DEcision framework for location and selection of container multimodal hubs: a case in China under the Belt and road Initiative

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Abstract. The location and selection of logistics nodes that facilitate the China Railway Express and rail-sea intermodal transportation has received increasing attention in China under the Belt and Road Initiative. The objective is to solve problems caused by the increasing number of origin cities opening international trains, such as disorderly competition, insufficient cargoes and low overall coordination. This study screens 22 cities as candidate Chinese international container multimodal hubs (CICMHs) in consideration of the actual situation of China’s trade transportation. Thirteen indicators are screened using the information contribution rate-information substitutability method. Then, a comprehensive evaluation model is proposed to evaluate the candidate CICMHs and rank them. The model is based on the extended grey relational analysis-technique for order preference similar to ideal solution in combination with prospect theory. Chongqing, Guangzhou, Shanghai, Wuhan, Chengdu, Xi’an, Nanjing, Tianjin, Zhengzhou and Dalian are selected as the CICMHs. Moreover, a sensitivity analysis of the index weight fluctuations and decision-makers’ preference and a comparative analysis of different decision-making methods are performed. The robustness and stability of the proposed model are demonstrated. This study can support the location and selection of CICMHs and expand the methods and applications in the decision-making field.

1. Introduction. Container multimodal networks have been constantly reshaped based on the massive trade along the Sino-European routes under the Belt and Road Initiative (BRI) in recent years [14]. The BRI of China aims to jointly build the Silk Road Economic Belt (SREB) and the 21st century Maritime Silk Road (MSR) as a way of opening up and establishing cooperation amongst countries involved in this initiative [43]. The formal BRI document (Vision and Actions on Jointly Building Silk Road Economic Belt and 21st Century Maritime Silk Road) issued in 2015 highlights the China Railway Express (CRexpress) and international shipping as two important international transport corridors along BRI. As the key node
in transport corridors and multimodal networks, container multimodal hubs with functions of consolidation, storage, transhipment and distribution play a crucial role \[29\]. At present, the location and selection of multimodal hubs along BRI (specifically, the starting node in mainland China) has become a topic of concern.

By the end of 2019, international trains were operating from more than 150 Chinese cities, with more than 60 and 130 cities being served by CRexpress trains and rail-sea intermodal transportation and certain cities being served by both types of trains. Such accessibility has enhanced the diversity and connectivity of the international multimodal network, improved the level of foreign trade and facilitated interconnection in BRI. However, due to the lack of holistic planning and optimisation of the train network at the national level, several problems, such as disorderly competition, insufficient cargo supply and poor coordination, have emerged. Therefore, the Chinese government must strengthen its top-level design to provide a reasonable allocation of freight flows. Setting up several consolidation hubs is a promising solution to these problems because the rationality of the location and layout of logistics facilities not only reduces costs by delivering an economy of scale, but also maximises transportation efficiency and service quality by planning efficient multimodal networks \[3\]. Against this backdrop, this work discusses the location and selection problem of container multimodal centres in China under BRI, which are defined as Chinese international container multimodal hubs (CICMHs).

CICMHs are expected to connect not only the hinterland origin cities in China but also foreign destinations (European cities in this work). The former is connected through multiple modes of transportation and the latter through land transportation (CRexpress) and shipping (rail-sea intermodal transport). The significance of location and selection can be summarized as follows: Firstly, a scientific and reasonable site can reduce the cost of construction and operation, and more logistics integrators be served. Secondly, the scientifically chosen location can provide an important guarantee for sustainable development of CRexpress and rail-sea intermodal trains. Therefore, how to lay out scientifically and reasonably is a subject worthy of deep study. Thirdly, by choosing the suitable CICMHs is the key to enhancing the efficiency of international container land/ocean transportation and refining China’s domestic/international freight multimodal networks.

