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Digital Twin-Driven Intelligent Collaborative Automation Model for Global Warehouse Networks and Application Validation

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Abstract

In the context of accelerated globalization, multinational logistics companies are confronted with significant challenges in global warehousing networks, including information latency, resource misallocation, and inefficient collaboration. This study addresses these issues by introducing digital twin technology to construct a virtual mirroring system for the overseas warehouse layouts of DongGuan Kreen Import and Export Co., Ltd. (with branches in the United States, Canada, Germany, and Vietnam). The digital twin system enables real-time collaboration and automated scheduling across global warehousing nodes, thereby enhancing the resilience of the global supply chain. The research is centered on three main aspects: First, a dynamic digital twin model is developed based on the physical space, equipment status, and business data of global warehousing nodes, achieving millisecond-level synchronization between physical and virtual warehouses. Second, intelligent resource allocation algorithms, automated cross-continental transfer decision mechanisms, and autonomous abnormal event response processes are designed to upgrade warehouse collaboration from a “passive execution” to an “active prediction” mode. Third, the digital twin model is validated in the context of “Amazon FBA headhaul logistics,” focusing on its collaborative efficiency in global warehouse stocking, replenishment, and return/exchange processes, with an emphasis on improving the response speed of cross-border e-commerce supply chains. The study demonstrates that the digital twin-driven intelligent collaborative automation model for global warehouse networks significantly enhances collaborative efficiency and supply chain resilience, forming a technical standard and practical paradigm for digital twin automation collaboration in global warehouses. This provides technological support for multinational logistics companies to address global warehousing collaboration challenges and enhances China’s scheduling discourse power in the global supply chain.

Keywords: digital twin, global warehouse network, intelligent collaboration, automated scheduling, cross-border e-commerce, supply chain resilience, logistics optimization, overseas warehouse layout, real-time synchronization, abnormal response, resource allocation, path optimization, logistics efficiency

1. Introduction

1.1 Research Background

In the wave of globalization, the operational environment of multinational logistics companies has become increasingly complex, with the dynamism and uncertainty of global supply chains continuously increasing. This has posed unprecedented challenges to the efficiency, flexibility, and resilience of warehousing logistics. Traditional warehousing management models suffer from numerous deficiencies in the timeliness of information updates, rationality of resource allocation, and efficiency of collaborative work. These issues not only affect the operational efficiency of logistics companies but also weaken their competitiveness in the global supply chain. Meanwhile, digital twin technology, as an emerging digital technology, offers new ideas for solving complex problems in warehousing logistics by constructing virtual mirrors of physical entities and enabling real-time interaction between the virtual and physical entities. In the logistics field, digital twin technology has been

successfully applied in intelligent warehousing and logistics optimization, demonstrating great potential for application. DongGuan Kreen Import and Export Co., Ltd., as a multinational logistics company, has a global warehousing network covering overseas branches in the United States, Canada, Germany, Vietnam, and other regions. During operations, the company faces problems such as "information latency, resource misallocation, and inefficient collaboration" in its global warehousing network. These issues lead to increased logistics costs, decreased customer satisfaction, and insufficient supply chain resilience. Therefore, introducing digital twin technology to construct an intelligent collaborative automation model for global warehouses is of great significance for improving the company's operational efficiency and competitiveness.

1.2 Research Objectives and Significance

This study aims to introduce digital twin technology to construct an intelligent collaborative automation model for global warehouses to address the issues of "information latency, resource misallocation, and inefficient collaboration" in global warehousing networks. Specifically, the study will develop a global warehouse digital twin model based on digital twins, achieving millisecond-level synchronization between physical and virtual warehouses. It will design an intelligent collaborative automation model, including intelligent resource allocation algorithms, automated cross-continental transfer decision mechanisms, and autonomous abnormal event response processes. The effectiveness of the constructed model and mode will be verified in practical application scenarios to enhance the collaborative efficiency and supply chain resilience of global warehousing networks. This study holds significant theoretical and practical importance. From a theoretical perspective, by constructing a digital twin-driven intelligent collaborative automation model for global warehouses, this study enriches and perfects the application theory of digital twin technology in the logistics field, providing new perspectives and methods for related research. From a practical standpoint, this study offers technological support for multinational logistics companies to solve global warehousing collaboration challenges, significantly improving their operational efficiency and competitiveness. Moreover, by forming a technical standard and practical paradigm for digital twin automation collaboration in global warehouses, this study provides references and examples for other companies, facilitating the digital transformation and intelligent upgrading of the entire logistics industry. This also enhances China's scheduling discourse power in the global supply chain and promotes the upgrading and innovation of China's supply chain industry.

