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Evaluating the impact of Trans-Asian railway on logistics mode selection between Thailand and China: An AHP-TOPSIS approach

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ABSTRACT

The newly opened Trans-Asian Railway offers opportunities for trade logistics between China and ASEAN (Association of Southeast Asian Nations). This study selected six factors including cost, time, transport volume, reliability, safety, and environmental friendliness to investigate the impact on logistics for trade between China and ASEAN. It explores the most ideal solution for the Sino-Thai logistics route by using the AHP-TOPSIS approach and ranks the current five Sino-Thai logistics routes. The results indicate that the Sea-land transport (0.787) is still the best option, the Kunming-Bangkok Roadway (0.452) came in second, followed by the newly opened Trans-Asian Railway (0.431); The Nanning-Bangkok Roadway (0.373) ranks second to last, and the river-land transport service (0.249) is the last resort. In this sense, the newly opened Trans-Asian Railway would influence the current pattern of Sino-Thai logistics to some extent. The results will offer insight into the managerial decisions for the Sino-Thai trade.

1. Introduction

In 2001, China and the Association of Southeast Asian Nations (ASEAN, which includes Laos, Cambodia, Myanmar, Thailand, Vietnam, Malaysia, Singapore, Brunei, the Philippines, Indonesia, and East Timor.) signed the Framework Agreement on Comprehensive Economic Cooperation. And the China-ASEAN Free Trade Area was officially launched. From 2001–2021, the trade turnover between China and ASEAN expanded almost by 22 times [1]. The prosperity of trade requires efficient and convenient trade channels and a more diversified transportation layout. Therefore, the Trans-Asian Railway between Yiwu and Bangkok was built in July 2022. Within the China-ASEAN trade, small commodity from Yiwu, the world's largest small commodity distribution center, enters ASEAN through various transportation routes such as sea, air, river, and road. In previous decades, cargoes were welcomed to be delivered by railways and shipping [2]. Under these circumstances, the Trans-Asian Railway represented a new option for the logistics of China-ASEAN trade, benefiting from market demand and policy orientation. The transportation mode between Yiwu and ASEAN is expected to be restructured in the near future.

Since the 1960 s, container transport has changed the port hinterland traffic, and the changes continue to this day [3]. More than 70 % of freight transport worldwide is based on container transport [4], and this also applies to small commodities in Yiwu. The opening of the Trans-Asian Railway has promoted the development of container transportation between China and Thailand, especially sea transport. It verifies that the development of container transportation requires sustainable port connections with the hinterland, which is consistent with Zondag, B. and de Jong, G. [5]. On the other hand, the competition in multichannel transportation is also analyzed from multiple dimensions by researchers. Neumann, T. analyzed the long-distance transportation modes between China and Poland as well as the competitiveness of railway and sea transport [6]. Van den Bos, G. and Wiegmans, B. conducted a statistical analysis of the influencing factors of road, rail, and short sea shipping (SSS) in EU countries [7]. This discussion leads to **Research Question 1: How does the new transportation route from Yiwu (China) to Bangkok (Thailand) affect existing logistics models?**

Following question 1, researchers hope to draw quantitative conclusions. Dorhetso, S. N., and Tefutor, I. K identified key factors for sustainable regional and cross-border road, railway, and shipping infrastructure in Ghana, and reviewed and ranked the identified factors

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using the best-worst method based on weighted averages [8]. Paulauskas et al. [9] investigated technically or economically effective transport solutions in road, rail, and inland waterway transport from an ecological and energy economic perspective following the "state of the art" and the establishment of a comparative index of transport modes, including transport costs, time, and the fuel used in the modes. The above scholars' research can be applied to different scenarios, while the Geographically Weighted Regression (GWR) model was used to assess the impact of local key factors on public transport usage. It is evident that the traffic distribution of unique geographical regions needs to be studied. So the R**esearch Q**uestion **2 is: What will be the most important factors in the new transportation pattern for container transportation from Yiwu to Bangkok?**

To investigate the above two questions, an Analytic Hierarchy Process and a Technique for Order Preference by Similarity to the Ideal Solution (AHP-TOPSIS) model are employed to explore the competition between different logistics routes and evaluate the impact on the patterns of previous transportation. In order to identify the impact of new transportation channels on the inherent transportation route, an empirical study on Yiwu to Bangkok rail transport was conducted to determine the impact of the entry of the Trans-Asian railway on the freight transport market in specific regions as well as the competitive relationship between multiple transport modes (including multimodal transport models). This paper first determines the benchmark tariff by calculating the costs for transporting the same or similar freight transport profiles (for example, similar transport dimensions/weights, and transportation routes). Furthermore, to simplify the algorithm, we also assume that all shippers choose a door-to-door service and compare the transport costs between shippers to check if this strategy is conducive to finding the most attractive mode of transportation.

The main work and contributions of this study are threefold. (1) we formulate a model with transportation influencing factors of the same or similar freight transport profiles, for the purpose of determining benchmark tariffs, comparing transportation key factors in different transportation channels through sensitivity analysis, and examining whether this strategy helps shippers find the most attractive transportation solution. (2) AHP and TOPSIS are comprehensively applied in the hierarchical multivariate analysis, evaluate the matching analysis of containers on the new railway and inherent transportation channels under the door-to-door service, determine the weighting of key factors, and help shippers with different requirements in specific areas to obtain a more matching transportation means. (3) To verify the above models, we evaluated the impact of the railway on the existing transportation market and examined the competition between different logistics routes between Yiwu and Bangkok. It is based on the situation that the opening of the Trans-Asian railway has disrupted the distribution of sea, air, river, and road transport between China and ASEAN countries. We highlighted the optimization of transportation routes and further explored intermodal transportation modes. The results support shippers to select suitable logistics routes for the Sino-Thai trade with individual preferences, benefiting from exploring the long-term operation strategy of the China-ASEAN logistics network, and providing more comprehensive management reference recommendations for the authorities, and shipping companies.

The rest of this paper is organized as follows. Section 2 is the literature review. The third section covers the materials and methods. Section 4 is the obtained results and the discussion. The final section concludes the key findings with the limitations and future work.

2. Literature review

Container transportation is one of the most flexible modes of transportation and has made considerable progress since its inception [10–15]. The superiority of containers allows them to adapt to multimodal transportation modes such as roads, waterways, railways, and aviation. Therefore, Yin et al. [16] argued that the development of container transportation would promote a sustainable connection between the port and the hinterland. For container ports, Liu et al. [17] believed that the railway can relieve the pressure of road transport, a special railway loading and unloading station should be established, and the free port policy should be adopted between the railway and the inland river to increase the traffic volume on a branch line. The development of dry ports or intermodal terminals in the vicinity of rail and road transport hubs can encourage the choice of different modes of container transportation and support more environmentally friendly transport routes, such as inland waterways and railways [18]. The literature shows that inland container transportation often adopts intermodal transportation mode, which is of practical significance for the study of the multimodal logistics network for container transportation between Yiwu and Bangkok.