In this study, a comprehensive decision framework for the location and selection of CICMHs under BRI is proposed in accordance with the actual situation of China’s trade transportation. In view of the complexity and diversity of evaluation factors, the establishment of a scientific and reasonable evaluation index system is the premise of a comprehensive evaluation, and this index system directly affects the rationality of the evaluation results. To eliminate the indexes that have little influence on the evaluation results and reflect redundant information, this work uses the information contribution rate–information substitutability method to screen the evaluation indexes. The location evaluation of CICMHs involves a complex external environment and many different attributes; hence, it can be viewed as a Multi-Criteria Decision Making (MCDM) problem. Many methods have been proposed to solve the MCDM problem. The Grey Relational Analysis Technique for Order Preference Similar to Ideal Solution (GRA-TOPSIS) integrates the advantages of GRA and TOPSIS approaches (make up for their respective shortcomings), adopts Euclidean distance and grey relational degree to reflect the proximity between alternative and ideal solutions from the similarity in position and shape, respectively, and is an extensive MCDM method \[18\]. In the actual
evaluation process, the MCDM method seldom considers the influence of experience and knowledge of decision-makers (DMs) on the evaluation results. Therefore, this study combines prospect theory with GRA-TOPSIS, improves the Euclidean distance and grey correlation coefficient in GRA-TOPSIS and proposes an extended GRA-TOPSIS (eGRA-TOPSIS) method to evaluate the location of CICMHs carefully. The integration of the MCDM method has not been applied in the research on the location decision of multimodal hubs.

The innovations of this research are as follows. (1) A scientific and reasonable evaluation index system for the location of logistics hubs is established using the information contribution rate-information substitutability method to screen the primary indicators in consideration of the characteristics of CICMHs. It can provide a meaningful reference for index screening in other research fields and regions. (2) This study improves the GRA-TOPSIS method by introducing relative entropy and considering the shape similarity and numerical proximity between sequences. This study also introduces prospect theory into the MCDM environment to express the preference of DMs for risk and loss avoidance. It enriches the methodology for evaluating the location decision problem of logistics facilities in other regions. (3) This study constructs a practical analysis and decision-making framework for the location and selection of CICMHs (i.e. qualitative screening of candidate hubs, quantitative screening of evaluation indexes and comprehensive evaluation). It provides novel ideas for facility location research and can efficiently reduce the complexity of such a problem. Therefore, the aim of this paper is to provide DMs with a practical and reasonable approach for location decision of hubs.

The rest of the paper is structured as follows. Section 2 outlines the related literature. Section 3 introduces the study area, index screening method and evaluation framework of the hub location decision. Section 4 presents the application of the proposed method, and Section 5 shows the sensitivity and comparative analyses of the proposed method. Section 6 concludes the study.

2. Literature review.

2.1. Location of logistics hubs. The hub location problem involves locating hubs and determining the routing flows of origin-destination pairs that pass through these hubs [22]. Several previous studies have focused on the evaluation and justification of location problems for logistics hubs. After the seminal work of O’Kelly [31], a few hub location problems have been introduced and formulated in several contexts, including charging stations [1], warehouses [11], collection facilities [15] and transport/logistics centres [29, 37]. In most cases, the decision problem of logistics hubs is strategic, and the generated solutions/decisions have a long-term effect. Multiple evaluation methods and optimisation algorithms have been used to solve this problem [8, 17, 16].

Since its introduction in 2013, BRI has accelerated the development of logistics networks in tandem with economic and transport corridors along BRI. Despite focusing on the operation and organisation of multimodal networks in the BRI region in association with container transport by land/CRedxpress and sea, only a few studies have examined the operations and management of global logistics [14], especially the location problem of multimodal transport hubs in China. Previous studies on hub location have focused on the individual aspects of BRI. On the one hand, a series of studies have examined seaport location and shipping network planning along MSR [38, 33]. On the other hand, with the increasing international influence
of CRexpress, several studies have recently discussed the problems associated with this new cross-continent railway transport along SREB \cite{43, 44, 30}. Although existing studies have considered the location problem of freight hubs, they focused on the individual aspect of BRI (either MSR or SREB), which is not in line with the actual situation of China’s foreign trade transportation. Therefore, in the present study, the location of multimodal hubs with the operating characteristics of land and rail-sea intermodal transportation is examined.

2.2. Evaluation index in location and selection. The rationality and accuracy of influencing factors play an important role in the decision-making process of location and selection. Scholars have conducted an extensive detailed analysis of the factors that affect location and selection by using various methods. Their research results provide important support for the location decision of CICMHs studied in this work.