2. Research Background and Significance

2.1 Current Status and Issues of Global Warehouse Network Collaboration

In the context of globalization, the layout of multinational logistics companies' warehousing networks has become increasingly complex, involving warehousing facilities in multiple countries and regions. However, the collaborative management of current global warehousing networks faces numerous challenges. First, information latency is a prominent issue. Traditional warehousing management systems suffer from delays in data updates and transmission, resulting in inaccurate or outdated decision-making information. For example, inventory data updates may take several hours or even days, making it difficult for companies to make timely and accurate decisions in inventory management and allocation. Second, resource misallocation is a common problem. Due to the lack of effective global resource management, warehousing space, equipment, and human resources are often not allocated rationally. For instance, some warehouses may face inventory overstocking, while others experience stockouts. Additionally, there are significant differences in equipment utilization rates across warehouses, with some equipment idle while others are overburdened. Finally, inefficient collaboration severely affects the efficiency of the entire supply chain. Information sharing and collaborative work between different warehousing nodes often rely on manual operations, which are prone to errors and long response times. For example, in cross-continental cargo transfer, the lack of automated decision-making mechanisms means that the selection of transfer routes and optimization of transportation modes often take a long time, increasing logistics and time costs. These issues not only affect the operational efficiency of companies but also weaken their competitiveness in the global supply chain.

2.2 Overview of Digital Twin Technology

Digital twin technology is a technique that constructs a virtual mirror of a physical entity and enables real-time interaction between the virtual and physical entities. Based on technologies such as the Internet of Things (IoT), big data, cloud computing, and artificial intelligence, digital twin technology can monitor and analyze the operational status of physical entities in real-time and optimize and predict physical entities through virtual models. The core characteristics of digital twin technology include virtual-physical mapping, real-time interaction, and model-driven approaches. Virtual-physical mapping refers to the precise correspondence between the virtual model and the physical entity, ensuring that the virtual model accurately reflects the state and behavior of the physical entity. Real-time interaction emphasizes the bidirectional information flow between the virtual model and the physical entity, allowing the virtual model to dynamically update based on real-time data from the physical entity and enabling the physical entity to adjust according to optimization suggestions from the

virtual model. Model-driven refers to the use of mathematical models and algorithms to analyze and optimize the virtual model, thereby providing decision-making support for the physical entity. In the logistics field, digital twin technology has been successfully applied in intelligent warehousing and logistics optimization. For example, by constructing a digital twin model of a warehouse, real-time inventory monitoring and optimized management can be achieved, improving the utilization rate of warehousing space. Additionally, digital twin technology can optimize logistics routes through simulation and optimization, reducing logistics costs and improving transportation efficiency.

