



Research Article

A Data-Informed Evaluation Framework for Improving Logistics Mode Selection in Cross-Border E-Commerce

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KEYWORDS

cross-border e-commerce
logistics mode selection
data-informed evaluation
framework
analytic hierarchy process
fuzzy comprehensive evaluation

ABSTRACT

With the rapid development of cross-border e-commerce, logistics mode selection has become an important factor affecting cost control, service efficiency, and customer experience in transnational supply chains. Cross-border e-commerce logistics involves fragmented orders, small shipment sizes, diverse destinations, high delivery-time requirements, and complex customs clearance procedures. These characteristics make it increasingly difficult for firms to rely on a single logistics mode or managerial experience alone. To support more systematic logistics mode selection, this study develops a data-informed evaluation framework that integrates the analytic hierarchy process and fuzzy comprehensive evaluation. The analytic hierarchy process is used to determine the weights of influencing factors, while fuzzy comprehensive evaluation is applied to compare alternative basic logistics modes under specific business conditions. The framework is applied to an anonymized Japanese cross-border e-commerce platform selling small household appliances to the East China market. Four alternative logistics modes are evaluated: overseas warehouses, dedicated-line logistics, postal parcels, and outsourced international express delivery. The results show that dedicated-line logistics obtains the highest evaluation score, while overseas warehousing can serve as a supplementary option for popular products and demand fluctuations. To improve the transparency of the expert-informed evaluation, the framework incorporates AHP consistency testing, sensitivity analysis, and post-implementation triangulation with operational indicators. The study contributes to logistics mode selection research by showing how managerial judgment, numerical calculation, and operational evidence can be combined to support logistics mode formulation under a clearly defined product-market context, while empirical rankings require context-specific interpretation.

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ARTICLE INFO

Received: 26 January 2026 | Revised: 24 February 2026 Accepted: 26 February 2026 | Published Online: 27 February 2026

DOI: <https://doi.org/10.65773/tscr.2.1.139>

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1. Introduction

Cross-border e-commerce logistics refers to the logistics services involved in e-commerce activities that cross national borders, including transportation, warehousing, distribution, customs clearance, and related service processes. With the development of globalization and Internet-based trade, cross-border e-commerce has become an important form of international business and has attracted increasing academic attention in recent years [1,2]. However, compared with ordinary domestic e-commerce and traditional international trade, cross-border e-commerce has distinctive operational characteristics, such as fragmented orders, small shipment sizes, high requirements for timeliness, complex customs procedures, longer delivery lead times, and diverse customer demands [3-5]. These characteristics make logistics mode selection more difficult and create higher requirements for cost control, service efficiency, and operational coordination [6-8].

In practice, unsuitable logistics modes can have a direct negative impact on cross-border e-commerce operations. They may increase unnecessary logistics costs, reduce delivery efficiency, complicate returns and exchanges, and weaken the customer experience. Previous studies have shown that logistics cost, delivery time, return policy, service timeliness, information quality, price fairness, and overall logistics service quality can affect consumer satisfaction, purchase intention, and repurchase intention in cross-border e-commerce [5,9,10]. As competition in cross-border e-commerce becomes more intense, logistics is no longer only a supporting activity. It has become an important factor affecting platform competitiveness, customer satisfaction, and business sustainability. Cross-border e-commerce firms increasingly need to coordinate product flows, information flows, financial flows, logistics resources, and platform-based service capabilities in a more integrated way [11-13].

Recent studies further suggest that logistics mode selection should be understood as a multi-dimensional supply chain decision. In cross-border e-commerce, logistics mode selection may be affected by demand uncertainty, exchange rate risk, information sharing, cost pressure, and the coordination between platforms and logistics service providers [14]. At the same time, studies on green and sustainable supply chains show that supply chain decisions are increasingly shaped by carbon-related constraints, environmental performance, and coordination mechanisms among different actors [15,16]. Therefore, it is necessary to examine how logistics modes can be selected and improved under specific business conditions.

Existing studies have examined cross-border e-commerce logistics from different perspectives. One line of research focuses on the coordination between cross-border e-commerce firms, logistics enterprises, integrated logistics service platforms, and local market conditions. These studies suggest that logistics modes need to fit both the operational characteristics of e-commerce platforms and the institutional and market environment of the destination country [17-19]. Another line of research examines logistics mode formulation from the perspective of enterprise profitability and mode selection. With the development of information and transportation technologies, the logistics modes available to cross-border e-commerce firms have expanded from postal services, consolidated shipping, third-party logistics, and overseas warehouses to a wider range of options, including bonded zones, self-built overseas warehouses, third-party overseas warehouses, and platform

-based warehouse services [20]. In response to this diversification, previous studies have used methods such as the AHP, entropy weighting, and logistic regression to evaluate overseas warehouse selection and logistics mode formulation under different logistics conditions [21,22].

International studies have also analyzed cross-border e-commerce logistics mode formulation from broader perspectives. Existing research shows that logistics mode choice can be affected by infrastructure quality, destination-country income levels, production fragmentation, logistics competitiveness, transportation infrastructure, and supportive government policies [23,24]. At the same time, emerging data technologies, such as blockchain, Internet of Things-based data integration, and big data storage and analysis, may support logistics mode formulation by improving the visibility of logistics needs, demand fluctuations, inventory conditions, and supply chain risks [25]. Other studies have addressed missing logistics data and proposed improved quantitative models to help e-commerce operators evaluate existing logistics modes more effectively [26].

Recent research has examined logistics mode selection under uncertainty more directly. For example, Zha et al. [12] and Zhang et al. [13] analyzed logistics mode selection and information sharing in cross-border e-commerce supply chains, while Li et al. [14] examined the choice between direct mail and bonded warehouse modes under exchange rate risk and demand uncertainty. These studies show that logistics mode selection is also affected by information availability, risk exposure, demand fluctuation, and the operational flexibility of different logistics modes. In parallel, studies on sustainable logistics have extended logistics evaluation to vehicle routing optimization, operating cost control, last-mile logistics, reverse logistics, and carbon-emission-based evaluation systems for cross-border e-commerce logistics modes [27,28]. Sustainable supply chain research also suggests that firms may adjust their decisions under carbon tax, carbon cap, and carbon trading policies, and that coordination mechanisms become important when emission reduction, demand uncertainty, and different profit motives coexist [15,16]. These findings are relevant to cross-border e-commerce logistics because logistics mode selection increasingly requires firms to consider cost, coordination, risk, and environmental constraints together.

To clarify the position of this study in relation to existing logistics evaluation frameworks, Table 1 compares the main focus of several related approaches in the logistics literature. Existing frameworks provide useful tools for evaluating logistics service providers, logistics service quality, mode choice under uncertainty, and sustainable logistics performance. The present study builds on these discussions while focusing on a more specific problem: how a cross-border e-commerce firm can compare alternative logistics modes under a clearly defined product-market context and translate the evaluation result into an operational logistics arrangement.

Table 1. Comparison between existing logistics evaluation frameworks and the proposed framework.

Framework type in previous studies	Main focus	Usefulness for logistics evaluation	Remaining gap for this study's problem	Position of this study
Logistics service provider selection frameworks	Selection or ranking of third-party logistics providers	Useful for comparing providers based on cost, service, reliability, and operational capability	The decision object is usually the provider, while the present study evaluates logistics modes and their fit with a product-market context	Evaluates overseas warehouses, dedicated-line logistics, postal parcels, and outsourced express delivery as alternative logistics modes
Cost-, time-, or service-quality-based evaluation frameworks	Freight cost, delivery time, customer satisfaction, service reliability, and complaint-related performance	Useful for measuring key logistics outcomes	A single performance perspective may not fully capture product type, platform strategy, policy environment, and e-	Combines cost, quality, product type, logistics environment, and e-commerce environment in one indicator system

commerce environment				
Cross-border e-commerce mode choice models under uncertainty	Choice between specific modes, such as direct mail and bonded warehouses, under demand uncertainty, information sharing, or exchange-rate risk	Useful for explaining how uncertainty affects logistics mode decisions	Many models focus on a limited number of modes or formal assumptions, with less attention to operational implementation after evaluation	Compares four practical modes and links the evaluation result to a concrete logistics arrangement
Digital or data-oriented logistics evaluation frameworks	Use of logistics data, information sharing, and digital technologies to improve logistics decisions	Useful for reducing information fragmentation and improving decision support	Data are often incomplete in early-stage cross-border e-commerce platforms, and some factors still require managerial judgment	Uses expert-informed judgment together with consistency testing, sensitivity analysis, and operational triangulation
Sustainable logistics evaluation frameworks	Carbon emissions, energy use, green logistics capability, and environmental performance	Useful for extending logistics evaluation beyond short-term cost and service performance	Sustainability indicators may need to be adapted according to data availability and the firm's decision stage	Provides a framework that can later incorporate sustainability-related indicators while retaining product-market fit as the core decision context

Taken together, these studies have advanced the understanding of cross-border e-commerce logistics, but three issues remain insufficiently addressed. First, existing studies often examine logistics cost, service quality, uncertainty, information sharing, digital technologies, and sustainability as separate themes, whereas firms usually need to consider them together when selecting a logistics mode. Second, many evaluation frameworks focus on logistics service provider selection, single performance dimensions, or specific mode choices under formal assumptions, and therefore provide limited guidance on how a firm can move from multi-criteria evaluation to an operational logistics arrangement in a specific product-market context. Third, empirical applications in cross-border e-commerce logistics remain limited, especially those that clarify which parts of an evaluation procedure can be adapted to other contexts and which results remain tied to the case setting.

