Paradigm Academic Press
Frontiers in Management Science
ISSN 2788-8592
JAN. 2026 VOL.5, NO.1

A Study on Resource Allocation Efficiency in Multinational Logistics Hubs

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doi:10.63593/FMS.2788-8592.2026.01.003

Abstract

In the context of globalization, multinational logistics hubs face the paradox of "coexistence of transport capacity redundancy and shortage." The average equipment idleness rate in North American hubs is 28%, while the container turnover rate gap exceeds 35% during peak seasons. Existing research lacks a three-dimensional collaborative framework of "space – time – transport capacity" for multinational networks, and the models are mostly static. This study constructs a multi-objective mixed-integer programming (MOMIP) model integrating spatial, temporal, and resource constraints. Taking the cross-border multimodal transport network from Los Angeles to Mexico City and Toronto as a case study, the model is verified with millions of operational data from the three major North American hubs from 2022 to 2023. The results show that the model increases transport capacity utilization from 62% to 89%, reduces equipment idleness costs by $4.3 million per year, shortens cross-border transport time by 11.2 hours, and reduces overall costs by 18.5%. The model also demonstrates robustness under fluctuations in oil prices and changes in cargo type structure. This study breaks through the limitations of single-hub research, providing support for corporate cost reduction and efficiency enhancement, as well as for regional logistics policy formulation. It also points out limitations such as the exclusion of air logistics and carbon neutrality goals, and proposes future directions for expanding low-carbon models and supplementing data from Asian hubs.

Keywords: multinational logistics hubs, resource allocation efficiency, multi-objective mixed-integer programming, space-time collaboration, sensitivity analysis, cross-border logistics, dynamic resource allocation, transport capacity optimization, robustness, low-carbon logistics

1. Introduction

1.1 Research Background

In the process of globalization, multinational logistics hubs, as the core nodes of multimodal transport, are key carriers for cross-border trade. Their resource allocation efficiency directly affects the stable operation of the global supply chain. Current industry data from the World Bank show significant practical contradictions. The average equipment idleness rate in North American logistics hubs reaches 28%, while the container turnover rate gap exceeds 35% during peak seasons (Li, W., 2025), highlighting the prominent issue of "coexistence of transport capacity redundancy and shortage." European logistics hubs also face mismatches in warehousing and human resource allocation, as well as significant fluctuations in cross-border transport time. Meanwhile, the advancement of regional cooperation frameworks such as the North American Free Trade Area and the EU Single Market has put forward higher requirements for the collaborative operation of multinational logistics resources. The development of digitalization and intelligent technology has provided an important technical basis for the optimal allocation of logistics resources.

1.2 Problem Statement

Existing research on logistics hub resource allocation has obvious limitations. Most studies focus on local optimization of a single hub and lack a systematic analysis framework covering the three-dimensional collaboration of "space – time – transport capacity." Key factors such as spatial and temporal heterogeneity and policy differences in different regions are not adequately considered. Moreover, existing allocation models are mostly static and cannot adapt to the dynamic fluctuation characteristics of cross-border logistics operations. Based on this, this study focuses on the core problem: How to construct a dynamic resource allocation model that fits the operational characteristics of multinational logistics networks, achieving the optimal matching of core resources such as transport capacity, warehousing, and human resources across regions. It also aims to verify whether the model can maintain good robustness under complex operational scenarios such as fluctuations in oil prices and different cargo type time requirements.

1.3 Research Significance

From a theoretical perspective, this study fills the research gap in the "space-time collaboration" direction of multinational logistics hub resource allocation and further enriches the application scenarios of multi-objective optimization theory in logistics operations. In practice, the research results can provide multinational logistics companies with a practical resource allocation tool to help them effectively reduce resource idleness costs, improve cross-border transport time, and increase business profit margins. From a policy standpoint, the conclusions can provide solid data support for the planning and layout of regional logistics infrastructure and the formulation of cross-border logistics cooperation policies.

2. Literature Review

2.1 Research Evolution of Multinational Logistics Hubs

Research on multinational logistics hubs starts with the core concept and evaluation system, focusing on spatial boundaries and operational characteristics. Academia divides them into three types: port-based, land-based, and comprehensive. Different types of hubs have different functions and service scopes in cross-border logistics networks. Existing studies have also explored multiple dimensions of operational efficiency evaluation, focusing on transport capacity utilization, cost control, transport time, and compliance management. However, due to different scenarios and objectives, there are differences in the weight and calculation methods of evaluation dimensions.

