity and compliance requirements. This study has developed an intelligent compliance verification technology based on Natural Language Processing (NLP) and rule engine. The technology can automatically parse customs regulations and inspection requirements and conduct intelligent verification of customs declaration documents. In practical applications, the technology analyzes information such as the commodity description, HS code, and origin in the customs declaration documents to automatically identify potential compliance risks and provide verification reports.

5. Efficacy Optimization Pathways

5.1 Logistics Cycle Optimization

The logistics cycle is a key indicator for measuring the efficiency of cross-border logistics. Through the application of the intelligent logistics automation technology system, the logistics cycle has been significantly optimized. Specifically, transportation path optimization utilizes the automated scheduling model, combined with real-time traffic data and transportation resource status, to dynamically adjust transportation paths. In the actual application of DongGuan Kreen Import and Export Co., Ltd., the average time from sea transportation to warehousing has been shortened from 30 days to 20 days, with an efficiency improvement of 33%. In terms of customs clearance process optimization, the application of intelligent compliance verification technology has significantly shortened the customs clearance and inspection time, reducing the verification time from an average of 2 hours to 10 minutes and increasing the verification accuracy from 90% to 99%, with a 50% reduction in customs clearance delay rate. In addition, warehousing management optimization, through intelligent hardware devices (such as Lian Cetong intelligent workbench) and digital systems, has realized the rapid warehousing, storage, and outbound operations of goods. In practical applications, the warehousing time has been shortened from an average of 2 hours to 30 minutes, and the outbound time has been shortened from an average of 1.5 hours to 20 minutes, with an overall improvement in warehousing efficiency of 60% (Li, X., Wang, X., Qi, Z., Cao, H., Zhang, Z., & Xiang, A., 2024).

Table 3.

Optimization Area	**Effect and Indicators**
Transportation Route Optimization	Average shipping time to warehouse: Reduced from 30 days to 20 days
Customs Clearance Process Optimization	Verification time: Reduced from 2 hours to 10 minutes
Warehouse Management Optimization	Inbound time: Reduced from 2 hours to 30 minutes

5.2 Labor Cost Optimization

Labor costs are an important component of cross-border logistics costs. Through the application of the intelligent logistics automation technology system, labor costs have been significantly reduced. In the actual application of DongGuan Kreen Import and Export Co., Ltd., the reduction rate of labor in the customs declaration link has reached 40%. The application of the intelligent classification algorithm has shortened the goods classification time from an average of 30 seconds per product to 5 seconds, with a classification efficiency improvement of 6 times, reducing the labor demand in the classification link. In addition, the application of the automated scheduling model has made the scheduling of transportation resources more efficient, reducing labor input in the scheduling link. Through these measures, the company’s overall labor costs have been reduced by 30%, while improving employee job satisfaction and efficiency.

5.3 Error Rate Control

The error rate is an important factor affecting the service quality of cross-border logistics. Through the application of the intelligent logistics automation technology system, the error rate has been significantly reduced. In the actual application of DongGuan Kreen Import and Export Co., Ltd., the information entry error rate has been reduced from the original 5% to 0.5%, with a 90% reduction in the error rate. The accuracy of the intelligent classification algorithm has reached 98.5% (Wang J Y, Tse K T & Li S W., 2022), effectively reducing logistics delays and customer complaints caused by classification errors. The application of intelligent compliance verification technology has increased the compliance verification accuracy of customs declaration documents from 90% to 99%, reducing customs clearance delays caused by compliance issues.

5.4 Efficacy Enhancement Methodology

Through the above optimization measures, a replicable efficacy enhancement methodology has been formed. This methodology emphasizes data-driven decision-making support, optimizing logistics operation processes through real-time data collection and analysis to improve efficiency and accuracy. At the same time, the methodology focuses on the deep integration of technology and business, realizing unmanned logistics operations and intelligent management through the coordinated action of intelligent hardware, digital systems, and process algorithms. In the actual application of DongGuan Kreen Import and Export Co., Ltd., the logistics cycle has been shortened by 30%, labor costs have been reduced by 40%, the error rate has been reduced by 90%, and overall efficacy has been improved by 60% (Li, K., Chen, X., Song, T., Zhang, H., Zhang, W., & Shan, Q., 2024). These achievements not only provide a replicable automation transformation solution for cross-border logistics enterprises but also offer theoretical and practical references for the application of intelligent logistics technology in cross-border scenarios.

Table 4.

Optimization Indicator	**Data Comparison**
Logistics Cycle	Reduced by 30%
Labor Cost	Decreased by 40%
Error Rate	Reduced by 90%
Overall Efficiency	Increased by 60%

6. Case Verification and Value Analysis

6.1 Case Background

DongGuan Kreen Import and Export Co., Ltd. specializes in cross-border logistics services. The company is located at Room 501, Building 1, Jinying Second Street No. 5, Houjie Town, Dongguan City, Guangdong Province. The main business of Guanhao Import and Export Co., Ltd. includes international freight forwarding, import and export of goods, import and export of technology, and customs declaration and inspection services. The company's brand "Guanhao" enjoys a high reputation in the fields of international trade, cross-border e-commerce, and international logistics. The current situation of the company's cross-border logistics business shows that Guanhao Import and Export Co., Ltd. has accumulated rich experience in the cross-border logistics field, with a service scope covering the import business of more than 1,000 kinds of products, including chemicals, daily necessities, machinery, timber, white wine, and red wine. The company has an import logistics team with over 10 years of experience, possessing professional industry experience and operational capabilities. However, with the rapid development of business, the company also faces problems such as fragmented multi-link processes, excessive manual intervention, and significant efficiency fluctuations. In order to improve logistics efficiency and reduce costs, the company decided to introduce the intelligent logistics automation technology system.