Social, economic and environmental factors are key considerations for scholars when planning the location of logistics facilities. In accordance with the object of the location decision, the specific evaluation index changes at varying degrees. Rao et al. \cite{35} presented a sustainable evaluation system from economic, environmental and social dimensions to select the city logistics centre. With the development of location theory and transport geography, as an internal essential condition for location selection, location characteristics exert an important influence on location selection \cite{6}. Sun et al. \cite{39} studied the selection of consolidation centres of CRexpress whilst considering the location advantage, infrastructure and industry. Considering the uncertainty and complexity of the evaluation index, Essaadi, Grabot and Feniès \cite{12} summarised the 102 indicators that are often considered in location selection to examine global logistic hubs in Africa. With the increasing concern for the environment, carbon emissions are now regarded as an important factor in facility location \cite{7, 5}. Other scholars studied the index of hub location from multiple perspectives \cite{3, 32}.

The literature review above indicates that the location decision of CICMHs should consider economic, social, freight flow and geographical distribution factors. In addition, given the characteristics of CICMHs, the multimodal connectivity through land and sea should also be considered. These studies have shown that the location decision problem is usually based on multiple types of conflicting indicators. Some index information may be duplicated due to the diversity and complexity of the factors that affect location and selection. However, only a few studies have screened indicators to eliminate them. Therefore, this study selects multiple indicators from multiple dimensions and screens the indicators by using the information contribution rate-information substitutability method. Then, the final evaluation index system is established.

2.3. Comprehensive evaluation of hub location. The selection of a suitable MCDM method is the key to a successful analysis and evaluation. MCDM methods are well-adapted to complex decision-making from different types of data \cite{26}. Table 1 shows the advantages and limitations of various MCDM methods (Analytic Hierarchy Process, AHP; Elimination et Choix Traduisant la Realite, ELECTRE; Preference Ranking Organization Method for Enrichment Evaluations, PROMETHEE; Vlsekriterijumska Optimizacija I Kompromisno Resenje, VIKOR; an acronym in
Portuguese of interactive and MCDM, TODIM; Decision Making Trial and Evaluation Laboratory, DEMATEL; Best-Worst Method, BWM). Amongst such methods, the TOPSIS approach and its combination with other methods, especially GRA [34], have been successfully applied in location selection [12, 20]. GRA originally proposed and developed by Deng [9, 10] is a multi-factor analysis tool to measure the similarity in order to analyse uncertain relations between the alternative series and the reference series [21]. GRA, as a method to analyse the correlation degree amongst various factors in the grey system, can reflect the degree of affinity between system factors and is helpful for reducing the subjectivity generated in the process of setting the criteria [24]. GRA-TOPSIS, which integrates the advantages of GRA and TOPSIS, has been eliciting increasing attention since its proposal by Chen and Tzeng [4]. The successful application of GRA-TOPSIS in many decision-making fields, such as risk evaluation [13], facility location selection [28] and network node importance [27], provides support for the location selection of logistics hubs.

| Methods   | Advantages                                      | Limitations                                          |
|-----------|-------------------------------------------------|-----------------------------------------------------|
| AHP       | Flexible, concise, easy to calculate            | Does not consider the interaction between indicators |
| TOPSIS    | Can measure the proximity between alternative and ideal solutions | Cannot distinguish vertical line nodes in positive and negative ideal solutions |
| GRA       | Can measure the similarity degree of curve shapes between sequences | Does not consider the closeness of the sequence and the directionality of the numerical value |
| ELECTRE   | Applicable when incomparable substitutes exist   | Needs many parameters defined by decision-makers, and the calculation process is cumbersome |
| PROMETHEE | Can avoid information loss by focusing on various properties of attributes | Fails to consider DMi’s risk aversion psychology |
| VIKOR     | Considers the maximum benefit of the group and minimum regret of the individual | The evaluation of uncertainty factors is unsatisfactory |
| TODIM     | Can reflect DMi’s evasion of losses and risk psychology | Regression coefficient is not clearly defined, and evaluation results vary with the DMs |
| DEMATEL   | Can avoid consistency errors due to too many comparison times | Cannot reflect the fuzziness of decision information and the subjectivity of DMs |
| BWM       | Can reduce the number of comparisons and provide comparisons with consistency, leading to reliable results | Needs to be scored by experts with certain subjectivity; DMs’s confidence in their comparisons is not considered |

Table 1. Advantages and limitations of MCDM methods

In the actual location decision process, DMs have limited rational psychological characteristics due to the influence of cognitive ability and emotional and psychological factors, and a gap exists in their perception of the benefits and losses of each index [45]. Prospect theory can be used to describe the personal experience and value perception of psychological behaviour [19]. Therefore, this study introduces DM’s preference in the MCDM environment. In addition, this study quantifies the psychological preference in the form of risk attitude and loss aversion, which can solve the actual location decision problem of logistics hubs.