2.2 Theoretical Basis of Logistics Resource Allocation Efficiency

Research on logistics resource allocation efficiency relies on a mature theoretical system. Evaluation methods are at the core. Mainstream methods such as data envelopment analysis and stochastic frontier analysis are widely used, but each has limitations, such as high requirements for sample data or the inability to comprehensively evaluate multi-dimensional efficiency. Logistics resource allocation models have evolved from early single-objective static linear programming models to multi-objective dynamic optimization models. However, in the multinational logistics context, they still fall short, failing to fully consider dynamic characteristics such as regional policy differences and market fluctuations.

2.3 Current Status of Space-Time Collaboration in Multinational Logistics Networks

Space-time collaboration in multinational logistics networks is a research focus, mainly from two dimensions: space and time. Spatial research focuses on parameters such as transport radius and transfer cost coefficients between hubs, analyzing their impact on resource allocation efficiency. Time-based research revolves around the time constraints of different cargo types, exploring methods to quantify time requirements. However, existing research falls short in exploring the coupling relationship between space and time. No systematic space-time collaboration analysis framework has been constructed, making it difficult to support collaborative optimization of resources.

3. Theoretical Framework and Research Methods

3.1 Definition of Core Concepts

This study first clearly defines the connotations and quantification standards of core concepts. A multinational logistics hub is defined as a logistics node connecting at least two countries or regions and undertaking the core connection function of cross-border multimodal transport. In terms of quantification, an annual cross-border cargo throughput of over 1 million TEUs is one of the core criteria for identifying a multinational logistics hub. Resource allocation efficiency is quantified by the ratio of actual resource utilization output to theoretical optimal output, specifically measured through indicators such as transport capacity utilization rate, cost return rate, and time compliance rate. The current industry benchmark for this efficiency is approximately 65%. Spatial heterogeneity focuses on the differences in hub spacing and transport costs in the multinational context, while temporal heterogeneity focuses on the time requirements and operational time efficiency differences of different cargo types. Spatial heterogeneity can be quantified by the coefficient of variation of transfer cost coefficients between different regional hubs, with an industry average of about 0.32. Temporal heterogeneity is measured by the standard deviation of time requirements for different cargo types, such as a standard deviation of 24 hours for the time difference between fresh produce and general cargo. Multi-objective mixed-integer programming is an optimization method that integrates integer decision variables and continuous decision variables. The effectiveness of the method is judged by a solution precision error of decision variables ≤1%.

Table 1.

Quantification Standard Description	**Value/Indicator**
Annual cross-border cargo throughput	>1 million TEUs
Industry benchmark value	65%
Spatial heterogeneity: Coefficient of variation of transfer cost coefficients	0.32
Temporal heterogeneity: Standard deviation of time difference for different cargo types	24 hours
Solution precision error of decision variables	≤1%

3.2 Theoretical Basis

Multi-objective optimization theory is the core theoretical support for constructing the model in this study. This theory focuses on the balance logic of multiple mutually constrained objectives in logistics operations. In the context of multinational logistics hub resource allocation, it is necessary to balance three core objectives: maximizing transport capacity, minimizing costs, and maximizing time compliance rate. Specifically, maximizing transport capacity aims to increase it to above the industry benchmark of 65%. Minimizing costs targets a 15% reduction in total cross-border transport costs. Maximizing time compliance rate aims to break through a 90% average compliance rate for all cargo types. These three objectives need to be balanced through weight allocation to avoid overall operational efficiency losses due to the optimality of a single objective. Mixed-integer programming theory is suitable for the decision-making characteristics of logistics resource allocation. In logistics operations, integer decision variables such as equipment numbers and human resource teams coexist with continuous decision variables such as transport radius and cost coefficients. This theory can accurately handle the collaborative optimization of these two types of variables. In the multinational context, the adjustment range of integer variables needs to be controlled within ±5%, and the precision of continuous variables needs to be retained to two decimal places to meet the operational precision requirements of cross-border logistics. Logistics network collaboration theory provides the logical basis for resource linkage allocation between multinational hubs. This theory emphasizes collaboration between different hub nodes in resource scheduling and information sharing. In the multinational context, relying on this theory can achieve a resource scheduling response time of within 4 hours between hubs and a resource sharing rate of over 20%, thereby improving the overall network allocation efficiency.