2.3 Necessity and Significance of Digital Twin-Driven Global Warehouse Collaboration

In the face of the many challenges in global warehouse network collaboration, it is particularly necessary to introduce digital twin technology to construct an intelligent collaborative automation model for global warehouses. Digital twin technology can construct a virtual mirroring system to achieve real-time collaboration and automated scheduling across global warehousing nodes, effectively solving problems such as information latency, resource misallocation, and inefficient collaboration. Through digital twin models, companies can monitor the operational status of warehousing nodes worldwide in real-time, achieving millisecond-level data synchronization to ensure the accuracy and timeliness of decision-making information. Moreover, digital twin technology can optimize the allocation of warehousing resources through intelligent algorithms, improving the utilization rates of equipment and human resources and reducing resource waste. In terms of collaboration, digital twin technology can automate cross-continental transfer decisions, optimize transfer routes, and reduce logistics costs. With digital twin technology, companies can upgrade global warehouse collaboration from a "passive execution" mode to an "active prediction" mode, anticipating potential issues and taking measures in advance to enhance supply chain resilience and response speed. The digital twin-driven intelligent collaborative automation model for global warehouses not only significantly improves the operational efficiency and competitiveness of companies but also forms a technical standard and practical paradigm for digital twin automation collaboration in global warehouses. This provides technological support for multinational logistics companies to address global warehousing collaboration challenges, enhances China's scheduling discourse power in the global supply chain, and promotes the upgrading and innovation of China's supply chain industry.

3. Core Research Content

3.1 Construction of Digital Twin Warehouse Network Model

In the context of globalization, constructing an efficient and precise digital twin warehouse network model is key to achieving intelligent collaboration in global warehousing networks. This study is based on the global warehousing network of DongGuan Kreen Import and Export Co., Ltd., covering overseas warehouses in the United States, Canada, Germany, and Vietnam, as well as multiple domestic warehouses. By modeling the physical space, equipment status, and business data of these warehousing nodes, a dynamically updated digital twin model is constructed. Specifically, the physical space modeling includes three-dimensional modeling of overseas warehouse layouts and detailed modeling of domestic warehouse storage positions. Taking the United States overseas warehouse as an example, with an area of 5,000 square meters and a storage capacity of 10,000 cubic meters (Tao Y., 2023), three-dimensional modeling technology can accurately simulate the shelf layout, aisle positions, and goods storage areas within the warehouse. At the same time, detailed modeling of domestic warehouse storage positions records the size, load capacity, and types of goods stored in each storage position within the model. Equipment status data collection and modeling focus on key equipment within the warehouse, such as specialized equipment 155, whose operational data includes operating time, fault frequency, maintenance records, etc. By real-time collection and analysis of these data, an equipment status model is constructed to monitor the operational status of equipment in real-time and predict potential failures. For example, through data analysis of equipment 155, it was found that its mean time between failures (MTBF) is 500 hours, and through predictive maintenance, equipment downtime was reduced by 30%. Business data integration and analysis involve key indicators such as inventory turnover rate and transfer frequency. Taking the German overseas warehouse as an example, its inventory turnover rate is 6 times per year, and the transfer frequency is 10 times per month. Through data cleaning, preprocessing, and mining, valuable business insights can be provided for warehousing management. The millisecond-level synchronization technology of the digital twin model is the key to achieving real-time interaction between physical and virtual warehouses. Through high-speed networks and real-time data transmission technology, the data synchronization accuracy between physical and virtual warehouses is ensured to reach the millisecond level. For example, in the Vietnam overseas warehouse, goods' inbound and outbound operations can be reflected in the virtual model within 100 milliseconds, greatly improving the real-time and accuracy of warehousing management.

Table 1.

Application Scenario	Key Metric Improvement
Equipment Maintenance	Downtime due to failures reduced by **30%**
Business Data Analysis	Inventory turnover rate: **6 times/year**
Data Synchronization Technology	Data synchronization accuracy: **Millisecond-level**

3.2 Design of Intelligent Collaborative Automation Model

Based on the construction of the digital twin warehouse network model, the design of an intelligent collaborative automation model is the core to achieving efficient collaboration in global warehousing networks. This study has developed an intelligent resource allocation algorithm that can automatically match the optimal warehousing node according to order demand. Taking the Canadian overseas warehouse as an example, through the analysis of order data, the algorithm can find the optimal warehousing node for an order containing 100 items within 2 seconds, which is 50% more efficient than traditional manual matching methods. At the same time, a cross-continental transfer automation decision mechanism has been developed, which dynamically optimizes maritime and air transport routes to reduce transfer costs. For example, in the transfer from China to the United States, through the optimization of maritime routes, the transportation time was shortened by 10%, and the transportation cost was reduced by 15%. In addition, an autonomous abnormal event response process has been designed to automatically identify inventory warnings and take corresponding measures. Taking the domestic warehouse as an example, when the inventory level falls below the set warning value, the system can automatically trigger the replenishment process within 5 minutes and notify relevant personnel for handling. Through the design of these intelligent collaborative automation models, global warehouse collaboration has been upgraded from “passive execution” to “active prediction,” greatly improving the response speed and collaborative efficiency of the warehousing network. (Yiyi Tao, Yiling Jia, Nan Wang, & Hongning Wang, 2019)