To address these issues, this study develops a data-informed evaluation framework for diversified logistics mode selection in cross-border e-commerce. The framework integrates the AHP and the fuzzy comprehensive evaluation method. The AHP is used to determine the weights of the influencing factors, while the fuzzy comprehensive evaluation method is used to compare alternative basic logistics modes under specific business conditions. The framework is then applied to an anonymized Japanese cross-border e-commerce platform selling small household appliances to the East China market, in order to examine whether it can support practical logistics mode selection. Based on the case results, the study further discusses the broader problems, underlying causes, and improvement directions of cross-border e-commerce logistics modes.

This study contributes to the literature in three ways. First, it links the practical problems of cross-border e-commerce logistics with deeper structural causes. The framework evaluates alternative logistics modes through cost, quality, product type, logistics environment, and e-commerce environment, instead of relying on a single cost or delivery-speed criterion. Second, it develops a structured expert-informed evaluation framework that combines AHP-based weighting, fuzzy comprehensive evaluation, consistency testing, sensitivity analysis, and post-implementation operational triangulation. This design makes the role of managerial judgment more transparent and reduces the risk that the final ranking depends only on unchecked subjective assessment. Third, it provides a case-based application that shows how an evaluation result can be translated into a concrete logistics arrangement. At the same time, the study clarifies that the empirical ranking is tied to the case context, while the evaluation procedure can be recalibrated for other product categories, target markets, and platform types.

The remainder of this paper is organized as follows. Section 2 presents the evaluation framework and explains the construction of the AHP and fuzzy comprehensive evaluation model. Section 3 applies the proposed framework to a case platform and reports the evaluation results and the resulting logistics mode. Section 4 discusses the main problems, underlying causes, and improvement directions for cross-border e-commerce logistics modes based on the findings and relevant literature. Section 5 concludes the paper by summarizing the main findings, limitations, and future research directions.

2. Methodology

In cross-border e-commerce logistics, operational data are often fragmented across platforms, logistics providers, warehouses, customs clearance procedures, and last-mile delivery systems. Some evaluation dimensions, such as policy risk, service flexibility, product-mode fit, and customer experience, are also difficult to measure through a single quantitative indicator. Therefore, expert-informed judgment is used in this study as one component of a structured evaluation process. To reduce the influence of unchecked subjectivity, the framework combines AHP-based pairwise comparison, fuzzy comprehensive evaluation, consistency testing, sensitivity analysis, and post-implementation triangulation with operational indicators. In this framework, the AHP is first used to determine the weights of different influencing factors, and the fuzzy comprehensive evaluation method is then applied to compare alternative basic logistics modes under the given business conditions.

When the framework is applied to another context, the calculation procedure can remain the same, but the evaluation inputs need to be recalibrated. The product category, destination market, platform development stage, available logistics modes, and data availability should be reviewed before constructing the indicator system, judgment matrices, and fuzzy relation matrices. In this sense, the framework is designed as an adaptable evaluation procedure, while the weights, membership values, and final ranking are expected to vary across contexts.

2.1. Determination of the Weights of Influencing Factors

Cross-border e-commerce logistics lacks sufficient and effective quantitative evaluation data. In addition, the rapid development of cross-border e-commerce makes it difficult to directly apply existing quantitative evaluation models to the evaluation of logistics modes. Therefore, this study adopts the AHP, a method that lies between qualitative and quantitative analysis.

According to the theory of the AHP, the method can be carried out in the following four steps.

2.1.1. Establishment of a Hierarchical Structure Model

The hierarchical structure model required by the AHP generally takes the form of a three-level pyramid. The first level represents the highest objective of the entire analysis. In the logistics mode selection model, this level refers to the optimal selection of a logistics mode.

The second level consists of the main factors that affect the achievement of the objective. In the logistics mode evaluation model, this level refers to the broad categories of factors influencing logistics mode selection, hereafter referred to as “major factors.” Based on the actual conditions of cross-border e-commerce, the main influencing factors of logistics modes include six categories: scale, quality, cost, product type, logistics environment, and e-commerce environment.

The third level further subdivides the major factors in the second level. In this study, scale is divided into capital, labor, and operations, while quality is divided into timeliness, safety, and accuracy. Similarly, cost, product type, logistics environment, and e-commerce environment are divided into their corresponding sub-factors, forming the third level of the hierarchy.

2.1.2. Construction of All Judgment Matrices at Each Level

At the second level of the hierarchical model, the relative importance of the major factors is judged. At the third level, each major factor is taken as a unit, and the relative importance of its corresponding sub-factors is judged. The judgment results are expressed using numerical values and written in matrix form, thereby forming judgment matrices. Therefore, in this logistics mode evaluation model, there is one judgment matrix at the second level. Since there are six major factors at the third level, there are six judgment matrices at that level. In total, the whole model contains seven judgment matrices.

The numerical expression of the judgment results is based on the nine-point scale method. As shown in Table 2, values are assigned according to the degree of importance. Each comparison takes the ratio of the influence of two factors on the objective, and all comparison results together form the judgment matrix.

Table 2. Values used in the judgment matrix.

Scale	Meaning
1	The two factors are equally important.
3	The former factor is slightly more important than the latter.
5	The former factor is clearly more important than the latter.
7	The former factor is strongly more important than the latter.
9	The former factor is extremely more important than the latter.
2, 4, 6, 8	Intermediate values between the adjacent judgments above.

2.1.3. Expert Elicitation and Aggregation of Pairwise Judgments

Because the evaluation of cross-border e-commerce logistics modes involves both measurable operational factors and context-specific managerial judgments, the judgment matrices were constructed through a structured expert elicitation process. The expert panel consisted of staff members who were familiar with Platform A's logistics operations for Japanese small household appliances in the East China market. The panel covered four functional perspectives: logistics operations, warehousing and inventory management, customer service and after-sales support, and platform-level business management. These perspectives were included to reduce the risk that the pairwise comparisons would reflect only a single operational viewpoint.

The experts first reviewed the case background, the target product category, the destination market, the four alternative logistics modes, and the main operational problems faced by the platform. They then evaluated the relative importance of the second-level factors and the corresponding third-level sub-factors by using the nine-point scale shown in Table 2. The pairwise comparisons were discussed and adjusted until a group-level judgment matrix was obtained for each level of the hierarchy. The final matrices therefore represent case-specific collective judgments.

This study treats these expert judgments as structured inputs for the AHP calculation, and the experts' perspectives included are shown in Table 3. To reduce the risk of unchecked subjectivity, the final group-level matrices were tested using the consistency ratio, and the stability of the ranking results was further examined through sensitivity analysis. In addition, the recommended logistics mode was compared with post-implementation operational indicators in order to triangulate whether the model result was consistent with subsequent changes in logistics cost and service performance.

Table 3. Expert perspectives included in the structured elicitation process.

Expert perspective	Main operational knowledge	Role in the evaluation
Logistics operations	Shipment planning, transport arrangement, cross-border delivery	Evaluation of transportation cost, timeliness, delivery feasibility, and

	coordination	operational risk
Warehousing and inventory management	Storage arrangement, inventory turnover, warehouse operation, demand fluctuation	Evaluation of warehousing cost, stock pressure, product turnover, and overseas warehouse feasibility
Customer service and after-sales support	Customer complaints, returns and exchanges, delivery-related service issues	Evaluation of service quality, complaint risk, return handling, and customer experience
Platform-level business management	Cost control, platform strategy, product-market fit, implementation feasibility	Evaluation of business fit, financial pressure, and coordination with platform operations

2.1.4. Single-level Ranking and Consistency Test

The judgment matrices constructed manually in the second step are affected by subjective factors, so inconsistencies may arise after the comparison of different factors. For example, if A is twice as important as B, and B is twice as important as C, then according to mathematical reasoning, A should be four times as important as C. However, in a manually constructed matrix, the importance of A may be set as three times that of C. Therefore, in this step, the manually constructed judgment matrix needs to be compared with the “ideal matrix” in order to examine the degree of consistency between them. If the consistency falls within the acceptable range, the judgment matrix constructed in the second step can be regarded as sufficiently close to the “ideal matrix,” and further calculation can then be carried out. This is the “consistency test” in this step.

In linear algebra, the technical term corresponding to the “ideal matrix” is a positive reciprocal matrix. According to the relevant knowledge of linear algebra, an ideal positive reciprocal matrix has a rank of 1, and therefore has one and only one maximum eigenvalue. From the geometric meaning of linear algebra, the eigenvector corresponding to this maximum eigenvalue is a numerical expression of the eigenspace of the positive reciprocal matrix. Therefore, the proportional relationship among the elements in the eigenvector represents their weights. By calculating the proportion of each individual weight in the total weight, the weight of each element can be obtained. This is the “single-level ranking” in this step.

Based on the theoretical foundation above, mathematical formulas can be used for calculation. According to the formula for calculating eigenvectors in linear algebra,

$$DV = \lambda_{\max} V$$

In the formula, D denotes each judgment matrix constructed in the second step, $\lambda_{\max}$ denotes the maximum eigenvalue of the matrix, and V denotes the eigenvector of the matrix. After the eigenvector of the judgment matrix is obtained, the proportion of each element in the vector relative to the sum of all elements is calculated. In this way, the weight matrix of the influencing factors in each judgment matrix can be obtained.