The construction of a new transport channel is affected by the location, the existing transport routes, the financial, social, and political costs, and the environment [19]. Parida [20] noted that the rules, and core infrastructure for rail and water transport have become bottlenecks in the development of trade in mining and emerging economies in Southern Africa. Givoni and Banister [21] studied the integration of multimodal transportation by using rail services as a complement and alternative to existing air services and found that rail services can also be used as air transport infrastructure. The transport costs of rail and shipping are lower than those of single-road transport, and railway transport is not affected by congestion, resulting in higher expected growth. Currently, many studies use different transportation methods to reduce transport costs. This has been shown in markets with large quantities of goods, cost sensitivity, and long transport routes [22,23]. Generally, there was a competitive relationship between Short Sea Shipping (SSS) and overland transportation, especially railway transport [24]. Yotsov [25] analyzed SSS and rail as alternatives to road freight transport in terms of three main criteria: cost, delivery time, and environmental protection. Freight volume and service scope are the main advantages of SSS. Low prices encourage the SSS to increase freight volume in order to increase service frequency, improve service levels, and then achieve a lower freight price than the rail [26]. The literature shows that rail transport is one of the strongest competitors in the transportation market, and studying the impact of newly emerging railways on the existing transportation market is of academic importance.

Extensive research has been dedicated to examining shippers' preferences for logistics options. In terms of shipping competitiveness, terminal operators believe that hardware facilities are the most important factor, followed by channel depth, multimodal transport connectivity, vessel turnaround time, and distance to import and export areas, while shippers believe that vessel turnaround time is the most important factor for competitiveness, followed by multimodal transportation, port facilities, and equipment [27]. Considering the fluctuation of demand in the market and the inertia of shippers in selecting vessels, container shipping companies will develop operational strategies tailored to shippers' preferences to increase their market share [28]. Duan et al. [29] developed a model for transportation service networks that takes time value heterogeneity into account, and the results showed that taking shippers' time preferences into account can reduce the total generalized cost of users and improve service levels. Establishing a shipper attraction function in terms of time and freight service network shows that competitive customs clearance times and freight service network are key to attracting shippers [30]. All previous studies have explored the influencing factors and analyzed their importance. However, only a few studies have distinguished factors from quantitative and qualitative perspectives.

Previous literature [31,32] has shown that the application of scientific algorithms and technologies could optimize regional transportation networks. Related studies on the competitive relationship between different transportation modes, ie., SSS and land-based transportation, were studied by Yotsov [33]. However, few studies have focused on analyzing individual preferences for SSS and railway transport systems for the newly opened railway corridors. Analysis of container transportation with unique characteristics is multi-channel transportation. In addition, there have been few studies analyzing the impact of new channels on container transport via existing transport channels. The published studies hardly address the competition between newly established container transportation channels and existing land and water transport. Since we focus on examining the impact of newly established container transportation channels on existing transportation patterns, we will briefly review the literature on preference selection of transportation routes. Many existing research have considered the needs of cargo owners from a single perspective, but few have analyzed the problem from multiple perspectives.

We search the Web of Science for keywords such as "container transportation", "new channel", "owner preferences", "key factors", "time", "cost", "safety", "reliability", and "environmental friendliness" to find literature related to the multi-faced analysis of cargo owner's preferences in container transportation. No literature can cover all the above keywords, only two articles cover "container transportation" and "preferences". Hyun et al. [34] employed a consistent fuzzy preference relation (CFPR) method to prioritize government policies and found that among the 14 policies, the policy perceived most important was the "expansion of participation in the share of shipping company or ships of shipper" followed by "strengthening national shipper-centered service quality", and "providing a long-term transportation contract model of container cargo". Motlagh et al. [35] assessed the frameworks, infrastructure, training, and other critical factors and analyzed multiple operational and technological possibilities for decarbonization solutions considered in container shipping, using a multi-criteria decision-making (MCDM) approach to assess the desires of shipowners and stakeholders. In addition, existing research do not analyze multimodal single transportation and intermodal transportation and therefore do not take into account the actual distribution of the container transportation market in a specific region.

As one of the most popular models, used in 216 papers indexed in the Web of Science from 1991 to 2024 with the keywords "MCDM/A" and "transportation", AHP is the top-ranked method [36]. The AHP-TOPSIS approach was used in 19 cases of these research papers. Therefore, this method is comprehensively applied in our study for the hierarchical multivariate analysis to evaluate the matching analysis of containers in the new railway and SSS under door-to-door service and help shippers find a more suitable mode of transportation.

3. Materials and methods

3.1. Methods

This study used the AHP-TOPSIS to evaluate alternative transportation systems (see Fig. 1). First, AHP is used for analytical hierarchical partitioning, then TOPSIS classifies the alternative positions according to the characteristics of the scheme, and finally, the value closest to the positive ideal solution and farthest from the negative ideal solution is identified to obtain the optimal solution. This method overcomes the limitation of using AHP and TOPSIS alone and combines the advantages of AHP and TOPSIS to find the most suitable solution for Sino-Thai logistics.

3.1.1. AHP

AHP is an easy way of using a combination of qualitative and quantitative analysis methods to make decisions about more obscure, fuzzy, or complex decision-making problems [37]. This method has its origins in the well-known and popular Multiple Criteria Decision Making (MCDM) technology developed by Saaty [38]. AHP has clear advantages in quantifying the experiences and judgments of decision-makers, prioritizing people's thought processes, comparing the relative factors, and testing the rationality of the comparison results,

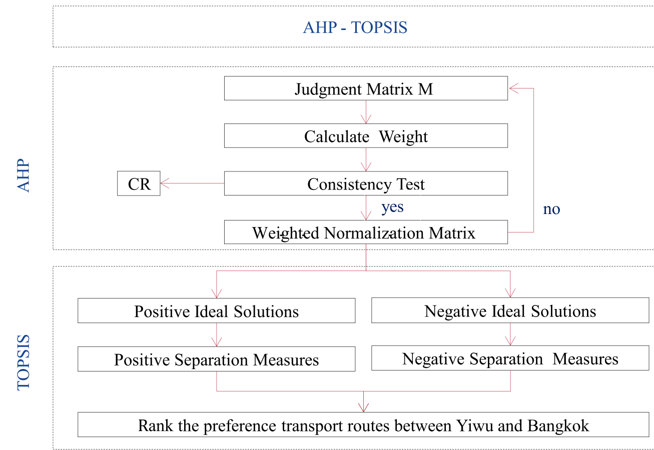

Fig. 1. The research framework of AHP – TOPSIS.

thus providing a more convincing basis [39]. Five examples were studied to explore the different applications and future research directions of AHP in transportation, including the selection of commuting routes, the best combination of routes to the airport, the best method for river crossing, the planning of transportation systems, and the selection of alternative automobile solution selection [40]. In order to prioritize different types of scenarios that highlight planning issues, a prioritization or assessment of specific scenarios based on the detailed planning of the transportation project was developed [41].

The modeling process of the AHP follows Bertsimas [41]:

(1) Create a hierarchical structural model

The research problems are organized according to certain principles, divided into several related small interrelated problems, and divided into different levels according to the relationships and subordination, and an advanced structural model with multi-level analysis is constructed. In view of the complexity of the decision-making problem and the detailed nature of the analysis to be interpreted, the number of layers in the model is not limited, but the top layer has only one element and is the desired goal or ideal result of the analysis problem. The intermediate level contains the intermediate links required to achieve the goal, which can be divided into several levels. The lowest level lists the various actions and decisions available to achieve the highest level. Once the hierarchical structural model has been completed, the subordination relationship of the factors between the levels is clarified. It is assumed that the L_0 index of a level is based on Criterion Z, and the influencing factor of the next level dominated by L_0 is $m_1, m_2, \dots, m_n$, the importance of factor m is evaluated using a scale of "1–9", Table 1 shows the meaning of the scale "1–9" scale.