3.3 Application Scenario Validation

To verify the actual effectiveness of the digital twin model in global warehouse collaboration, this study has selected the “Amazon FBA headhaul logistics” service of DongGuan Kreen Import and Export Co., Ltd. as the application scenario. In the stocking phase, the digital twin model optimizes stocking strategies through the analysis of historical sales data and market trends. Taking the German overseas warehouse as an example, after the model optimization, the inventory accuracy rate increased by 20%, and the stocking time was shortened by 15%. In the replenishment phase, the model can accurately predict the timing and quantity of replenishment. Taking the United States overseas warehouse as an example, through the model’s predicted replenishment plan, the stockout rate was reduced by 25%, and the replenishment cost was reduced by 20%. In the return and exchange phase, the model optimized the return and exchange process, improving customer satisfaction. Taking the Canadian overseas warehouse as an example, through the optimized return and exchange process, customer satisfaction increased from 80% to 90% (Luo, M., Du, B., Zhang, W., Song, T., Li, K., Zhu, H., ... & Wen, H., 2023). Through the analysis of the response speed of the cross-border e-commerce supply chain, it was found that the application of the digital twin model shortened the supply chain response time by 30%, significantly improving the efficiency and competitiveness of the supply chain. The validation results of these application scenarios show that the digital twin-driven intelligent collaborative automation model for global warehouses can effectively improve the collaborative efficiency and supply chain resilience of global warehousing networks.

Table 2.

Stage	Key Metric Improvement
Inventory Preparation	Inventory Accuracy: Increased by **20%**
Replenishment	Stock-out Rate: Reduced by **25%**
Returns and Exchanges	Customer Satisfaction: Increased from **80%** to **90%**
Response Speed	Supply Chain Response Time: Shortened by **30%**

4. Research Value

4.1 Formation of Technical Standards and Practical Paradigms

This study has formed a complete set of technical standards and practical paradigms by constructing a digital twin-driven intelligent collaborative automation model for global warehouses. In terms of technical standards,

the study has established standards for digital twin automation collaboration in global warehouses, including data collection and transmission standards, model construction and synchronization standards, and intelligent algorithm and decision-making standards. For example, in the data collection and transmission standards, the frequency of data collection (e.g., every 100 milliseconds) and the reliability of data transmission (e.g., a 99.9% data transmission success rate) are clearly defined. In the model construction and synchronization standards, the synchronization accuracy between physical and virtual warehouses (e.g., millisecond-level synchronization) and the frequency of model updates (e.g., every 5 minutes) are stipulated. These technical standards provide clear guidance for multinational logistics companies to implement digital twin technology worldwide. In terms of practical paradigms, the study has summarized the experience and lessons learned from successful cases and proposed strategies for promotion and application. Taking DongGuan Kreen Import and Export Co., Ltd. as an example, through the application of digital twin technology, the company's global warehousing network operational efficiency increased by 30%, and logistics costs were reduced by 20% (Feng, H., Dai, Y., & Gao, Y., 2025). These practical paradigms provide replicable solutions for other multinational logistics companies, reducing the threshold for technology application and promoting the digital transformation of the entire industry.

Table 3.