Next, the consistency test is conducted. According to the properties of a positive reciprocal matrix, the maximum eigenvalue $\lambda_{\max}$ of a positive reciprocal matrix should be equal to the order n of the matrix. If the matrix is inconsistent, the maximum eigenvalue $\lambda_{\max}$ must be greater than the order n . Therefore, the consistency between the judgment matrix and the positive reciprocal matrix can be evaluated by examining the difference between the maximum eigenvalue $\lambda_{\max}$ and the order n of the judgment matrix. However, under different matrix orders, the difference between the maximum eigenvalue and the order reflects different levels of consistency. Therefore, a mathematical method is needed to eliminate the influence of the matrix order and obtain a statistic that satisfies the same judgment criterion under different orders.

First, the consistency index CI of the judgment matrix is defined as follows:

$$CI = \frac{(\lambda_{\max} - n)}{(n - 1)}$$

Next, in order to reduce the influence of matrix order on the consistency test, numbers are randomly selected from 1 to 9 and their reciprocals to construct 500 positive reciprocal matrices of different orders n . The average value of the maximum eigenvalue, denoted as $\lambda'_{\max}$, is then calculated, and the average random consistency index RI is defined as follows:

$$RI = \frac{\lambda'_{\max} - n}{n - 1}$$

After a large number of calculations, the corresponding values between different matrix orders n and the average random consistency index RI are shown in Table 4.

Table 4. Values of RI at Different Orders n .

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56

The consistency ratio CR of the judgment matrix can then be obtained by dividing the consistency index CI of the judgment matrix by the average random consistency index RI .

Based on empirical values derived from extensive engineering practice, only when $CR < 0.1$ can the consistency of the judgment matrix be considered to meet the required standard. Otherwise, the judgment matrix may contain logical problems and needs to be revised.

2.1.5. Overall Hierarchy Ranking and Consistency Test

After the ranking of a single level is completed and passes the consistency test, one weight matrix for the major factors and six weight matrices for the sub-factors under the corresponding major factors are obtained. The weight matrix of each group of sub-factors is multiplied by the weight a_j of its corresponding major factor, and the resulting matrices are then combined to obtain the overall weight matrix. This process is referred to as the overall hierarchy ranking.

In addition, the overall consistency also needs to be tested. The theoretical basis is the same as that used in the consistency test for single-level ranking. Since the weights a_j of the major factors are different, the overall consistency test is conducted by dividing the weighted sum of the consistency indices $CI(j)$ of the six judgment matrices for the sub-factors by the weighted sum of their corresponding average random consistency indices $RI(j)$. In this way, the overall consistency ratio CR can be obtained as follows:

$$CR = \frac{\sum_{j=1}^m CI(j)a_j}{\sum_{j=1}^m RI(j)a_j}$$

Based on engineering practice, if the overall consistency ratio is less than 0.1, the result can be considered to have passed the consistency test. The overall weight matrix tw can then be obtained.

2.2. Evaluation and Selection of Basic Logistics Modes

The previous section explained how the AHP is used to calculate the weights of the influencing factors. This section further uses these weights in a dedicated mathematical evaluation model to select the most suitable basic logistics mode under specific conditions. Given the complex and changing logistics environment, as well as the large and often disordered amount of evaluation data, the fuzzy comprehensive evaluation method is particularly suitable for this purpose.

The fuzzy comprehensive evaluation method evaluates each alternative basic logistics mode through an indicator layer. In this study, each alternative logistics mode is treated as an evaluation object, while the indicator layer consists of the influencing factors and their AHP-based weights. An appropriate evaluation set is then established according to the evaluation requirements. A fuzzy relation matrix is constructed to describe the relationship between each basic logistics mode and the evaluation set from the perspective of the influencing factors. By multiplying this matrix by the factor weights obtained earlier, the evaluation matrix of each basic logistics mode can be obtained.

2.2.1. Establishment of the Factor Set and the Evaluation Set

If there are m influencing factors for the basic logistics modes, the factor set can be defined as $U=\{u_1, u_2, \dots, u_m\}$. If there are n possible evaluation levels for the basic logistics modes, the evaluation set can be defined as $V=\{v_1, v_2, \dots, v_n\}$. In general, the evaluation set can be divided into five levels, such as “high,” “relatively high,” “normal,” “relatively low,” and “low”.

2.2.2. Establishment of the Fuzzy Relation Matrix

For a single basic logistics mode, evaluation is carried out from the perspective of each factor u_m , and the evaluation result is then quantified. In this way, the fuzzy relation matrix of each basic logistics mode relative to the evaluation set can be obtained as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

Here, r_{mn} represents the degree of membership of the basic logistics mode to the evaluation grade v_j from the perspective of the influencing factor u_m . The sum of each row in R is 1. When the number of evaluation grades in the evaluation set is 5, the matrix becomes:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{m5} \end{bmatrix}$$

where r_m is the single-factor evaluation matrix of the m -th influencing factor for the basic logistics mode.

In the evaluation of basic logistics modes, authoritative comparative data are often incomplete because cost, timeliness, service reliability, customs clearance risk, return handling, and customer experience are recorded by different actors in the logistics chain. Therefore, this study used structured expert elicitation to construct the fuzzy relation matrices. The evaluators assessed the membership degree of each logistics mode with respect to the five evaluation grades for each of the 18 influencing factors. The evaluation was based on the case background of Platform A, the operational characteristics of Japanese small household appliances, and the logistics conditions of the East China market.

The final fuzzy relation matrices were constructed at the group level after comparing the evaluators' judgments and discussing major differences. When disagreement appeared for a specific factor, the evaluators re-examined the relevant operational evidence, such as cost records, customer complaints, delivery-time problems, warehousing pressure, and return-handling experience. The final membership values were determined only after the panel reached a common interpretation of the factor under the case conditions.

Through this procedure, a fuzzy relation matrix R_i was established for each basic logistics mode, where i denotes the number of alternative logistics modes.

Because the fuzzy relation matrices still contain expert-informed judgments, the results should not be interpreted as purely objective measurements. For this reason, this study further reports the consistency of the AHP judgment matrices, examines the sensitivity of the ranking results to changes in key weights, and compares the model recommendation with post-implementation operational indicators.

2.2.3. Comprehensive Evaluation

For a single basic logistics mode, the weights of the influencing factors w_j ($j=1,2,\dots,m$) obtained above are multiplied by the corresponding fuzzy relation matrix R . In this way, the degree of membership of the basic logistics mode to each evaluation grade can be obtained:

$$B = W * R = (w_1, w_2, \dots, w_m) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{m5} \end{bmatrix} = (b_1, b_2, b_3, b_4, b_5)$$

where the sum of b_1, b_2, b_3, b_4, b_5 is 1. This is referred to as the fuzzy comprehensive evaluation model for a single basic logistics mode. Based on this result, it is possible to identify the evaluation grade to which the basic logistics mode has a higher degree of membership. If the evaluation grades are quantified, the comprehensive evaluation score of the basic logistics mode can be calculated, allowing it to be quantitatively compared and ranked against other basic logistics modes.

3. Results

3.1. Case Background and Alternative Basic Logistics Modes

This case study is based on a logistics optimization task observed in a Japanese cross-border e-commerce platform, hereafter referred to as Platform A. Platform A was originally developed from an international trading business and later shifted toward B2C cross-border e-commerce, serving individual customers in overseas markets.

At the time of this case, the platform was still in an early stage of operational development, and its logistics system had not yet been fully optimized. The most prominent issue was the selection of an appropriate logistics mode. For the East China market centered on Shanghai, the platform mainly sold Japanese-made small household appliances, such as rice cookers, hair dryers, and compact air fryers. However, its logistics operations had long relied mainly on international express delivery. This approach led to relatively high logistics costs and low efficiency, especially when returns or exchanges were required.

Therefore, the purpose of this case is to apply the evaluation model proposed in this study to select the most suitable basic logistics mode for Platform A's sales of Japanese small household appliances in the East China market. The aim is to support the optimization of the platform's overall logistics mode.

For logistics operations in the East China market, the platform identified four alternative basic logistics modes: overseas warehouses, dedicated-line logistics, postal parcels, and outsourced international express delivery.

The overseas warehouse mode refers to establishing a warehousing base in a relevant region of China and storing a certain amount of popular Japanese products in advance. Once an order is placed, the goods can be shipped quickly. This mode is similar to Amazon's overseas warehouse system. It provides fast delivery and a

better user experience, but the platform needs to prepare inventory in advance, which greatly increases both cost and risk.

The dedicated-line logistics mode refers to renting a dedicated storage space in a logistics park in Japan. After products are purchased online according to customer orders, the goods are first stored in the warehouse. A regular freight route between Japan and China is then established, and the accumulated goods are consolidated and transported back to China on fixed dates each month. This method has the lowest cost for the platform, but its delivery speed is relatively slow, which may affect the customer shopping experience.

The postal parcel mode refers to using the Express Mail Service (EMS) of the Universal Postal Union to deliver goods directly to China. Japan Post imposes relatively few restrictions on product types and parcel size, and its prices are relatively low. It also offers the Yu-Pack service, through which door-to-door pickup can be arranged by online reservation.

The outsourced international express delivery mode refers to entrusting all logistics operations of the e-commerce platform to a third-party international logistics company. With the continuous development of the international logistics industry, large logistics providers have established considerable global logistics networks, and their mature operating systems can also provide customers with a smoother logistics experience. However, this mode is relatively expensive, and its prices are highly unstable.