Thus, for Criterion Z (square root method), the assessment matrix established $M = (m_{ij})_{n\times n}$.

(2) Structure of the assessment matrix

According to the evaluation standard, the relative importance of each influencing factor is compared in pairs at the same level, and then all the evaluation results are sorted, and finally, an assessment matrix is obtained. According to the assessment matrix, the weight value of each

Table 1
1–9 dividing rule.

Number	Rules
1	m_i and m_j are equally important.
3	m_i is slightly more important than m_j.
5	m_i is more important than m_j.
7	m_i is significantly more important than m_j.
9	m_i is extremely more important than m_j.
2, 4, 6, 8	The importance of m_i to m_j lies between the above two numbers.
Reciprocal	If the importance ratio of m_i to m_j is m_{ij}, then the importance ratio of m_j to m_i is $m_{ji} = 1/m_{ij}$.

influencing factor can be calculated. For example, based on a certain influencing factor *M*, there are n influencing factors that are under the influence of *M*, and the pairwise comparison of the n sub-factors is shown in Table 2. where m_{ij} is the scale of the importance of the indices m_i and m_j for the Criterion *Z*. m_{ij} has the following meaning:

$$m_{ij} > 0,\ m_{ij} = 1/m_{ji},\ m_{ii} = 1\cdots \tag{2}$$

Assessment matrix *M* can be generated:

$$M = \begin{bmatrix} 1 & m_{12} & \cdots & m_{1i} & \cdots & m_{1j} & \cdots & m_{1n} \\ m_{21} & 1 & \cdots & m_{2i} & \cdots & m_{2j} & \cdots & m_{2n} \\ \vdots & \vdots & 1 & \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{i1} & m_{i2} & \cdots & 1 & \cdots & m_{ij} & \cdots & m_{in} \\ \vdots & \vdots & \vdots & \vdots & 1 & \vdots & \vdots & \vdots \\ m_{j1} & m_{j2} & \cdots & m_{ji} & \cdots & 1 & \cdots & m_{jn} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 1 & \vdots \\ m_{n1} & m_{n2} & \cdots & m_{ni} & \cdots & m_{nj} & \cdots & 1 \end{bmatrix} = (M_{ij})_{n\times n} \tag{1}$$

Using the assessment matrix of the n indicators $m_1, m_2, \ldots, m_n$ for the *Z* criterion, calculate the weights $\beta_1, \beta_2, \ldots, \beta_n$ corresponding to the *Z* criterion, and calculate the weights of each indicator:

$$G = (\beta_1,\ \beta_2,\ \ldots,\ \beta_n)^{\mathrm{T}} \tag{3}$$

Normalize the assessment matrix *M* to obtain the matrix $MG = G(k_{ij})_{n\times n}$,

where,

$$k_{ij} = k_{ij} \Big/ \sum_{i=1}^{n} k_{aj} \tag{4}$$

Add the elements of the matrix *MG* row by row to obtain a vector $\alpha = (\alpha_1,\ \alpha_2\ ,\ \ldots,\ \alpha_n)^{\mathrm{T}}$, and

$$\alpha_i = \sum_{i=1}^{n} m_{ij} \tag{5}$$

where $\beta_i = m_{i1}/\Sigma m_{i1}, i = 1, 2, \ldots, n$. Normalize α,

$$G_i = \alpha_i \Big/ \sum_{i=1}^{n} \alpha_j \tag{6}$$

$G = (\beta_1,\ \beta_2,\ \ldots,\ \beta_n)^{\mathrm{T}}$

(3) Consistency test

In order to ensure the rationality of the AHP conclusions, a consistency test of the assessment matrix should be performed. Take the elements of Criterion *Z* as an example as follows:

Compute the largest eigenvalue ω_{max} of the assessment matrix *M*, where $(M\beta)_i$ represents the i^{th} component of the vector $M\beta$:

$$\omega_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(M\beta)_i}{\beta_i} \tag{7}$$

Table 2
Pair-wise comparison table.

Target layer	M_1	M_2	…	M_i	…	M_j	…	M_n
M_1	1	m_{12}	…	m_{1i}	…	m_{1j}	…	m_{1n}
M_2	m_{21}	1	…	m_{2i}	…	m_{2j}	…	m_{2n}
…	…	…	1	…	…	…	…	…
M_i	m_{i1}	m_{i2}	…	1	…	m_{ij}	…	m_{in}
…	…	…	…	…	1	…	…	…
M_j	m_{j1}	m_{j2}	…	m_{ji}	…	1	…	m_{jn}
…	…	…	…	…	…	…	1	…
M_n	m_{n1}	m_{n2}	…	m_{ni}	…	m_{nj}	…	1

$$M\beta = \begin{bmatrix} 1 & m_{12} & \cdots & m_{1i} & \cdots & m_{1j} & \cdots & m_{1n} \\ m_{21} & 1 & \cdots & m_{2i} & \cdots & m_{2j} & \cdots & m_{2n} \\ \vdots & \vdots & 1 & \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{i1} & m_{i2} & \cdots & 1 & \cdots & m_{ij} & \cdots & m_{in} \\ \vdots & \vdots & \vdots & \vdots & 1 & \vdots & \vdots & \vdots \\ m_{j1} & m_{j2} & \cdots & m_{ji} & \cdots & 1 & \cdots & m_{jn} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 1 & \vdots \\ m_{n1} & m_{n2} & \cdots & m_{ni} & \cdots & m_{nj} & \cdots & 1 \end{bmatrix}\begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_i \\ \vdots \\ \beta_j \\ \vdots \\ \beta_n \end{bmatrix} = \begin{bmatrix} \sum_{i=j=1}^{n} m_{1j}\beta_1 \\ \sum_{i=j=1}^{n} m_{2j}\beta_2 \\ \vdots \\ \sum_{i=j=1}^{n} m_{ij}\beta_i \\ \vdots \\ \sum_{i=j=1}^{n} m_{jj}\beta_j \\ \vdots \\ \sum_{i=j=1}^{n} m_{nj}\beta_n \end{bmatrix} \tag{8}$$

The consistency index *CI* in the matrix *M* was calculated,

$$CI = \frac{\omega_{\mathbf{max}} - n}{n-1} \tag{9}$$

$$CI = CR \times RI \tag{10}$$

where *CR* is the relative consistency index, *RI* refers to the average stochastic consistency index [42].

$$CR = \begin{cases} 0, & M \text{ is a complete consistency matrix.} \\ < 0.1, & \text{The consistency of } M \text{ passes the test.} \\ > 0.1, & M \text{ does not pass the test and has no consistency.} \end{cases}$$

(4) Evaluate the final decision

To evaluate the hierarchy with *n* different levels, set the levels from high to low as $M_1, M_2, M_3, \ldots, M_n$ to calculate the assessment matrix *M*, and calculate the weight vector of each level as $\omega_{M_1}, \omega_{M_2}, \omega_{M_3}, \cdots$.