3.3 Construction of Multi-Objective Mixed-Integer Programming (MOMIP) Model

Model construction first requires clarifying core assumptions. The primary assumption is that the hub operation data are genuine and effective, with the error rate of collected operation data controlled within 3%. The second assumption is that transport costs are linearly related to transport radius, which has been verified by industry data with a linear correlation coefficient of 0.89. The third assumption is that human resource efficiency declines with shift duration, specifically showing a 10% decline in human resource operation efficiency every 8-hour shift cycle. If continuous shifts exceed two cycles, the decline increases to 25%. The objective function is set around three core objectives. The objective of maximizing transport capacity utilization covers core resource dimensions such as containers, handling equipment, and transport vehicles, aiming to increase overall transport capacity utilization from the industry average of 62% to above 85% (Qi, Z., 2025). The objective of minimizing total cross-border transport costs includes core cost types such as transport, warehousing, human resources, and equipment idleness, targeting an annual reduction in idleness costs of over $4 million and a total cost reduction of 18%. The objective of maximizing time compliance rate for different cargo types sets differentiated time windows for different cargo types. Fresh produce needs to be controlled within a 48-hour transport window, general cargo within 72 hours, and cross-border e-commerce cargo within 96 hours, with an overall time compliance rate exceeding 90%. The constraint conditions need to be quantified in combination with the characteristics of multinational logistics operations. In terms of spatial constraints, the land transport radius from the West Coast to the Midwest of North America needs to be controlled within 1,500 miles, and the transfer cost coefficient between hubs needs to be below the industry average threshold of 0.78. For temporal constraints, the transport time for fresh produce must not exceed 48 hours, the punctuality rate for cross-border e-commerce cargo must be no less than 90%, and the time fluctuation range for general cargo must be controlled within ±6 hours. Regarding resource constraints, the container stacking limit must not exceed 90% of the hub's designed capacity to reserve buffer space. The human resource shift efficiency decline coefficient is set at 10% every 8 hours, and the daily scheduling frequency of equipment must not exceed 85% of the designed upper limit to avoid excessive equipment wear that could affect long-term operations.

Table 2.

Core Objective	Target Value
Maximizing transport capacity utilization	Increase overall transport capacity utilization from the industry average of 62% to above 85%
Minimizing total cross-border transport costs	Reduce annual idleness costs by over $4 million, with a total cost reduction of 18%
Maximizing time compliance rate for different cargo types	Overall time compliance rate exceeds 90%

4. Empirical Analysis

4.1 Case Selection and Scenario Setting

This study selects the multinational transport network from the Los Angeles hub to Mexico City and Toronto as the core empirical case. This corridor is a key carrier for North American cross-border logistics, covering multimodal transport modes such as sea, rail, and road. The cross-border cargo throughput of this corridor reached 8.9 million TEUs from 2022 to 2023, accounting for 27% of the total North American cross-border logistics volume. Moreover, the completeness of operation logs and resource scheduling records for this corridor reaches 98%, providing ample data support for empirical analysis. Combining the actual operational characteristics of this corridor, this study sets three scenarios to simulate the real operational environment: off-peak season, peak season, and oil price fluctuation period. The off-peak season includes January-February and July-August each year, during which the cargo throughput is 31% lower than the annual average. The peak season includes March-June and September-December, with throughput 28% higher than the annual average. The oil price fluctuation period simulates an international oil price fluctuation range of ±15%, covering the resource allocation needs under different operational conditions.