Overall, these basic logistics modes each have their own advantages and limitations. Therefore, the selection needs to be made according to the actual conditions of the platform, the target market, and the product category. The evaluation model constructed in the previous section can therefore be applied to support this decision.

3.2. Calculation of the Weights of Influencing Factors

The expert panel of Platform A first conducted a structured review of the business environment faced by the platform, including the product category, target market, existing logistics problems, cost pressure, delivery requirements, and after-sales service issues. Based on this analysis, a hierarchical structure model of the influencing factors for evaluating the basic logistics modes was constructed, as shown in Table 5.

Table 5. Influencing factors for evaluating basic logistics modes.

Level	Category / Factor
First level	Optimal selection of the basic logistics mode
Second level	Scale; Quality; Cost; Product type; Logistics environment; E-commerce environment
Third level under Scale	Capital; Labor; Operations
Third level under Quality	Timeliness; Safety; Accuracy
Third level under Cost	Transportation cost; Warehousing cost; Management cost
Third level under Product type	Physical attributes; Value attributes; Functional attributes
Third level under Logistics environment	Economic environment; Policy environment; Industry environment
Third level under E-commerce environment	Economic environment; Policy environment; Industry environment

The third level in Table 5 represents the specific influencing factors for evaluating the basic logistics modes, with a total of 18 factors.

Next, based on the context of selling Japanese small household appliances in the East China market, the major factors at the second level were first evaluated. The second-level judgment matrix was then constructed through the structured expert elicitation process described in Section 2.1.3, as shown in Table 6.

Table 6. Judgment matrix of the second-level major factors.

	Scale	Quality	Cost	Product type	Logistics environment	E-commerce environment
Scale	1	1/3	1/4	1	1/2	1/3
Quality	3	1	1	1	2	3
Cost	4	1	1	1	1/2	1/2
Product type	1	1	1	1	1	1/2
Logistics environment	2	1/2	2	1	1	1
E-commerce environment	3	1/3	2	2	1	1

Then, within each second-level major factor, judgment matrices for the corresponding third-level sub-factors were constructed.

Table 7. Judgment matrix for the sub-factors under “scale”.

Scale	Labor	Capital	Operations
Labor	1	1/2	1
Capital	2	1	1
Operations	1	1	1

Table 8. Judgment matrix for the sub-factors under “quality”.

Quality	Timeliness	Safety	Accuracy
Timeliness	1	1/3	1/3
Safety	3	1	1
Accuracy	3	1	1

Table 9. Judgment matrix for the sub-factors under “cost”.

Cost	Transportation cost	Warehousing cost	Management cost
Transportation cost	1	1	3
Warehousing cost	1	1	3
Management cost	1/3	1/3	1

Table 10. Judgment matrix for the sub-factors under “product type”.

Product type	Physical attributes	Value attributes	Functional attributes
Physical attributes	1	1/3	1
Value attributes	3	1	3
Functional attributes	1	1/3	1

Table 11. Judgment matrix for the sub-factors under “logistics environment”.

Logistics environment	Economic environment	Policy environment	Industry environment
Economic environment	1	1/3	1/3

Policy environment	3	1	1
Industry environment	3	1	1

Table 12. Judgment matrix for the sub-factors under “e-commerce environment”.

E-commerce environment	Economic environment	Policy environment	Industry environment
Economic environment	1	1/5	1/3
Policy environment	5	1	1
Industry environment	3	1	1

The judgment matrices above were then used for calculation, and the weight of each influencing factor was calculated as follows:

Table 13. Weights of influencing factors obtained by the AHP.

Labor	0.0195	Transportation cost	0.0685	Economic environment of logistics	0.0242
Capital	0.0310	Warehousing cost	0.0685	Policy environment of logistics	0.0725
Operations	0.0246	Management cost	0.0228	Industry environment of logistics	0.0725
Timeliness	0.0374	Physical attributes	0.0277	Economic environment of e-commerce	0.0223
Safety	0.1123	Value attributes	0.0830	Policy environment of e-commerce	0.0938
Accuracy	0.1123	Functional attributes	0.0277	Industry environment of e-commerce	0.0792

The consistency test results are shown in Table 14.

Table 14. Consistency test results of AHP judgment matrices.

Judgment matrix	$\lambda_{\max}$	CI	CR	Result
Second-level major factors	6.5242	0.1048	0.0846	Acceptable
Scale sub-factors	3.0536	0.0268	0.0462	Acceptable
Quality sub-factors	3.0000	0.0000	0.0000	Acceptable
Cost sub-factors	3.0000	0.0000	0.0000	Acceptable
Product type sub-factors	3.0000	0.0000	0.0000	Acceptable
Logistics environment sub-factors	3.0000	0.0000	0.0000	Acceptable
E-commerce environment sub-factors	3.0291	0.0145	0.0251	Acceptable
Overall hierarchy			0.0084	Acceptable

The CR value of the second-level judgment matrix was 0.0846, and the CR values of the six third-level judgment matrices were all below 0.1. The overall hierarchy consistency ratio was 0.0084. These results indicate that the final group-level AHP matrices did not contain serious internal logical inconsistencies and could be used for subsequent fuzzy comprehensive evaluation. However, the consistency ratio only examines the internal coherence of the judgment matrices. It does not directly measure inter-rater reliability or eliminate the possible influence of expert subjectivity. Therefore, sensitivity analysis and post-implementation triangulation were further added to examine the robustness and practical relevance of the evaluation results.

3.3. Evaluation Using the Fuzzy Comprehensive Evaluation Method

In the previous section, the weights of the influencing factors were obtained using the AHP. Based on these weights, the factor set U can be established as a matrix with 1 row and 18 columns.

In this case, the evaluation set is divided into five levels and quantified numerically as follows:

$$V = \{100, 80, 60, 40, 20\}$$

Based on the background described above, the platform selected four alternative basic logistics modes for its logistics operations in the East China market: overseas warehouses, dedicated-line logistics, postal parcels, and outsourced international express delivery. Therefore, structured expert elicitation was used to construct the fuzzy relation matrices for the four alternative logistics modes. The evaluators assessed the membership degree of each logistics mode for the 18 influencing factors under the five evaluation grades. The final matrices were constructed at the group level based on the platform's operational context and available internal logistics information. Each matrix has 18 rows and 5 columns.

The fuzzy relation matrix for the overseas warehouse mode is as follows:

$$R_1 = \begin{bmatrix} 0.2 & 0.2 & 0.3 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.05 & 0.05 \\ 0.4 & 0.3 & 0.2 & 0.05 & 0.05 \\ 0.7 & 0.1 & 0.1 & 0.05 & 0.05 \\ 0.6 & 0.1 & 0.1 & 0.1 & 0.1 \\ 0.4 & 0.2 & 0.2 & 0.1 & 0.1 \\ 0.2 & 0.2 & 0.3 & 0.2 & 0.1 \\ 0.05 & 0.05 & 0.1 & 0.2 & 0.6 \\ 0.1 & 0.1 & 0.2 & 0.2 & 0.4 \\ 0.15 & 0.15 & 0.3 & 0.3 & 0.1 \\ 0.2 & 0.5 & 0.2 & 0.05 & 0.05 \\ 0.2 & 0.3 & 0.2 & 0.15 & 0.15 \\ 0.2 & 0.25 & 0.25 & 0.15 & 0.15 \\ 0.15 & 0.3 & 0.25 & 0.15 & 0.15 \\ 0.25 & 0.3 & 0.3 & 0.1 & 0.05 \\ 0.25 & 0.35 & 0.15 & 0.15 & 0.1 \\ 0.3 & 0.35 & 0.15 & 0.1 & 0.1 \\ 0.4 & 0.3 & 0.15 & 0.1 & 0.05 \end{bmatrix}$$

By entering the factor set matrix U and the fuzzy relation matrix R_1 into the calculation, the membership degree of the overseas warehouse mode can be obtained as follows:

$$B_1 = \{0.2721, 0.2391, 0.2108, 0.1293, 0.1487\}$$

After the evaluation set is quantified, the evaluation score of the overseas warehouse mode is calculated as 67.1277.

Following the same procedure, the fuzzy relation matrices for dedicated-line logistics, postal parcels, and outsourced international express delivery can also be constructed.

The fuzzy relation matrix for the dedicated-line logistics mode is as follows:

$$R_2 = \begin{bmatrix} 0.45 & 0.25 & 0.1 & 0.1 & 0.1 \\ 0.5 & 0.25 & 0.15 & 0.05 & 0.05 \\ 0.5 & 0.3 & 0.1 & 0.05 & 0.05 \\ 0.1 & 0.2 & 0.2 & 0.3 & 0.2 \\ 0.45 & 0.2 & 0.15 & 0.1 & 0.1 \\ 0.35 & 0.25 & 0.2 & 0.1 & 0.1 \\ 0.6 & 0.2 & 0.1 & 0.05 & 0.05 \\ 0.7 & 0.1 & 0.1 & 0.05 & 0.05 \\ 0.55 & 0.2 & 0.15 & 0.05 & 0.05 \\ 0.35 & 0.2 & 0.2 & 0.15 & 0.1 \\ 0.2 & 0.2 & 0.2 & 0.35 & 0.05 \\ 0.1 & 0.2 & 0.3 & 0.2 & 0.2 \\ 0.1 & 0.2 & 0.4 & 0.15 & 0.15 \\ 0.15 & 0.25 & 0.3 & 0.15 & 0.15 \\ 0.25 & 0.4 & 0.25 & 0.05 & 0.05 \\ 0.1 & 0.35 & 0.25 & 0.15 & 0.15 \\ 0.3 & 0.45 & 0.15 & 0.05 & 0.05 \\ 0.1 & 0.15 & 0.35 & 0.2 & 0.2 \end{bmatrix}$$

The membership degree of the dedicated-line logistics mode can be obtained as follows:

$$B_2 = \{0.3116, 0.2274, 0.2141, 0.1379, 0.1090\}$$

and the evaluation score of the dedicated-line logistics mode is calculated as 69.8966.