The consistency index of the relative hierarchical structure of the overall judgment is as follows:

$$CR_t = \sum\nolimits_{j=1}^{k} \sum_{i=1}^{nj} \omega_{nj} CI_{ni+1} \Big/ \sum\nolimits_{j=1}^{k} \sum_{i=1}^{nj} \omega_{nj} RI_{ni+1} \tag{11}$$

The result is valid when $CR_t < 0.1$.

3.1.2. TOPSIS

Pant et al. [43] point out that the subjective weights are easily lost in the AHP. Therefore, a combination with other MCDM methods is needed to accurately determine the general criteria weights. TOPSIS can be an effective complementary approach. This method has no requirement for the sample size, avoids subjectivity of the data, does not require an objective function, and does not require passing a test. The distance between the optimal solution and the worst solution of a multi-objective decision-making problem determines the comparison method of the selected scheme [44]. The TOPSIS is a scalar value that explains the best and worst alternatives, where the alternatives chosen are located closest to the positive ideal and furthest from the negative ideal. This value can be scanned as a distance measure on the visual polyhedron. The relative proximity of the individual programmers to their objectives is as follows:

$$R_i = D_i^- / D_i^+ + D_i^- \quad ,i \in N \tag{12}$$

where D_i^+ is the distance of each solution from the positive ideal solution, and D_i^- is the distance of each solution from the negative ideal solution. The schemes are ranked according to the value of the closeness relative to R_i, and the larger the value R_i value, the better the schemes are.

The fundamentals of using the TOPSIS method is that the decision-maker does not require that the outcome of the decision-making process is aimed at maintaining the order, but if the decision-maker requires that increasing or decreasing the scheme does not result in the reverse order phenomenon, the TOPSIS ordering phenomenon cannot fully account for the uncertainty and inaccuracy inherent in the perceptual mapping process. The AHP-TOPSIS hybrid model, combining the advantages of both methods, can reduce the uncertainty and information loss, and generate a robust solution to the uncertainties associated with the research problem.

3.1.3. AHP-TOPSIS

According to Abdullah et al. [45], the assessment matrix is obtained utilizing AHP and normalized to obtain the normalized matrix *N*. Considering the different importance of each factor, the weighted normalized decision matrix *V* is constructed by combining the scheme attribute weight vector ω and the normalized matrix *N*.

$$V = N\omega = \begin{bmatrix} n_{11}\omega_1 & n_{12}\omega_2 & \cdots & n_{1n}\omega_n \\ n_{21}\omega_1 & n_{22}\omega_2 & \cdots & n_{2n}\omega_n \\ \vdots & \vdots & \vdots & \vdots \\ n_{m1}\omega_1 & n_{m2}\omega_2 & \cdots & n_{mn}\omega_n \end{bmatrix} = (V_{ij})_{m\times n} \tag{13}$$

Positive and negative ideal solutions are based as follows:

$$S_i^+ = \left\{ \left(\max_i v_{ij} | j \in J \right), \ i, \ j = 1, \ 2, \ \cdots, \ n \right\} \tag{14}$$

$$S_i^- = \left\{ \left(\min_i v_{ij} | j \in J \right), i, j = 1, 2, \cdots, n \right\} \tag{15}$$

The distance between the object of evaluation and the positive ideal solution and the negative ideal solution is:

$$d^+ = \left\{ \sqrt{\sum_{j=1}^{n} \left(v_{ij} - S_i^+ \right)^2}, \ i, \ j = 1, \ 2, \ \cdots, \ n \right\} \tag{16}$$

$$d^- = \left\{ \sqrt{\sum_{j=1}^{n} \left(v_{ij} - S_i^- \right)^2}, \ i, \ j = 1, \ 2, \ \cdots, \ n \right\} \tag{17}$$

The ranking score *R* is obtained,

$$R_i = d_i^- / d_i^+ + d_i^- \quad ,i \in N \tag{18}$$

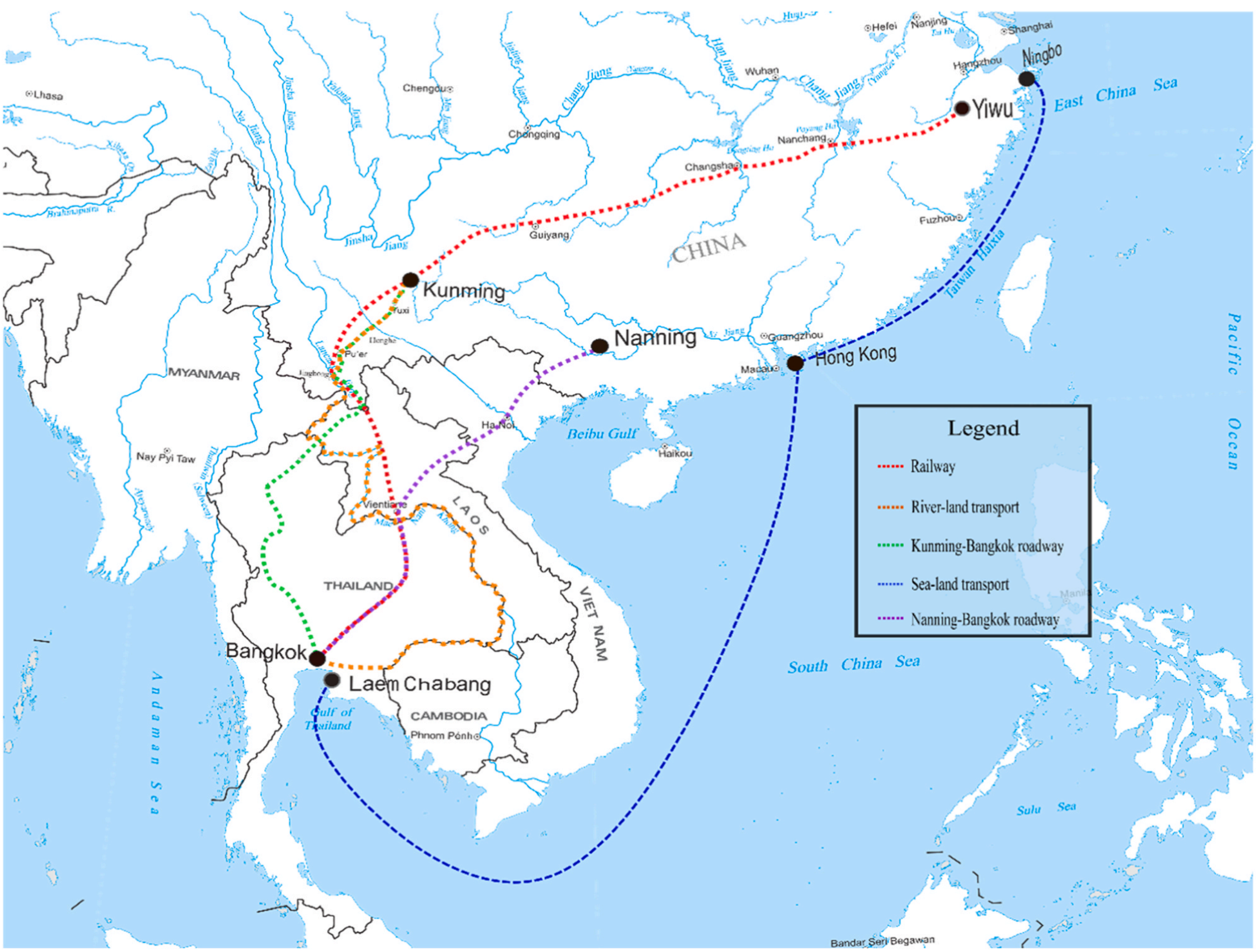

Fig. 2. Geographical and available transportation routes in OD interval.