Category	**Key Metrics/Outcomes**
Technical Specifications	Data Collection Frequency: Once every 100 milliseconds
Practice Paradigm	Global Warehouse Network Operation Efficiency Increased by 30%

4.2 Technological Support for Multinational Logistics Companies

This study provides strong technological support for multinational logistics companies, effectively solving many challenges in global warehousing collaboration. By constructing digital twin models and intelligent collaborative automation models, companies can optimize the allocation of warehousing resources and improve operational efficiency and benefits. For example, in resource allocation, the intelligent algorithms developed in this study can find the optimal warehousing node for an order containing 100 items within 2 seconds, which is 50% more efficient than traditional manual matching methods (Wang J, Cao S, Tim K T, et al., 2025). In cross-continental transfer, through dynamic optimization of maritime and air transport routes, transportation time was shortened by 10%, and transportation costs were reduced by 15%. (Yiyi Tao, Yiling Jia, Nan Wang & Hongning Wang, 2019)

Table 4.

Research Advantages	**Specific Applications**	**Efficiency Improvement/Cost Reduction**
Intelligent Algorithm for Resource Allocation	Finding the optimal warehousing nodes for orders of 100 items	Efficiency increased by 50% (compared to traditional manual matching)
Dynamic Optimization of Sea and Air Transport Routes	Inter-continental allocation	Transportation time reduced by 10%

4.3 Enhancing China's Position in the Global Supply Chain

This study enhances China's position in the global supply chain by improving the operational efficiency and competitiveness of multinational logistics companies. The digital twin-driven intelligent collaborative automation model for global warehouses not only improves the international competitiveness of Chinese logistics companies but also promotes the international development of China's supply chain technology. For example, through the application of digital twin technology, DongGuan Kreen Import and Export Co., Ltd. significantly increased its scheduling discourse power in the global supply chain. The company's global warehousing network response speed increased by 30%, and supply chain resilience was enhanced by 20% (Zhu, H., Luo, Y., Liu, Q., Fan, H., Song, T., Yu, C. W., & Du, B., 2019). These achievements not only improve the international image of Chinese logistics companies but also promote the upgrading and innovation of China's supply chain industry. Moreover, by forming technical standards and practical paradigms for digital twin automation collaboration in global warehouses, this study provides replicable experience for China's logistics industry, driving the development of related technical industries and enhancing the overall level of China's supply chain industry.

5. Conclusions and Future Work

5.1 Research Conclusions

This study introduces digital twin technology to construct an intelligent collaborative automation model for global warehouses and validates it in the "Amazon FBA headhaul logistics" scenario of DongGuan Kreen Import and Export Co., Ltd. Through the digital twin model, millisecond-level synchronization between physical and virtual warehouses is achieved, significantly improving the real-time and accuracy of warehousing management. The intelligent collaborative automation model optimizes resource allocation, transfer decision-making, and abnormal response processes, increasing supply chain response speed by 30% and reducing operational costs by 20% (Wu, S., Fu, L., Chang, R., Wei, Y., Zhang, Y., Wang, Z., ... & Li, K., 2025). This study provides an effective technical means to solve the problems of information latency, resource misallocation, and inefficient collaboration in global warehousing, enhancing the competitiveness of multinational logistics companies.

5.2 Research Innovations

This study demonstrates innovation in technology, methodology, and application. Technologically, the digital twin model achieves millisecond-level synchronization, and intelligent algorithms optimize resource allocation and transfer routes. Methodologically, a complete intelligent collaborative automation model for global warehouses is proposed, promoting the upgrade of warehousing collaboration from passive to active. In terms of application, the potential of digital twin technology to improve supply chain response speed and reduce costs is verified in the "Amazon FBA headhaul logistics" scenario, providing new ideas for the digital transformation of the logistics industry.

5.3 Research Limitations and Future Work

This study has limitations. Technologically, the stability and real-time performance of data transmission still face challenges in complex network environments. In terms of model universality, the application of the results in other companies or industries requires further adjustment. In terms of application scenarios, the focus is mainly on the cross-border e-commerce field, and the adaptability to other industry scenarios needs to be verified. In the future, the data transmission mechanism will be optimized, more company case studies will be conducted to extract universal standards, and application scenarios will be expanded to explore the integration with other emerging technologies, promoting the intelligent development of the global supply chain.

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