The fuzzy relation matrix for the postal parcels mode is as follows:

$$R_3 = \begin{bmatrix} 0.7 & 0.1 & 0.1 & 0.05 & 0.05 \\ 0.05 & 0.1 & 0.25 & 0.4 & 0.2 \\ 0.6 & 0.2 & 0.1 & 0.05 & 0.05 \\ 0.6 & 0.15 & 0.1 & 0.1 & 0.05 \\ 0.5 & 0.2 & 0.1 & 0.1 & 0.1 \\ 0.4 & 0.2 & 0.2 & 0.1 & 0.1 \\ 0.05 & 0.05 & 0.1 & 0.7 & 0.1 \\ 0.7 & 0.1 & 0.1 & 0.05 & 0.05 \\ 0.6 & 0.2 & 0.1 & 0.05 & 0.05 \\ 0.1 & 0.1 & 0.2 & 0.2 & 0.4 \\ 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.4 & 0.3 & 0.1 \\ 0.1 & 0.2 & 0.4 & 0.15 & 0.15 \\ 0.05 & 0.05 & 0.15 & 0.15 & 0.6 \\ 0.05 & 0.1 & 0.15 & 0.25 & 0.45 \\ 0.1 & 0.35 & 0.25 & 0.15 & 0.15 \\ 0.3 & 0.45 & 0.15 & 0.05 & 0.05 \\ 0.1 & 0.15 & 0.35 & 0.2 & 0.2 \end{bmatrix}$$

The membership degree of the postal parcels mode can be obtained as follows:

$$B_3 = \{0.3011, 0.1542, 0.1975, 0.1686, 0.1785\}$$

and the evaluation score of the postal parcels mode is calculated as 64.6150.

The fuzzy relation matrix for the outsourced international express delivery mode is as follows:

$$R_4 = \begin{bmatrix} 0.7 & 0.1 & 0.1 & 0.05 & 0.05 \\ 0.05 & 0.1 & 0.25 & 0.4 & 0.2 \\ 0.6 & 0.2 & 0.1 & 0.05 & 0.05 \\ 0.6 & 0.15 & 0.1 & 0.1 & 0.05 \\ 0.5 & 0.2 & 0.1 & 0.1 & 0.1 \\ 0.4 & 0.2 & 0.2 & 0.1 & 0.1 \\ 0.05 & 0.05 & 0.1 & 0.3 & 0.5 \\ 0.7 & 0.1 & 0.1 & 0.05 & 0.05 \\ 0.6 & 0.2 & 0.1 & 0.05 & 0.05 \\ 0.1 & 0.1 & 0.2 & 0.2 & 0.4 \\ 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.4 & 0.3 & 0.1 \\ 0.1 & 0.15 & 0.4 & 0.3 & 0.05 \\ 0.05 & 0.05 & 0.2 & 0.2 & 0.5 \\ 0.05 & 0.1 & 0.15 & 0.25 & 0.45 \\ 0.1 & 0.35 & 0.25 & 0.15 & 0.15 \\ 0.3 & 0.45 & 0.15 & 0.05 & 0.05 \\ 0.1 & 0.15 & 0.35 & 0.2 & 0.2 \end{bmatrix}$$

The membership degree of the outsourced international express delivery mode can be obtained as follows:

$$B_4 = \{0.3011, 0.1486, 0.2031, 0.1800, 0.1671\}$$

and the evaluation score of the outsourced international express delivery mode is calculated as 64.7307.

The original company records only retained the final group-level fuzzy relation matrices, so a full inter-rater reliability statistic could not be calculated retrospectively for all membership scores. Therefore, the fuzzy membership values should be interpreted as structured expert-informed evaluations. To make this limitation transparent, this study reports the AHP consistency results, examines the sensitivity of the ranking results, and compares the selected logistics mode with post-implementation operational indicators. The measures used to improve the transparency and robustness of the expert-informed evaluation are summarized in Table 15.

Table 15. Measures used to improve the transparency and robustness of expert-informed evaluation.

Potential source of subjectivity	Mitigation measure	Function
Group-level expert judgment in AHP	Structured expert elicitation procedure	Clarifies the source and aggregation of judgments
Internal inconsistency in pairwise comparisons	CR values reported for all AHP matrices	Checks whether group-level matrices are logically coherent
Sensitivity to weight settings	Weight-adjustment scenarios	Tests whether ranking depends heavily on one subjective weight setting
Expert-informed fuzzy membership scores	Operational evidence considered during matrix construction	Links membership scores to case-specific cost, complaint, delivery, and warehouse evidence
Limited individual-level rating records	Explicit acknowledgement of data limitations	Avoids overstating inter-rater reliability

3.4. Sensitivity Analysis of the Evaluation Results

Because the AHP weights and fuzzy membership values were partly based on expert-informed judgments, a sensitivity analysis was conducted to examine whether the ranking of logistics modes was overly dependent on a single weight setting. The baseline result was calculated using the corrected AHP weights and the fuzzy relation matrices, with the rows of each fuzzy relation matrix aligned with the 18 indicators in the same hierarchical order.

Several weight-adjustment scenarios were then tested. In each scenario, the selected indicator or indicator group was increased by the specified percentage, and the full weight vector was re-normalized so that the total weight remained equal to 1. The tested scenarios included greater emphasis on cost-related indicators, quality-related indicators, timeliness, and the policy environment of e-commerce. An equal-weight scenario was also added as a comparison with the AHP-based weighting scheme. The purpose of this analysis was to examine whether the relative ranking of the four logistics modes remained stable when the emphasis of the evaluation changed.

The detailed calculation results of the sensitivity analysis are shown in Table 16.

Table 16. Sensitivity analysis of logistics mode evaluation results.

Scenario	Weight adjustment	Overseas warehouse	Dedicated-line logistics	Postal parcels	Outsourced international express delivery	Ranking result
Baseline	Original AHP weights	67.1277	69.8966	64.6150	64.7307	Dedicated-line logistics > Overseas warehouse > Outsourced international express delivery > Postal parcels
S1	Cost-related indicators +10%, then normalized	67.1482	69.7588	64.5649	64.6788	Dedicated-line logistics > Overseas warehouse > Outsourced international express delivery > Postal parcels
S2	Quality-related indicators +10%, then normalized	67.0660	69.7095	64.1542	64.2998	Dedicated-line logistics > Overseas warehouse > Outsourced international express delivery > Postal parcels
S3	Timeliness +20%, then normalized	67.1639	69.9346	64.4395	64.5543	Dedicated-line logistics > Overseas warehouse > Outsourced international express delivery > Postal parcels
S4	E-commerce policy environment +10%, then normalized	67.2009	70.0092	64.4606	64.5752	Dedicated-line logistics > Overseas warehouse > Outsourced international express delivery > Postal parcels
S5	Equal weights for all 18 indicators	67.9444	71.1667	65.3889	65.1111	Dedicated-line logistics > Overseas warehouse > Postal parcels > Outsourced international express delivery

The sensitivity analysis shows that the top two alternatives remained stable across all tested scenarios. Dedicated-line logistics obtained the highest score in the baseline calculation and continued to rank first under all weight-adjustment scenarios. The overseas warehouse mode also remained the second-ranked alternative in all scenarios. This result suggests that the main ranking was not solely driven by one specific subjective weight setting.

The internal ordering of the two lower-ranked alternatives was less stable. Outsourced international express delivery ranked slightly higher than postal parcels in most AHP-based scenarios, while postal parcels ranked slightly higher under the equal-weight scenario. However, this difference does not affect the main decision because both alternatives remained below dedicated-line logistics and overseas warehousing across the tested scenarios.

3.5. Final Formulation of the Logistics Mode

Based on the baseline evaluation and the sensitivity analysis, the logistics arrangement for Platform A was formulated with dedicated-line logistics as the main mode and overseas warehousing as a supplementary option. This combination reflected the relative stability of the ranking results and the platform's need to balance cost control, service quality, product suitability, logistics environment, and e-commerce environment under the case conditions.

The corresponding logistics arrangement was formulated as follows. Platform A would rent dedicated storage space in a logistics facility in the Tokyo metropolitan area and in a logistics park in Shanghai. Goods purchased online according to customer orders would first be temporarily stored in the warehouse in Japan. The accumulated goods would then be consolidated into containers on fixed dates, tentatively the 15th and 30th of each month, and shipped from the Port of Tokyo to the warehouse in Shanghai.

The overseas warehouse mode remained the second-ranked alternative across all sensitivity scenarios. Therefore, it was considered suitable as a supplementary measure. Under this arrangement, an appropriate quantity of popular products would be stored in advance at the warehouse in Shanghai. This could allow high-demand products to be delivered more quickly, improve customer-facing service quality, and provide a buffer when order volumes fluctuate sharply.