3.2. Application to the selection of logistics mode between Yiwu and Bangkok

3.2.1. Brief description of the logistics mode selection between Yiwu and Bangkok

Before the construction of the Trans-Asian Railway, there were four transportation routes between China and Thailand (see Fig. 2). The first way is by shipping. After arriving at the coastal ports, the goods are transported to Thailand by shipping. The second route is multimodal transportation. The goods are transported to Yunnan province by road, which borders the ASEAN countries, and then transported across the Mekong River to Bangkok. The third way is road transport. The goods cross the border between Yunnan and the ASEAN countries and then continue to Thailand. The last channel is by air. This study focuses on analyzing the traffic patterns between the new transport channels and the existing transport routes and aims to explore the competition in the origin-destination (OD) interval and the preferences of cargo owners. The OD interval of this study is from Yiwu to Bangkok.

3.2.2. Identify impact factors

Numerous publications have been published on the analysis of freight transport modes. The most comprehensive recent study is Stockhammer et al. [46], which consulted 80 relevant literature in 2022 and defined 13 categories based on the 332 influencing factors proposed in the study in terms of physical characteristics, shipping characteristics (including transport volume), costs, the spatial distribution of goods, route characteristics, services, merchant characteristics, time, shipper characteristics, environment, economy, supply chain, and individual characteristics. As part of an online study, 86 shippers external freight forwarding and third-party logistics companies were surveyed, and Konstantinos et al. [47] identified the following levels of importance in 2019: (1) reliability, (2) transport cost, (3) damage risk (safety), (4) service frequency (transport volume), (5) transport time, (6) customer service, (7) service flexibility, (8) monitoring, and (9) environmental friendliness. After comparing the results of the two studies, the following six overlapping factors are proposed: cost, time, transport volume, reliability, safety, and environmental friendliness.

3.2.3. Data

In this study, 143 structured questionnaires were collected in the form of personal interviews. According to the announcement of the People's Government of Yiwu City in January 2023, there are 781 logistics enterprises in the compulsory city, and the number of enterprises engaged in international freight transport is far less than this number. The sample size collected this time meets the sample size requirements for exploratory factor analysis [46]. The interview was conducted between November 1, 2021, to January 31, 2022, in Shanghai, Ningbo, and Guangzhou. The questionnaire is based on existing research and was jointly developed by a freight forwarder from a Sino-Thai logistics company, a shipping employee, and a logistics employee.

All interviewed samples use the same survey form, which consists of the following seven parts:

(1) Obtaining basic information about the respondents.

(2) Product information for the matching transport channels.

(3) Transport information to capture the transportation activities of the respondents.

(4) Information on previous journeys conducted within the OD interval.

(5) Simulate the route selection preferences of the respondents using a 40-foot container as the unit of measurement.

(6) Diagnose issues and evaluate whether the SP's tasks were understandable and realistic.

(7) Conclusion: The investigator presents opinions and suggestions.

As shown in Fig. 2, the Sino-Thai freight routes between China and Thailand mainly include the Kunming-Bangkok roadway, Nanning-Bangkok roadway, Mekong River-land intermodal transportation, sea transport, and railway transport. To simplify the analysis, the objects of investigation are 40-foot containers of 26 tons and 68 cubic meters. The key indicators for these transport modes are listed in Table 3. In general, a longer distance means lower transport costs and freight fares for all modes of transport [48]. In studies, we allow all the goods to be transported over the shortest distance in the OD interval.

4. Results and discussion

4.1. Results

This case is based on the opinions of ten experts and four cross-border logistics companies and considers transport time, cost, transport capacity, safety, reliability, and environmental friendliness as six factors. Among them, transport time and cost are quantitative indicators, while the other four factors are qualitative indicators. The quantitative indicators refer to the situation in the transport market from 2019 to 2020 and are combined with questionnaire data. Based on these indices, a hierarchical structural model is established, which is divided into a target layer, criterion layer, and measure layer. The target layer is the optimal choice of transport mode. The criteria layer is the relevant factors that influence the final decision: transport cost, time cost, transport volume, safety, reliability, and environmental friendliness. The measured layer is the type of container transport. In view of the high freight rate, low volume, and low market share of air service in containerized freight transport, air transport is removed from the list of research objects in this study. Based on the influence of the above six factors on each factor of the measure layer, a comparison matrix using the pairwise comparison method is created in Table 4.

After normalizing the matrix, the weight

$$G_0 = (0.305,\ 0.277,\ 0.083,\ 0.157,\ 0.120,\ 0.058)^{\mathbf{T}}.$$

Therefore,

$$M\beta = \begin{bmatrix} 1 & 0.5 & 2 & 2 & 5 & 7 \\ 2 & 1 & 3 & 0.5 & 0.5 & 5 \\ 0.5 & 0.333 & 1 & 2 & 0.5 & 1 \\ 0.5 & 2 & 0.5 & 1 & 2 & 3 \\ 0.2 & 2 & 2 & 0.5 & 1 & 2 \\ 0.143 & 0.2 & 1 & 0.333 & 0.5 & 1 \end{bmatrix} \begin{bmatrix} 0.305 \\ 0.277 \\ 0.083 \\ 0.157 \\ 0.120 \\ 0.058 \end{bmatrix} = \begin{bmatrix} 2.085 \\ 1.857 \\ 0.524 \\ 0.976 \\ 0.818 \\ 0.352 \end{bmatrix}$$

The largest eigenvalue

$$\omega_{\max} = \frac{1}{6}\left(\frac{2.085}{0.305} + \frac{1.857}{0.277} + \frac{0.524}{0.083} + \frac{0.976}{0.157} + \frac{0.818}{0.120} + \frac{0.352}{0.058}\right) = 6.499$$

The consistency indices

$$CR = \frac{\frac{6.499-6}{6-1}}{1.24} = 0.080 \ < \ 0.1$$

Thus, the assessment matrix for the cargo transportation channel between China and Thailand has acceptable consistency.

Likewise, the values of the six impact factors of the steering layer for the Kunming-Bangkok roadway (L_1), the Nanning-Bangkok roadway (L_2), River-land transport (L_3), Sea-land transport (L_4), and Railway (L_5) were calculated in Table 5.

All coherence indicators are below 0.1 and pass the test. Then obtain the multiplied terms of weight aggregation terms and each value of M_i (i

Table 3
Comparisons of main transportation modes for a 40-foot container.