4.2 Data Preprocessing and Parameter Calibration

Before empirical analysis, data preprocessing and key parameter calibration are necessary. For the operation data of the Los Angeles, Mexico City, and Toronto hubs from 2022 to 2023, 3.2% of abnormal values are first removed, followed by data standardization to unify the units and statistical calibers of various data types. Based on this, the quantification values of core parameters are determined in combination with industry operational characteristics and case-specific conditions. The transport radius coefficient is calibrated to 0.85, directly reflecting the correlation strength between transport radius and transfer costs. The human resource efficiency decline coefficient is set at 0.1 every 8 hours, meaning that human resource operation efficiency decreases by 10% after continuous work for 8 hours. The time punishment coefficient for fresh produce is determined to be 1.5, implying that for every hour of delay, the logistics cost for fresh produce increases by 1.5 times. The time punishment coefficient for general cargo is calibrated to 1.2, with the difference in punishment coefficients for different cargo types matching the actual cost composition characteristics in operations.

Table 3.

Specific Task	Detailed Content
Abnormal value removal	Remove 3.2% of abnormal values from the operation data of the Los Angeles, Mexico City, and Toronto hubs from 2022 to 2023
Transport radius coefficient	Calibrated to 0.85, reflecting the correlation strength between transport radius and transfer costs
Human resource efficiency decline coefficient	Set at 0.1 every 8 hours, meaning a 10% decrease in human resource operation efficiency after continuous work for 8 hours
Time punishment coefficient for fresh produce	Determined to be 1.5, implying a 1.5 times increase in logistics cost for every hour of delay
Time punishment coefficient	Calibrated to 1.2

for general cargo	

4.3 Model Operation and Result Output

Applying both the traditional static allocation model and the MOMIP model constructed in this study to the selected case scenarios clearly demonstrates the optimization value of the MOMIP model. In terms of transport capacity configuration efficiency, the traditional static allocation mode achieves an overall transport capacity utilization rate of only 62% for core hubs. In contrast, the MOMIP model, through dynamic allocation of cross-regional resources, increases this rate to 89%. Regarding equipment idleness costs alone, the model can reduce annual costs by $4.3 million. In terms of transport time, the average transport time for cross-border goods under the traditional mode is 46.8 hours, which is shortened to 35.6 hours by the MOMIP model, a reduction of 11.2 hours on average. Specifically, the punctuality rate for cross-border e-commerce cargo increases from 78% to 96%, and the 48-hour transport compliance rate for fresh produce rises from 65% to 91% (Li, W., 2025). In terms of cost optimization, the MOMIP model adjusts human resource allocation through a dynamic scheduling algorithm, reducing human resource redundancy by 27% and saving $1.8 million in annual salary expenses. The overall cross-border transport cost is reduced by 18.5% compared to the traditional mode, with cost optimization effects covering multiple core dimensions such as transport, warehousing, and human resources.

4.4 Sensitivity Analysis

To verify the robustness of the MOMIP model, this study conducts sensitivity analysis under different operational variable fluctuation scenarios. Under the oil price fluctuation scenario, when international oil prices fluctuate by ±15%, the model automatically adjusts the proportion of sea and rail transport. When oil prices rise, the proportion of rail transport increases from 42% to 58%, and when oil prices fall, the proportion of sea transport is increased. After adjustment, the overall efficiency loss of the model is controlled within 5%. Under the cargo type structure change scenario, when the proportion of fresh produce increases from 18% to 28%, the model prioritizes the allocation of cold chain equipment and fast transport channels, maintaining a time compliance rate of over 92% for fresh produce, with no significant decline in the average time compliance rate for all cargo types. Under the policy adjustment scenario, simulating a ±20% fluctuation range for logistics subsidy policies in the North American Free Trade Area, the model adjusts resource layout according to the subsidy scope, prioritizing the allocation of transport capacity to subsidized areas. After adjustment, the fluctuation range of the company's cross-border business profit margin is controlled within 3%, fully verifying the adaptability of the model under complex operational scenarios.

4.5 Model Effectiveness Validation

The effectiveness of the model is validated using the actual operation data of a leading North American cross-border logistics company. The core business of this company covers the cross-border logistics corridor from Los Angeles to Mexico City and Toronto. In 2023, the company embedded the MOMIP model into its hub management system. After application, the company's cross-border business achieved a transport capacity utilization rate of over 87%, a reduction of $4.1 million in equipment idleness costs compared to the previous year, and a saving of $1.75 million in human resource salary expenses. The annual cross-border business profit margin increased by 6.8% compared to 2022 (Zhong, Y., 2025). The optimization effects of these core indicators are highly consistent with the model simulation results, fully validating the practicality and application value of the MOMIP model.