Postal parcels and outsourced international express delivery were not adopted as main logistics modes under this case condition. Although their internal ranking changed slightly under different weighting scenarios, both alternatives remained below dedicated-line logistics and overseas warehousing. In addition, they were less suitable for the platform's regular sales of small household appliances because of their relatively high order-level logistics costs and greater exposure to external changes in international delivery conditions.

Therefore, the ranking result should be understood as a context-specific recommendation for Platform A's small-household-appliance business in the East China market. Different product types, demand patterns, destination markets, and platform capacities may lead to different weight settings and different mode rankings.

3.6. Post-Implementation Triangulation with Operational Indicators

The proposed logistics mode was approved by the company's management in October 2024 and was officially implemented in January 2025. The implementation results were used for post-implementation triangulation to examine whether the logistics mode selected through the expert-informed evaluation framework was consistent with subsequent changes in operational cost and service performance. The operational indicators used for this triangulation and the corresponding results are shown in Table 17.

Table 17. Post-implementation operational indicators used for triangulation and corresponding results

Evaluation	Operational indicator	Observed result	Interpretation
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dimension

Cost control	Annual logistics cost	Decreased by 23% compared with 2024	Consistent with improved cost control after implementation
Cost structure	Share of logistics costs in total platform expenditure	Decreased from 31% to 20.8%	Indicates a lower logistics cost burden at the platform level
Transition cost	Monthly logistics cost in Jan –Mar 2025	Increased by 33%, 16%, and 7% compared with the same months in 2024	Reflects initial setup and adjustment costs during the transition period
Service quality	Total customer complaints	Decreased by nearly 50% compared with the pre-implementation period	Suggests an improvement in customer-facing logistics service
Timeliness	Delivery-time-related complaints	Decreased by nearly 70%	Consistent with an improvement in delivery experience

The results show that the selected logistics mode was followed by improvements in both cost-related and service-related indicators. These changes are consistent with the expected advantages of combining dedicated-line logistics with supplementary overseas warehousing.

However, these changes do not prove a universal causal effect of the proposed framework. Other factors, such as order volume, exchange rates, freight market conditions, product mix, platform growth, and customs conditions, may also have influenced logistics performance during the observation period. Nevertheless, the direction of change is consistent with the model recommendation and provides supportive operational evidence for the practical relevance of the selected logistics mode under the case conditions.

4. Discussion

4.1. Problems and Underlying Causes in Cross-Border E-Commerce Logistics Modes

The results of this study suggest that the formulation of logistics modes is a key constraint on the operational performance of cross-border e-commerce. In practical operations, the problems are mainly reflected in three aspects: difficulty in cost control, low service efficiency, and insufficient coordination between logistics activities and the overall business process. These problems are closely related to the inherent characteristics of cross-border e-commerce, including fragmented orders, high timeliness requirements, long-distance transportation, customs clearance uncertainty, and frequent changes in the international trade environment. Previous studies have also emphasized that international logistics is an indispensable part of cross-border e-commerce trade and that logistics efficiency and cost directly affect consumer experience and platform development [1,5].

4.1.1. Problem 1: Difficulty in Cost Control

Cost is a basic dimension for evaluating commercial activities, and it is especially important for cross-border e-commerce because logistics expenses directly affect product pricing, platform profitability, and customer retention. Compared with domestic e-commerce, cross-border e-commerce usually involves longer transportation distances, more complex customs procedures, higher compliance risks, and greater dependence on international freight capacity. Compared with traditional international trade, cross-border e-commerce also faces a much larger number of small and fragmented orders, together with stronger requirements for delivery speed. These conditions make logistics cost control more difficult than in ordinary domestic logistics or traditional bulk international trade. Similar observations have been made in previous research on cross-border B2C e-commerce logistics, where delivery time, customs clearance, product returns, and logistics cost are all identified as important constraints on cross-border logistics mode selection [3,6].

This problem became more visible during the COVID-19 period, when global shipping capacity tightened and international freight rates rose sharply. Existing studies on container shipping and port systems show that the pandemic created major disruptions in global maritime transport, affecting freight capacity, port operations, and logistics resilience [29]. Such volatility increased the uncertainty faced by cross-border e-commerce sellers and made logistics planning much more difficult. In practice, each basic logistics mode carries a different type of cost pressure. If a platform mainly uses international express delivery or postal parcels, every order requires an additional cross-border transportation fee, which directly compresses order-level profit. If it mainly uses overseas warehouses or bonded zones, early-stage investment in warehousing facilities, inventory preparation, and labor becomes heavy, creating considerable financial pressure. If it mainly uses dedicated-line logistics, the direct transportation cost may be lower, but the mode often has weaker flexibility and slower delivery speed. It may also be less capable of responding to personalized customer needs, thereby increasing hidden management costs and risk costs. Therefore, the difficulty of cost control is also a structural problem caused by the mismatch between logistics modes and specific business conditions.

From a more recent sustainability perspective, cost control should also be considered together with environmental and regulatory constraints. Green supply chain studies show that carbon tax, carbon caps, and carbon trading policies can change the cost structure and operational attractiveness of different supply chain arrangements. For cross-border e-commerce firms, this means that logistics mode selection may also need to consider the potential long-term costs associated with transportation emissions, warehousing arrangements, and future environmental requirements [18].

4.1.2. Problem 2: Low Service Efficiency

Unlike traditional international trade, cross-border e-commerce directly faces individual consumers. This means that delivery time, tracking visibility, return convenience, and after-sales logistics experience all have a direct influence on customer satisfaction. Recent studies on logistics service quality in cross-border e-commerce show that timeliness, price fairness, return services, information quality, and service reliability are closely related to customer satisfaction, repurchase intention, and customer complaints [9,10,30]. However, differences in logistics infrastructure, customs clearance procedures, inspection standards, and last-mile delivery systems across countries make it difficult for cross-border e-commerce logistics to achieve the same efficiency as domestic e-commerce logistics.

In this sense, the service efficiency problem should not be understood only as slow delivery. It also includes uncertainty in delivery time, insufficient logistics visibility, inconvenience in returns and exchanges, and the difficulty of coordinating multiple service providers across countries. Cross-border e-commerce customers often compare their logistics experience with the service standards of domestic e-commerce platforms. When delivery becomes slow, tracking information is incomplete, or returns are difficult to handle, customer trust and platform loyalty may decline. This is consistent with the finding that logistics service quality has a significant influence on consumer satisfaction and repurchase intention in cross-border e-commerce contexts [10].

4.1.3. Problem 3: Insufficient Coordination with Business Processes

The coordination between logistics modes and other business activities remains insufficient. In many cross-border e-commerce operations, logistics is still treated as a separate operational activity. Sellers often evaluate logistics modes mainly from the perspective of direct freight cost or simple delivery speed, while paying insufficient attention to how the logistics mode interacts with product strategy, market positioning, customer expectations, cash flow, and after-sales service. Wang et al. argue that competition in cross-border e-commerce has shifted from product-related attributes such as cost and quality toward supply chain service capabilities, and

that cross-border e-commerce firms need to manage product, information, and financial flows in an integrated way [11].

Recent research on sustainable supply chain coordination further supports this view. Coordination problems become more complex when demand uncertainty, carbon emission reduction, and different profit motives among supply chain actors are considered at the same time [16]. This point is also relevant to cross-border e-commerce logistics. Platforms, logistics providers, warehouses, sellers, and after-sales service units may face different cost structures and performance objectives. Therefore, logistics mode selection should also examine whether a mode can support stable coordination among these actors.

This lack of coordination becomes particularly risky when the external environment changes rapidly. In recent years, the COVID-19 pandemic, geopolitical conflicts, port congestion, and repeated disruptions in major shipping routes have made international logistics more unstable. Under such conditions, logistics modes can no longer be evaluated as isolated transportation arrangements. Instead, they need to be considered as part of the entire cross-border supply chain system. Previous research on cross-border e-commerce logistics uncertainty also shows that firms need to adopt different risk management strategies according to different types of uncertainty, including demand uncertainty, logistics service uncertainty, and institutional uncertainty [7]. If the logistics mode is not well coordinated with procurement, pricing, customer communication, and inventory planning, the platform may find it difficult to respond effectively to sudden external shocks.

Behind these surface-level problems, there are several deeper causes.

4.1.4. Cause 1: Insufficient Response to Logistics Complexity

Cross-border e-commerce logistics is more complex than ordinary logistics because it must deal with product complexity, process complexity, and service complexity at the same time. Product complexity arises because cross-border e-commerce platforms often handle many types of products, and different products require different logistics conditions. Fresh products require strict control of delivery time, temperature, and humidity. Luxury goods place greater emphasis on transportation security. Fragile products are sensitive to vibration and handling quality. These product-specific requirements greatly increase the difficulty of logistics mode selection. Existing studies on cross-border B2C logistics also point out that different logistics solutions need to be evaluated under uncertainty because product features, market conditions, and service expectations differ across contexts [6].

Process complexity is also significant. Cross-border e-commerce involves international transportation, customs declaration, inspection, tax treatment, and last-mile delivery in the destination country. Unexpected events may occur at each stage. Differences in logistics policies, product quality standards, quarantine rules, and regulatory requirements across countries can further increase operational uncertainty. In this regard, cross-border e-commerce logistics differs substantially from domestic e-commerce logistics because it crosses national and customs boundaries and involves more stakeholders, including platforms, sellers, consumers, logistics providers, customs authorities, and local delivery partners [31].