Routes	Kunming-Bangkok	Nanning-Bangkok	River-land transport	Sea-land transport	Railway	Air
Distance (km)	R3A road,1847	R9 road, 1900	550 (road)+350 (river)	3500 (SZ)-5800(TJ)	1800 (KM)-4200 (YW)	Min: 1400 (BKK-KMG) Max: 3300 (BKK-PEK)
Transport time (hour)	36–84	36–96	72–168	96–480	96–120	2–5
Transport cost (RMB/ton)	668	668	630–760	Sea 60–90, 4000 $/container	300	9 (RMB/Kg)
Transport volume	normal	normal	small	big	big	small
Safety	low	low	low	normal	high	high
Reliability	normal	normal	low	low	high	high
Environmental friendliness	low	low	normal	high	high	normal

Table 4
Comparison matrix of the selected six factors.

Factors	Transport time (M_1)	Transport cost (M_2)	Transport volume (M_3)	Safety (M_4)	Reliability (M_5)	Environmental friendliness (M_6)
M_1	1	1/2	2	3	5	7
M_2	2	1	3	2	1	5
M_3	1/2	1/3	1	1/2	1/2	1
M_4	1/3	1/2	2	1	2	3
M_5	1/5	1	2	1/2	1	2
M_6	1/7	1/5	1	1/3	1/2	1

Table 5
The values of the six factors.

Factors Transport routes	M_1	M_2	M_3	M_4	M_5	M_6
L_1	0.259	0.161	0.214	0.153	0.181	0.089
L_2	0.231	0.169	0.161	0.132	0.143	0.096
L_3	0.129	0.221	0.053	0.126	0.093	0.202
L_4	0.183	0.276	0.446	0.368	0.386	0.421
L_5	0.198	0.173	0.126	0.221	0.197	0.192

= 1, … , 6) from Table 5, where each term corresponds to one of the 30 units provided in Table 6. The overall evaluation of the competitiveness of the different routes is carried out by summing the six factors to obtain the total weights of the alternative solutions and classifying them.

Positive and negative ideal solutions are according to Table 7.

The distance between the different ways and the positive ideal solution and the negative ideal solution are shown in Table 8.

The transport systems are sorted according to the relative closeness degree of proximity, and the results are reported in Table 9. L_4 (0.787) is the best choice for container freight transport, while L_3 (0.249) service is the last resort. In actuality operation, sea transport is the main mode of transportation in global cross-border trade and also applies to the Sino-Thai trade market. As a traditional mode of transportation, L_4 has the advantage of a relatively larger freight-carrying capacity, and the longer the transportation distance, the cheaper the price and cost. In second place is road traffic L_1 (0.452), followed by L_5 (0.431). As the oldest operating land transportation corridor, L_1 is at the forefront of land transportation with its mature cross-border transportation model, geopolitical compatibility, competitive customs procedures, and global tariffs. The transportation routes between China and Thailand are mainly by sea and land transport. The time required for sea transport is relatively high for these two modes of transportation, while the price for road transport is relatively high. After the completion of L_5, the speed of trains from China to Thailand has increased, saving transport time and becoming the most suitable transport way for shippers considering both time and cost. Road transport L_2 (0.373) ranks second to last because it was opened later than L_1 and is popular in some regions but is not acquainted with the national market. Inadequate infrastructure construction such as roads and ports, inconvenient customs formalities such as customs clearance, inspection and quarantine, reverse cargo, backward cargo connection methods, imperfect cross-border professional services, and other factors lead to its higher transport costs than road transportation from Kunming to Bangkok, which has significantly affected its competitiveness in the market. The Lancang Mekong International Waterway, which is in the last place, is the Sino-Thai transportation channel with the longest history. However, the water level of the Mekong River is heavily influenced by the seasons, and the dry

Table 6
Construction of the weighted normalized decision matrix.

Factors Transport routes	M_1	M_2	M_3	M_4	M_5	M_6
L_1	0.079	0.045	0.018	0.024	0.022	0.005
L_2	0.070	0.047	0.013	0.021	0.017	0.006
L_3	0.039	0.061	0.004	0.020	0.011	0.012
L_4	0.056	0.077	0.037	0.058	0.046	0.024
L_5	0.060	0.048	0.010	0.035	0.024	0.011

Table 7
Positive and negative ideal solutions.

Criteria	M_1	M_2	M_3	M_4	M_5	M_6
S^+	0.079	0.077	0.037	0.058	0.046	0.024
S^-	0.039	0.045	0.004	0.020	0.011	0.005

Table 8
The distance between positive and negative ideal solutions.

	L_1	L_2	L_3	L_4	L_5
d^+	0.0591	0.0639	0.0758	0.0229	0.0558
d^-	0.0488	0.0380	0.0251	0.0844	0.0422

Table 9
Relative closeness and route priority ranking.

	L_1	L_2	L_3	L_4	L_5
Closeness	0.452	0.373	0.249	0.787	0.431
Rank	2	4	5	1	3

season from March to April limits freight traffic each year. In addition, the width of the riverbed is narrow, and the freight capacity of the route is small, which leads to large fluctuations in the freight volume and sailing time of this waterway transportation line.

4.2. Discussion

The final ranking is consistent with how the market actually works and shows that the benchmarking principles we have developed are reasonable and beneficial for logistics and freight forwarding companies, helping them to make the appropriate decision on transportation mode selection. To optimize the freight transport costs, the shippers are recommended to regularly evaluate the distance, transport time, price, safety, reliability, and environmental factors to find the most suitable transportation scheme. When transporting the 40-foot containers, the time costs are the most heavily weighted, showing that the on-time arrival of goods is paramount in international business activities. However, the choice of transportation scheme can have an important influence on transport time. An incorrectly chosen transport route can lead to violations of international trade agreements.

In the pairwise comparison recognition process, the weight value indicates the preference of experts for each criterion. The *CR* value was calculated as 0.080, which indicates a consensus among the experts. After the weight value, the transport time is in first place. The weight value is 0.305 and is linked to the delivery time specified in the commercial contract. Then comes the transport price; the value is 0.277. The safety of the transport process (0.157) was more important to the experts and shippers than reliability (0.120), and shippers placed more emphasis on the ability of goods to reach their destination intact and without incident than on the ability to arrive on time, which is consistent with Chacón et al. [49] and Huang et al. [50,51]. The next criterion is the carrying capacity, the mass of which is 0.083. Shippers only take this into account when transporting larger quantities of goods and are therefore at the bottom of the list. The final weight of environmental factors is 0.058, which objectively reflects the current situation in the Chinese market, where consumers place more value on benefits and are willing to trade environmental costs for economic benefits.

4.2.1. Sensitivity analysis

Sensitivity analysis based on input data represents an important step in many applications, designed to address the problem of data inaccuracy and immutability in decision analysis [52]. The final selection is often made with even a slight change in the coefficients of the weighting criteria, and the result is often accompanied by a sensitivity analysis for the development of the coefficients of the weighting criteria [53]. The sensitivity analysis of freight route choices in multimodal transportation was performed by changing the key factors from ±5 % to ±20 %, which were selected and based on the criteria with the greatest weight compared to the others [54]. Koohathongsumrit and Meethom [55] found that the absolute percentage error rate of transport cost and total transport time were 11.18 % and 4.29 % respectively, and proposed a new model to obtain an absolute percentage error of about 29.98 % and reduced the average absolute error from 18.43 % to 15.15 %. Nowadays, the various modes of transport are very sophisticated, both from a technological and managerial point of view. In addition, the transport market between China and Thailand has also entered a stable development phase after decades of development and competition. Therefore, it is unlikely that there will be significant fluctuations in transport time, cost, safety conditions, reliability, transport volume, and environmental friendliness in the near future. For this consideration, we carried out a sensitivity analysis with a fluctuation range of ± 50 % for each evaluation indicator (See Fig. 3).