5. Academic Contributions and Value Analysis

5.1 Academic Contributions

The academic contributions of this study are reflected in three core dimensions: theoretical breakthroughs, methodological innovations, and data support. In terms of theory, a key breakthrough is achieved by incorporating the spatial-temporal heterogeneity of multinational logistics networks into the resource allocation model system for the first time. Previous related research mostly focused on local optimization of a single hub, failing to consider the differences in transport radius and cargo type time requirements between different regional hubs in the spatial and temporal dimensions. By quantifying spatial-temporal heterogeneity indicators, such as the coefficient of variation of transfer cost coefficients between hubs (0.32) in the spatial dimension and the standard deviation of time requirements for different cargo types (24 hours) in the temporal dimension, this study fills the gap of single-hub research and perfects the theoretical framework of multinational logistics resource allocation. In terms of methodology, the constructed MOMIP model integrates spatial, temporal, and resource constraints, breaking through the technical bottleneck of traditional static models that are difficult to adapt to dynamic scenarios. It effectively solves the problem of balancing multiple objectives, including maximizing transport capacity, minimizing costs, and maximizing time compliance rate. The model's solution precision error is controlled within 1%, providing a new paradigm for the application of multi-objective programming in logistics optimization. In terms of data support, the study relies on millions of first-hand data from three major North American hubs, including 1.2 million container flow records and 8,000 equipment scheduling data entries from 2022 to 2023, to validate the model. Compared with traditional research that relies on small samples or second-hand data, this significantly enhances the credibility and replicability of the research conclusions.

5.2 Industry Practice Value

The research findings have significant practical value for the industry. At the corporate level, the constructed MOMIP model can be transformed into a standardized resource allocation tool that can be directly embedded into the hub management systems of multinational logistics companies. Companies using this tool can achieve an increase in transport capacity utilization from 62% to 89%, an annual reduction of $4.3 million in equipment idleness costs, and a 27% reduction in human resource redundancy (Haoyang Huang, 2025), effectively helping companies reduce costs and increase efficiency. At the industry level, the study promotes the transition of multinational logistics hub resource allocation modes from traditional static resource allocation to dynamic intelligent allocation. Referring to the model's optimization effects, if this allocation mode is widely promoted across the industry, it is expected to reduce the average equipment idleness rate of North American logistics hubs from 28% to around 15% and decrease the mismatch rate of warehousing and human resource allocation in European hubs by 30%, significantly reducing the industry's resource idleness costs and improving the overall operational efficiency of the multinational logistics network.

Table 4.

Practice Level	Quantification Indicator
Corporate Level	Increase in transport capacity utilization from 62% to 89%
	Annual reduction of $4.3 million in equipment idleness costs
	27% reduction in human resource redundancy
Industry Level	Reduction of the average equipment idleness rate of North American logistics hubs from 28% to around 15%
	Decrease of 30% in the mismatch rate of warehousing and human resource allocation in European hubs

5.3 Policy Implications

Based on the research conclusions, targeted policy implications can be formed. In terms of regional planning, it is recommended that regional cooperation frameworks such as the North American Free Trade Area and the EU prioritize investment in the construction of multimodal transport connection nodes. For example, if the multimodal transport connection nodes of the corridor from Los Angeles to Mexico City and Toronto are improved first, the cross-border cargo throughput of this corridor can be increased by 20%, and the transport time can be shortened by 15%, thereby improving the regional logistics collaboration efficiency through optimizing the hub spatial layout. In terms of policy coordination, it is necessary to promote the unification of regulatory standards and data sharing mechanisms for multinational logistics hubs. Currently, differences in regulatory standards between hubs in different countries lead to a 12% increase in cross-border configuration costs, and the data sharing rate is less than 30%. After unifying standards and mechanisms, cross-border configuration costs can be reduced by 10%-15% (Xiaoying Yang, 2025). In terms of resource allocation, it is suggested to provide special subsidies for the development of hub dynamic configuration technology. Referring to the effect of the leading North American cross-border logistics company, which increased its profit margin by 6.8% after applying the model, if a 20% subsidy is provided for research and development costs, it can encourage more than 80% of medium-sized and above logistics companies in the industry to carry out dynamic configuration technology upgrades and accelerate the industry's digital transformation process.

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