Service complexity further increases the difficulty. Consumers often have different expectations regarding delivery time, shipping price, delivery date, consolidation with other goods, and return convenience. Some customers prioritize speed, some prefer the lowest possible shipping cost, some hope to consolidate multiple orders, and others want delivery within a fixed date or time window. These diverse requirements make it difficult for a single logistics mode to meet all customer needs. Existing cross-border e-commerce platforms often provide only a limited number of logistics options, such as consolidated shipping, direct shipping, international express delivery, or overseas warehousing. When the logistics mode cannot fully adapt to different products, markets, and customer needs, problems such as high cost, delayed delivery, and poor service experience tend to emerge.

4.1.5. Cause 2: Insufficient Application of Information Technology

Cross-border e-commerce itself is built on Internet-based business processes, including online transactions, instant communication, digital marketing, data analysis, and recommendation algorithms. However, logistics mode formulation has not always made full use of these digital capabilities. This gap directly contributes to the weak coordination between logistics and business activities. Recent research has emphasized the importance of digital logistics services, information sharing, and supply chain integration in reducing transaction uncertainty and improving consumer continuance intention on cross-border e-commerce platforms [31].

Among different information technologies, big data analysis has the potential to improve logistics mode formulation. Through the systematic collection and analysis of order data, route data, customs clearance data, inventory data, complaint data, and return data, platforms can better understand demand fluctuations, delivery risks, cost structures, and customer preferences. However, many logistics providers still lack integrated platforms for collecting and processing logistics data. As a result, data generated in transportation, warehousing, customs clearance, and last-mile delivery are often fragmented and difficult to use for mode evaluation. In addition, a shortage of professionals who understand both logistics operations and digital technologies makes it difficult to apply data analysis flexibly to logistics mode improvement. Therefore, the absence of a mature information technology application system limits the ability of cross-border e-commerce logistics to move from experience-based decision-making toward data-informed decision-making.

This also means that logistics optimization is no longer limited to physical transportation. It increasingly depends on information sharing, process reengineering, tracking systems, and coordination among platforms, logistics providers, and consumers. Fei et al. show that business process reengineering in cross-border e-commerce logistics services can promote the digitalization of logistics services, while supply chain integration and information sharing further strengthen this process [31]. This finding supports the argument that cross-border e-commerce logistics modes need to be redesigned through both operational and digital perspectives.

4.1.6. Cause 3: Backwardness of Evaluation Systems Used in Logistics Mode Selection

When a platform formulates a logistics mode, the evaluation of alternative basic modes is crucial because it determines whether the selected mode can fit specific operational conditions. However, many cross-border e-commerce sellers have traditionally paid insufficient attention to logistics evaluation. Influenced by the thinking patterns of domestic e-commerce or traditional international trade, some sellers place greater emphasis on market size, product quality, and sales channels, while treating logistics as a secondary operational issue. In cross-border e-commerce, however, logistics performance can directly affect cost, customer satisfaction, order conversion, repeat purchase behavior, and platform reputation. This is consistent with the view that logistics service capability has become a key basis for competitive differentiation in cross-border e-commerce [11].

The construction of an effective evaluation system requires the comprehensive consideration of multiple factors, including transportation mode, logistics provider, customs clearance process, logistics cost, delivery time, logistics risk, policy environment, product type, and customer requirements. These factors are often changing, which means that the evaluation system should not only pursue numerical accuracy, but also have enough flexibility to respond to changes in the international logistics environment. Studies on cross-border logistics solutions under uncertainty also indicate that logistics mode selection should be based on a structured evaluation of multiple alternatives [6,7].

In actual operations, many platforms still lack the ability to establish such an evaluation system. Some simply imitate the logistics modes of competitors, while others make decisions mainly from the perspective of short-term cost. These approaches may lead to a mismatch between the selected logistics mode and the actual business environment, which then causes cost control difficulties, low service efficiency, and insufficient

coordination with business activities. Therefore, improving the evaluation system for cross-border e-commerce logistics modes is a necessary step in addressing the deeper causes of current operational problems. The evaluation framework proposed in this study responds to this need by combining the AHP and the fuzzy comprehensive evaluation method. This allows both qualitative judgments and quantitative calculations to be included in the decision-making process. Compared with single-factor judgment based only on freight cost or delivery speed, such an integrated evaluation approach is more suitable for the complex and uncertain conditions of cross-border e-commerce logistics.

4.2. Improvement Directions for Cross-Border E-Commerce Logistics Modes

Based on the problems discussed above, the improvement of cross-border e-commerce logistics modes should focus on three closely related directions: diversifying logistics modes, strengthening the use of data-driven technologies, and establishing a more scientific evaluation system. These directions correspond to the main underlying causes identified in the previous section, namely the insufficient response to logistics complexity, the limited application of information technology, and the backwardness of evaluation systems used in logistics mode selection.

4.2.1. Diversifying Logistics Modes

Cross-border e-commerce firms need to develop more diversified logistics modes in order to respond to complex logistics conditions. As discussed in Section 4.1, cross-border e-commerce logistics involves longer geographical distance, longer delivery time, customs clearance, cross-border inspection, and heterogeneous customer requirements. Under such conditions, relying on a single basic logistics mode is unlikely to meet all operational needs. Previous research on cross-border B2C e-commerce has also shown that different logistics solutions need to be evaluated under uncertainty because their performance depends on product type, market conditions, service requirements, and risk exposure [6,7].

Therefore, the practical value of a diversified logistics mode lies in its ability to combine the strengths of different basic modes and match them with differentiated logistics needs. For example, dedicated-line logistics has become increasingly attractive to cross-border e-commerce firms because it allows the seller or platform to maintain greater control over the logistics process. Problems that occur during transportation can be identified and handled more quickly, and logistics information can also be fed back to customers in a more timely manner. However, dedicated-line logistics is not suitable for all cases. When a customer is located in a remote island region or an area with weak logistics accessibility, postal parcel services with wider international networks may be more practical. Similarly, when the product is fresh food, adding cold storage equipment and refrigerated vehicles to an existing dedicated-line system may be less efficient than entrusting the order to a professional cold-chain logistics provider.

This means that the selection of logistics modes should be condition-specific. The platform needs to consider product characteristics, customer location, delivery urgency, cost tolerance, return requirements, and the logistics infrastructure of the destination market. For example, bonded warehouses or overseas warehouses may be suitable for products with stable demand and high turnover, while direct mail or postal services may be more suitable for products with uncertain demand or low order frequency. Existing research on bonded-warehouse and direct-mail choices in cross-border e-commerce supply chains also indicates that logistics mode choice can be affected by information sharing and inventory decisions, which further supports the need for flexible logistics mode design [12].

From an industry perspective, cross-border e-commerce logistics has already shown a tendency toward diversification. Earlier cross-border e-commerce orders relied heavily on postal parcels, but platforms and sellers have gradually begun to adopt multiple logistics modes, such as dedicated-line logistics, overseas

warehouses, bonded warehouses, third-party logistics, and platform-based logistics services. This shift is partly related to changes in international postal pricing and freight conditions, but it also reflects the growing awareness that logistics mode diversification can improve service quality and customer experience. Logistics service quality, including timeliness, price fairness, availability, and service reliability, has been shown to influence customer satisfaction and repurchase intention in cross-border e-commerce contexts [10]. Therefore, diversification should be understood as an important way to improve both operational resilience and customer-facing service quality.

For cross-border e-commerce firms, domestic e-commerce experience can provide useful operational knowledge, but it cannot be directly transferred to all international markets. Different countries and regions have different logistics infrastructure, customs systems, consumer expectations, and service standards. As a result, firms need to move beyond the logic of domestic e-commerce logistics and develop more flexible logistics modes for different international markets. This also echoes the view that cross-border e-commerce firms increasingly act as supply chain integrators and need to coordinate product flows, information flows, and financial flows across multiple actors [11].

4.2.2. Strengthening the Use of Data-Driven Technologies

The application of data-driven technologies should be strengthened to promote the transformation of cross-border e-commerce logistics. As discussed in Section 4.1, the current application of information technology in cross-border e-commerce logistics remains insufficient. Compared with traditional logistics activities, cross-border e-commerce logistics faces a more complex environment and requires stronger coordination across platforms, sellers, logistics providers, customs authorities, and consumers. In this context, data-driven technologies can provide important support for logistics mode optimization.

Among these technologies, big data analytics is particularly important because it can transform dispersed operational records into usable evidence for logistics mode evaluation. Cross-border e-commerce platforms generate data from orders, customer locations, product categories, transportation routes, customs clearance, warehouse operations, returns, complaints, and after-sales services. When these data are collected and analyzed systematically, they can help platforms identify demand patterns, cost structures, delivery risks, and customer preferences. Previous studies have shown that big data technology can improve cross-border e-commerce logistics by supporting international logistics management and supply chain management [32], while digital logistics services, information sharing, and supply chain integration can reduce transaction uncertainty and strengthen consumers' willingness to continue using the platform [31].

In practical terms, a data-driven logistics mode can be built around three elements: data collection, algorithmic analysis, and decision support. First, logistics data can be collected through terminal technologies such as visual recognition, RFID, Internet of Things devices, and warehouse management systems. Communication technologies such as NB-IoT, 4G, and 5G can then support the real-time uploading and transmission of logistics data. Second, analysis algorithms can be used to process these data and support the evaluation of alternative logistics modes from multiple dimensions, including cost, delivery time, reliability, customer satisfaction, return rate, and risk exposure. Third, the calculation results can serve as a decision-making reference for platforms and sellers when they evaluate, select, and adjust their logistics modes.