The sensitivity analysis of whether the shipper changes the mode of transport when the core weight index changes is discussed in this section. By varying the six indicators of time, cost, safety, reliability, capacity, and environmental friendliness, the corresponding results are shown in Fig. 3. L_4 was always within ±50 % of first place, except for the time weight index. The most favorable weighting factor among the six indicators is transport capacity, which is 8.4 times that of L_3 in last place. On the contrary, L_3 was always in last place, except for the weight value of time and the change in environmental friendliness in the entire interval. The weighting of these two factors follows L_4, in second place. In terms of time weight, L_1 and L_2 are always in first and second place, which shows that the biggest advantage of road transport is the time advantage in the OD interval.

In these 5 scenarios, the positive and negative intervals vary in a slight, linear way. As shown in Fig. 3, slight changes in the weight values of time and cost were observed compared to the other values. Both factors are quantitative factors. There was therefore a significant change in the sensitivity analysis of the qualitative criteria with a relatively slight change in the quantitative data. When the quantitative indicator changes, L_4 shows the most significant change, while L_3 shows the least significant change. When the qualitative index changes, the trends of L_4 are similar, and L_1, L_2, and L_3 show almost identical differences in these four weighting criteria. In all evolutionary scenarios, the six weighting factors of L_5 are always kept at an intermediate level, which means that each change in the factor corresponds to a significant evolution of L_5.

4.2.2. Managerial and policy implication

The change caused by the change in the quantitative standard is verified by the actual situation, which is shown in Table 10.

Sea-land transport (L_4) ranks first in the normalized weight ranking of the above indicators in terms of cost, safety, reliability, and environmental friendliness, giving it an absolute advantage by taking the top spot. For transport needs without delivery pressure, this is undoubtedly the best choice. The geographical location of Yiwu is very favorable, there are many optional expressways connecting Yiwu with the nearby Shanghai Port and Ningbo-Zhoushan Port [56]. These two ports have simple and efficient import and export procedures and a wide range of optional shipping schedules, which only take 2–3 hours by highway [57]. Transportation by highway from Yiwu to Shekou Port, which has a direct sea route to Thailand, takes 13 hours. This is the route with the shortest transport time of all sea transport routes. On the other hand, due to the unique tax concessions policy in Hong Kong, some shippers prefer to transit to Hong Kong [58], and then take the sea route from Hong Kong to Thailand. Compared with land transport, sea transport takes longer time, but the transport process is more stable except in extreme weather conditions, and the carrying capacity of ships is also larger than that of land transport. The Shekou Port in Shenzhen is an important port in Southern China, like the Hong Kong Port, which facilitates the further distribution of transport in China. Most container transportation from Yiwu is for bulk cargo, easy storage, and the loss of smaller transfers, making it the most popular mode of transportation. Combined sea-land transportation has become the first choice for customers who do not pay attention to the arrival time of the goods.

In the ranking of normalized weights, the time ranking of the two highways is at the top and the corresponding environmental friendliness ranking is at the bottom, indicating that roadway transport is fast and convenient but offers no environmental benefits [59]. The Kunming-Bangkok roadway (L_1) is more than 200 km longer than the Nanning-Bangkok roadway (L_2), and the cost is slightly higher, but it is more popular in our model, which is related not only to regional transportation needs but also to cross-border customs clearance procedures. The customs clearance mode of L_1 is mature, which simplifies the procedure and saves time, making it more competitive when the difference in cost and distance is not obvious. Road transport is preferred by customers who are located near the highways or the borders and use distance to control costs or have high arrival time requirements.

Railway (L_5), for the one-stop customs clearance of cross-border railway, is economical, fast, safe, and reliable, ranks 3rd in our model, and will be accepted by the market sooner after it is opened to traffic. In the ranking of normalized weights, the railway traffic volume is in last

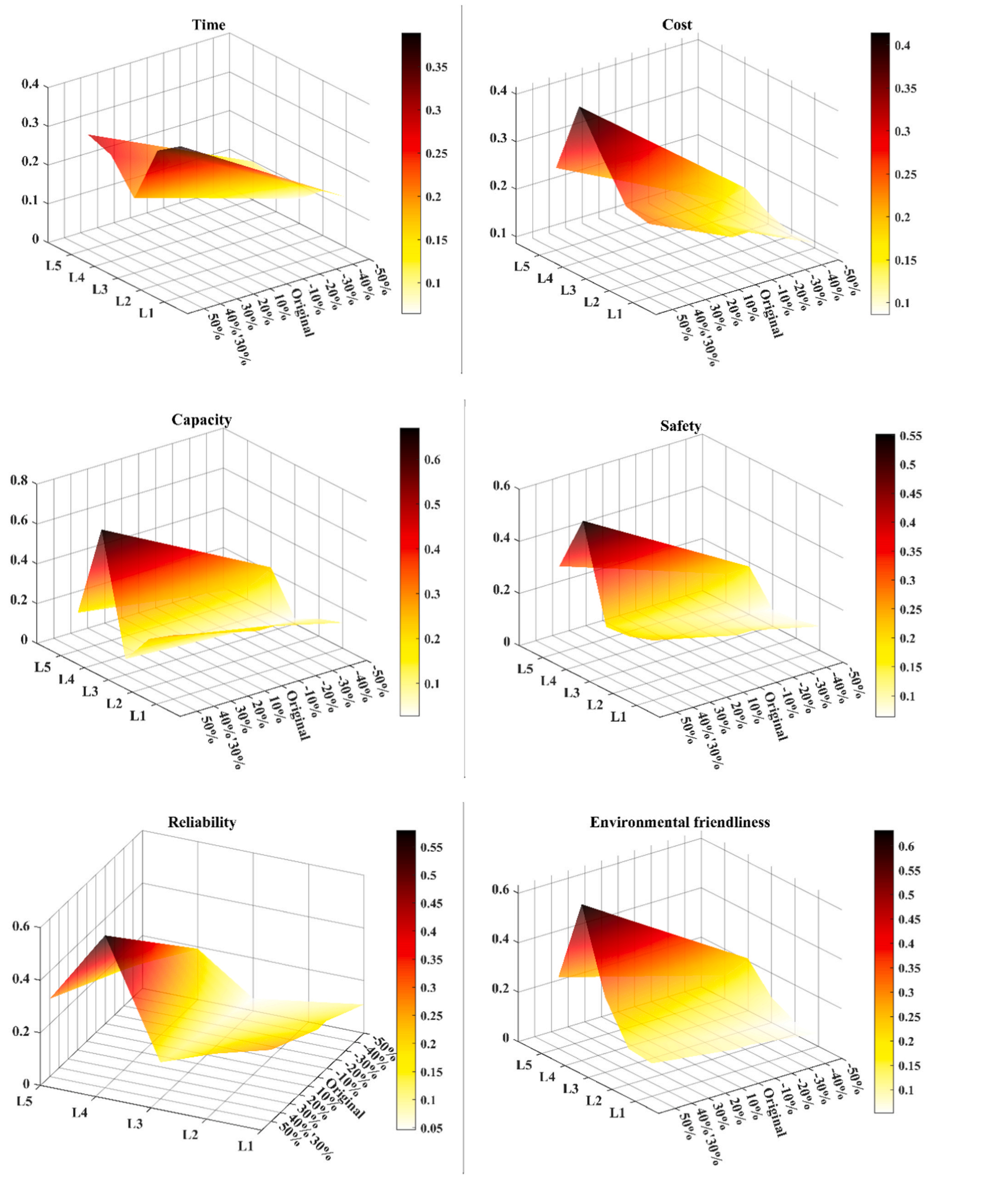

Fig. 3. Sensitivity analysis of the selected six indicators (i.e., transport time, transport cost, transport capacity, safety, reliability and environmental friendliness).