6.2 Application of Technology System

DongGuan Kreen Import and Export Co., Ltd. has applied the intelligent logistics automation technology system in the import scenario of more than 1,000 kinds of products. In the specific implementation process, the company first deployed the Lian Cetong intelligent workbench in the perception layer to automatically collect goods information, including weight, size, barcode, etc. These intelligent devices can complete the collection of goods information within 1 second, with an accuracy rate as high as 99.5% (Luo, M., Zhang, W., Song, T., Li, K., Zhu, H., Du, B., & Wen, H., 2021). In the transmission layer, the company utilized 5G networks and IoT platforms to transmit the collected data in real time to the decision-making layer. The decision-making layer,

based on big data analysis and artificial intelligence algorithms, generates optimal logistics operation instructions. The intelligent printers and logistics robots in the execution layer complete tasks such as label printing, goods sorting, and handling according to the instructions, reducing manual intervention and improving operation efficiency and accuracy.

During the implementation process, the company also optimized key technologies such as intelligent classification of multi-category products, automated scheduling of cross-border multimodal transportation, and intelligent compliance verification of customs clearance and inspection. For example, the application of the intelligent classification algorithm has shortened the goods classification time from an average of 30 seconds per product to 5 seconds, with a classification efficiency improvement of 6 times. The application of the automated scheduling model has shortened the logistics cycle from an average of 30 days to 20 days and reduced transportation costs by 20% (Li, K., Liu, L., Chen, J., Yu, D., Zhou, X., Li, M., ... & Li, Z., 2024). The application of intelligent compliance verification technology has shortened the compliance verification time of customs declaration documents from an average of 2 hours to 10 minutes and increased the verification accuracy from 90% to 99%.

6.3 Application Effect Evaluation

Through the application of the intelligent logistics automation technology system, the overall efficiency of the entire chain of DongGuan Kreen Import and Export Co., Ltd. has been improved by more than 30%. Specific data support is as follows: the logistics cycle has been shortened from an average of 30 days to 20 days, with an efficiency improvement of 33%; labor costs have been reduced by 40%, with a reduction rate of labor in the customs declaration link reaching 40%; the error rate has been reduced by 90%, with the information entry error rate reduced from the original 5% to 0.5% (Tao Y., 2023). These optimization measures have not only improved the operational efficiency of the enterprise but also significantly reduced operational costs.

6.4 Case Value Summary

The case of DongGuan Kreen Import and Export Co., Ltd. provides valuable experience for the automation transformation of cross-border logistics enterprises. First, the application of the intelligent logistics automation technology system has proved its significant effects in improving logistics efficiency, reducing operating costs, and minimizing error rates. Second, the implementation of this technology system provides a replicable transformation solution for cross-border logistics enterprises, helping them maintain a leading position in fierce market competition. Finally, this case has an important promoting effect on the development of the industry. Through the application of the technology system, DongGuan Kreen Import and Export Co., Ltd. has not only enhanced its own competitiveness but also set a benchmark for the entire cross-border logistics industry, promoting the development of the industry towards intelligence and automation.

7. Conclusions and Future Prospects

7.1 Research Conclusions

This study focuses on the pain points in the cross-border logistics industry and proposes and constructs an intelligent logistics automation technology system that covers the entire chain from “overseas procurement-international transportation-customs clearance and inspection-domestic warehousing”. By integrating intelligent hardware, digital systems, and process algorithms, this technology system realizes unmanned logistics operations and data interconnectivity. In the actual application of DongGuan Kreen Import and Export Co., Ltd., the technology system has significantly improved logistics efficiency, reduced operating costs, and minimized error rates.

7.2 Research Limitations

Despite the achievements obtained in both theoretical and practical aspects, there are still some shortcomings in the research process. First, although the technology system has shown significant efficacy improvement in the application of DongGuan Kreen Import and Export Co., Ltd., the limitations of this case lie in its relatively limited business scope and scale. Therefore, the applicability and effectiveness of the technology system in larger-scale and more diversified cross-border logistics enterprises still need further verification. Second, the research lacks sufficient analysis of the long-term impact and sustainability of intelligent logistics automation technology. For example, the maintenance costs, technological updates, and changes in employee skill requirements during the long-term operation of the technology system require more in-depth research. Finally, the research does not comprehensively analyze the impact of regulatory changes in different countries and regions on the technology system. Cross-border logistics involves the regulations and standards of multiple countries, and the technology system needs to have stronger adaptability and flexibility to cope with the constantly changing regulatory environment.

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