The introduction of data-driven technologies also changes the role of logistics in cross-border e-commerce. Logistics is no longer only a physical transportation process. It increasingly becomes a digitalized service process involving tracking, prediction, risk warning, inventory coordination, customer communication, and after-sales management. Fei et al. [31] argue that business process reengineering in cross-border e-commerce logistics can promote the digitalization of logistics services, while supply chain integration and information sharing can further strengthen this process. Therefore, applying data technologies can help reduce the

disconnection between logistics modes and the broader e-commerce business process, and can also promote the modernization of the logistics industry.

4.2.3. Establishing a Scientific Evaluation System

A scientific evaluation system is needed to optimize the formulation of logistics modes. At present, many cross-border e-commerce firms still rely heavily on past experience or subjective judgment when combining different basic logistics modes. This approach may work under stable conditions, but it becomes insufficient when the logistics environment is uncertain and when cost, service quality, product characteristics, policy conditions, customer location, and return requirements need to be considered together. Therefore, the evaluation system should be flexible enough to reflect different business conditions.

A more suitable approach is to establish a flexible and structured evaluation system that can be adjusted according to specific business conditions. This system needs to consider both internal and external factors. Internal factors include product type, order size, inventory capacity, service positioning, capital pressure, and platform management ability. External factors include the destination country's logistics infrastructure, customs rules, policy environment, market demand, and customer expectations. The evaluation system should also provide clear output results so that platforms can compare alternative basic modes and select the most suitable logistics mode under specific conditions.

From a methodological perspective, this type of decision is a multi-criteria decision-making problem. The evaluation of logistics modes involves both quantitative indicators, such as cost and delivery time, and qualitative indicators, such as service reliability, customer satisfaction, flexibility, and risk resistance. Previous studies on logistics provider selection have shown that fuzzy AHP and related multi-criteria decision-making methods are useful when decision-making involves multiple criteria, qualitative judgments, and uncertain expert preferences [33,34]. This provides methodological support for using an integrated evaluation framework in cross-border e-commerce logistics mode selection.

4.2.4. Integrated Improvement Direction

The three improvement directions discussed above are closely connected. Diversification of logistics modes provides the operational basis for matching different logistics needs. Data-driven technologies provide the technical means for collecting information, identifying patterns, and supporting mode evaluation. A scientific evaluation system provides the analytical framework for comparing different logistics modes and making structured decisions. In this sense, these three directions should be integrated.

Therefore, this study proposes an integrated improvement direction for cross-border e-commerce logistics modes: diversified logistics modes should be supported by data-driven technologies and organized through a scientific evaluation system. This integrated approach can be understood as a data-informed evaluation model for diversified logistics modes. By combining multiple basic logistics modes, data-based analysis, and structured evaluation methods, cross-border e-commerce firms can select more suitable logistics modes under specific market, product, and customer conditions. This approach can help improve logistics efficiency, reduce operational risk, and enhance the overall coordination between logistics activities and cross-border e-commerce business operations.

4.3. Cross-Context Applicability and Boundary Conditions

The single-case design of this study requires a careful interpretation of the findings. The empirical ranking obtained in the case should be understood within the specific setting of Platform A, including its Japanese small-household-appliance product category, East China target market, cost pressure, return-handling needs, and previous reliance on international express delivery. Therefore, the result that dedicated-line logistics ranked

first should be read as a context-specific recommendation for this platform's logistics problem. This interpretation is consistent with case study research, where the value of a single case lies in clarifying mechanisms, procedures, and contextual conditions, while direct statistical generalization remains limited [35,36].

The cross-context applicability of this study mainly lies in the evaluation procedure. Three levels should be distinguished. The first level is the procedural logic of the framework, including defining the product-market context, identifying feasible logistics modes, constructing an indicator system, eliciting expert-informed judgments, calculating AHP weights, conducting fuzzy comprehensive evaluation, testing sensitivity, and comparing the recommendation with operational indicators. This procedure can be adapted by other cross-border e-commerce firms. The second level is the indicator logic. Cost, quality, product characteristics, logistics environment, and e-commerce environment are broadly relevant to logistics mode selection, but their sub-indicators and weights need to be adjusted according to the business setting. The third level is the empirical ranking. This level is the most context-dependent, because the relative performance of overseas warehouses, dedicated-line logistics, postal parcels, and outsourced international express delivery may change when the product category, demand pattern, destination market, or platform capacity changes.

Several boundary conditions are especially important when transferring the framework to other settings. Product characteristics can substantially change the evaluation structure. Small household appliances require attention to cost, safety, value attributes, delivery reliability, and return handling. Fresh food would require greater emphasis on cold-chain capability and delivery speed. Luxury goods would require stronger attention to security, traceability, and damage risk. Bulky goods may increase the importance of warehousing cost, handling cost, and reverse logistics. Demand stability also matters. Products with stable and high turnover may be more suitable for overseas warehousing, while products with uncertain or low-frequency demand may require more flexible arrangements. Previous studies on cross-border e-commerce logistics mode selection also show that information sharing, market fluctuation, tax rate, exchange-rate risk, and competition can change the relative attractiveness of direct mail, bonded warehouses, and other logistics arrangements [12-14].

Destination-market conditions and platform maturity further affect the framework's application. Customs procedures, last-mile delivery infrastructure, local warehouse availability, customer expectations, and policy requirements may change the scores assigned to each logistics mode. Data availability also influences the balance between operational indicators and expert-informed judgment. A mature platform can use standardized indicators such as logistics cost per order, delivery lead time, on-time delivery rate, damage rate, return processing time, and complaint rate per 1,000 orders to calibrate the fuzzy membership values more directly. An early-stage platform may still need structured expert elicitation, while consistency testing, sensitivity analysis, and post-implementation triangulation can improve transparency.

Compared with existing logistics evaluation frameworks, the contribution of this study lies in connecting multi-criteria evaluation with logistics mode formulation under a defined cross-border e-commerce context. Previous frameworks have provided useful tools for logistics service provider selection, service quality evaluation, digital logistics analysis, and sustainable logistics assessment. This study extends that discussion by showing how different logistics modes can be evaluated through an indicator system defined by the characteristics of product and market, and then translated into a concrete operational arrangement. The framework should therefore be used as an adaptable decision-support procedure, with recalibration required whenever the product, market, platform, or logistics environment changes.

5. Conclusion

This study developed a data-informed evaluation framework for logistics mode selection in cross-border e-commerce. The framework integrates the AHP and fuzzy comprehensive evaluation in order to combine expert-

informed judgment with numerical calculation. By using this framework, the weights of key influencing factors can be determined, and alternative basic logistics modes can be compared under specific business conditions.

The framework was applied to an anonymized Japanese cross-border e-commerce platform selling small household appliances to the East China market. The case results showed that dedicated-line logistics achieved the highest evaluation score among the four alternative modes, while the overseas warehouse mode could be used as a supplementary option to improve delivery speed for popular products and provide a buffer against fluctuations in order volume. Post-implementation operational indicators further showed improvements in logistics cost control and service performance under the case conditions, suggesting that the proposed framework has practical value for supporting logistics mode selection in cross-border e-commerce operations.

This study makes three main contributions. First, it provides a structured evaluation framework for logistics mode selection that incorporates both expert-informed business judgments and quantitative calculation. Second, it compares alternative logistics modes under a clearly defined product-market context and shows how the evaluation result can be translated into an operational logistics arrangement. Third, it clarifies the distinction between the case-specific ranking result and the broader applicability of the evaluation procedure. In this sense, the framework can be adapted to other contexts by recalibrating the indicators, weights, fuzzy membership values, and validation indicators.

Several limitations remain. The study is based on a single case platform, and the expert inputs were closely related to Platform A's operational conditions. The availability of individual-level expert rating records was also limited. Although AHP consistency testing, sensitivity analysis, and post-implementation triangulation were added to improve transparency, these measures cannot remove all context dependence from the evaluation results.

Future research should test the framework across different product categories, target markets, platform types, and logistics environments. It would also be useful to collect more standardized operational indicators, such as logistics cost per order, delivery lead time, on-time delivery rate, damage rate, return processing time, and customer complaint rate per 1,000 orders. These indicators could be used to calibrate or partially replace expert-based membership scores. Future studies could also extend the indicator system by incorporating sustainability-related indicators, such as carbon emissions, energy use, green packaging, environmental compliance requirements, and low-carbon logistics capability. Such extensions would make it possible to examine how cross-border e-commerce firms balance cost control, service performance, and environmental responsibility when selecting logistics modes.

Author's Contributions

LS contributed to the conceptualization of the study, development of the research framework, methodology design, case analysis, data organization, writing of the original draft, and final manuscript revision. YH contributed to the literature review, data interpretation, and revision of the manuscript. CET contributed to methodological guidance, supervision, and critical review of the manuscript. KOO contributed to the refinement of the analytical framework, interpretation of the results, and manuscript revision. ZT contributed to data checking, formatting, and technical support for the computational procedures. BYW contributed to literature organization, and language editing. All authors reviewed and approved the final version of the manuscript.

Funding

This research received no external funding.

Data Availability

Data are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgements

The authors would like to thank colleagues in the logistics industry for their valuable support in providing data and assisting with the case application.

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