Table 10
40-foot container quantitative criteria between Yiwu and Bangkok.

Line (km)	L_1 (3939)	L_2 (3710)	L_3 (3505+350)	L_4 (250+4700)	L_5 (1830+2348)
Time	3–4days	4–5days	5–8days	8–15days	4–5days
Cost	4339	4319	4191	3566	3692
List	0.369 RMB/ ton/km	0.39 RMB/ ton/km	Road: 0.369 RMB/ton/km River (Jinghong-Qingsheng): 0.317 RMB/ ton/km	Domestic road: 0.36 RMB/ton/ km Shipping: 0.235 RMB/ ton/km	Domestic: 4.3 RMB/40'/km Overseas: 8 RMB/40'/ km

place, but in the overall ranking, it is in third place, which also indicates that the opening of the railway will disrupt the current market structure. With the promotion of an environmentally friendly transport policy, the prospects for railway transport are promising. This confirms the opinion of Li et al. [60].

Table 10 shows that although the transport time and transport cost of river-land transport (L_3) are at the intermediate level but are at the bottom of the preference selection ranking. This cannot be accurately analyzed using quantitative standards alone, which is consistent with an interval change in reliability in the model. In the ranking of normalized weights, time, transport volume, safety, and reliability of river-land intermodal transport are at the bottom. This result requires a comprehensive analysis from several aspects. Firstly, there are many options available for Sino-Thai logistics, and shippers have several matching or similar options. Secondly, the main market for river-land intermodal transport is the distance advantage, but the volatility of the supply market forces shippers to choose alternative solutions at certain times. Geographically, river channels are complex because shallow shoals and bank erosion lead to sedimentation and erosion. The reason is explained by Lu et al. [61] This means that the flow of the river is strongly influenced by the seasons, leading to unstable conditions in the canals, and affecting the transport of goods.

5. Conclusions

The Trans-Asian Railway provides a new opportunity for trade logistics between China and ASEAN countries and will restructure the transportation mode linking China and ASEAN countries in the near future. Small commodities from Yiwu play an important role in China-ASEAN trade, and the market share of transport from Yiwu to ASEAN countries is increasing with the development of the China-ASEAN trade. To evaluate the impact of the Trans-Asian Railway on logistics mode selection between Thailand and China, this study establishes an AHP model consisting of six factors (i.e., transport time, cost, transport capacity, safety, reliability, and environmental friendliness), and creates the optimal solution for the Sino-Thai logistics route with the TOPSIS approach.

According to the results of the AHP-TOPSIS approach, the transportation schemes will be classified as follows after the introduction of the Trans-Asian Railway: Sea-land transport (0.787) is the best choice for containerized goods, The Kunming-Bangkok roadway (0.452) transport ranks second, followed by the newly opened Trans-Asian Railway (0.431); The Nanning-Bangkok roadway (0.373) is the penultimate, while the river-land transport (0.249) is the last resort. In this sense, the new Railway would have a certain influence on the current pattern of Sino-Thai logistics.

Our case from Yiwu to Bangkok confirmed the following: I. Land-sea transport is the most popular transport route; II. Cost is the most important criterion among the six factors, followed by transport time. Then, we conduct a sensitivity analysis for the six factors and determine alternative transferability by adjusting the weighting of each factor. The results consistently show that regardless of how the weighting of each factor is adjusted, combined sea-land transport and road transport have higher priority values, while inland waterway transport always comes last.

The newly emerging Trans-Asian Railway transport is expected to be the strongest competitor for SSS, while inland waterway transport would continue to be the least competitive. In addition, road transport between China and Thailand must pass through Laos and Vietnam, and access to infrastructure and customs clearance costs between the different countries would have a significant impact on transport time. We insist that strengthening intergovernmental cooperation and introducing more trade-friendly road links would help to optimize the efficiency of road transport between China and Thailand and reduce transport costs. In addition, this study enables managers to better understand the five types of freight transportation between China and Thailand. It makes the optimal route choice according to the specific situation, which can effectively promote healthy competition in the freight transportation market and serve as a reference for policymakers to improve the efficiency of the SSS and railway transport.

The contributions of this research are threefold: (1) We formulated a model that includes transportation impact factors for the same or similar goods transportation profiles to determine reference tariffs, compare key transportation factors across different transportation channels using sensitivity analysis, and test whether this strategy helps shippers find the most attractive transportation solution. (2) AHP and TOPSIS are comprehensively applied in the multivariate hierarchical analysis to evaluate the suitability analysis of containers in the newly opened Trans-Asian Railway and inherent transport channels under the door-to-door service, to determine the weight of key factors to provide more appropriate transport for shippers with different needs in certain areas. (3) In order to verify the above models, in a situation where the opening of the Trans-Asian Railway has disrupted the market distribution of sea, air, river, and road transport between China and ASEAN countries, we studied the impact of the railway on the previous transportation patterns and explored the competition between different logistics routes between Yiwu and Bangkok. We focused on the optimization of transport routes and further examined intermodal transport patterns in more detail. The results support shippers to select appropriate logistics routes for the Sino-Thai trade based on individual preferences, benefit from the analysis of the long-term operation strategy of the China-ASEAN logistics network, and provide more comprehensive management reference recommendations for the authorities and shipping companies.

The data collection in this study is based on the opinions of transportation and logistics professionals, and the potential biases and ambiguities of personal opinions lead to some limitations. In addition, the competitiveness and transport preferences for short-distance cross-border container transport analyzed in this study are geographical in nature and do not apply to all scenarios. In the future, we will expand our research to larger trade routes and cover more transport nodes, such as Yiwu to Phnom Penh and Yangon in Myanmar. We will also consider various factors related to physical characteristics, shipping characteristics (including transport volume), costs, the spatial distribution of goods, route characteristics, services, merchant characteristics, time, shipper characteristics, environment, economics, supply chain, and individual characteristics.

CRediT authorship contribution statement

Qin Lin: Data curation, Investigation, Methodology, Software, Visualization, Writing – original draft. **Kai Zhang:** Data curation, Software, Validation. **Dong Huang:** Formal analysis, Visualization. **Manel Grifoll:** Conceptualization, Project administration, Writing – review & editing. **Hongxiang Feng:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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