3. Materials and methods.

3.1. Study object. Analysing all theoretically possible locations is difficult due to the large geographical area of China; therefore, the research scope must be narrowed by reducing the number of candidate cities before the comprehensive evaluation. The main factors considered in screening include national policy, geographical location and actual transportation of international trade.
In recent years, Chinese government sections have issued a series of documents related to the location and layout of national logistics hub cities, including the following: Allocation and Planning of China Logistics Hubs (APLH), Layout Planning of China Logistics Node Cities (2015-2020) (LPLN), Action Plan for Promoting the Construction of Logistics Corridor (2016-2020) (APLC), Development Planning for the China-Europe Train (2016-2020) (DPCT) and Notice on the Construction of National Logistics Hub in 2019 (CNLH). Additionally, with the construction of BRI (including SREB and MSR), more than 150 Chinese cities have opened CRexpress trains and rail-sea intermodal trains (certain cities are served by both types of trains). These actual conditions provide references for the preliminary selection of hub cities.

In this study, the research objects are determined through the following steps. Firstly, the national node cities that have been designated in the five national policies are selected. Secondly, these cities that are served by stably operating international trains (including CRexpress and rail-sea intermodal trains) are selected. Lastly, 22 hub cities are selected as the research objects because they appear at least four times in five national documents and operate CRexpress and rail-sea intermodal trains stably. The selected cities are Tianjin, Shenyang, Harbin, Nanjing, Hangzhou, Zhengzhou, Hefei, Wuhan, Changsha, Chongqing, Chengdu, Xi’an, Lanzhou, Urumqi, Dalian, Qingdao, Ningbo, Xiamen, Guangzhou, Shanghai, Suzhou and Nanning.

3.2. Indicator screening. In selecting the indicators, only relying on the meaning of indicators and personal experience is subjective and may lead to a weak effect of several indicators on the evaluation results. Moreover, an inevitable correlation exists amongst multiple indicators, reflecting the redundancy and overlapping of information. Therefore, the primary indicators must be simplified and screened, and the indicators that have a weak effect on the evaluation results and reflect repeated information must be eliminated.

3.2.1. Screening criteria. Criterion 1: Observability. The indicators with good evaluation capability and easy data acquisition are selected to ensure their practical application.

Criterion 2: Large information content. Information content reflects the discrimination of index data. Indicators with large information content contribute significantly.

Criterion 3: Eliminate redundant information. Redundant indicators affect the authenticity of the evaluation results. Redundant indicators are eliminated, and duplicate information is not included.

3.2.2. Screening steps. Screening based on the cumulative information contribution rate.

Step 1. Calculate the index information content. Considering that $n$ evaluation objects exist, each object contains $m$ indicators, and the evaluation matrix $X = (x_{ij})_{n \times m}$ is constructed. The information content $I_j$ of index $x_{ij}$ ($i = 1, 2, ..., n; j = 1, 2, ..., m$) is expressed by a relative discrete coefficient (ratio of standard deviation to mean value $\bar{x}_j = \frac{\sum_{i=1}^{n} x_{ij}}{n}$), which reflects the influence on the evaluation results.

$$I_j = \sqrt{\frac{\sum_{i=1}^{n} (x_{ij} - \bar{x}_j)^2}{\bar{x}_j^2}}.$$  

(1)
Step 2. Calculate the cumulative information contribution rate. The indicators are sorted in a descending order according to their information content. Then, the ratio of the first \( l \) indicators with large information content to all indicators is calculated.

\[
\beta_l = \frac{\sum_{j=1}^{l} I_j'}{\sum_{j=1}^{m} I_j'},
\]

where \( I_j' (j = 1, 2, ..., l) \) is the information content of the first \( l \) indicators after reordering.

Step 3. Screen the indicators with large information content. If \( \beta_l \geq \beta_0 > \beta_{l-1} \), then the first \( l \) indicators with large information content are retained. This study sets \( \beta_0 = 85\% \) to ensure the minimum information loss of the primary indicators on the basis of the principle of selecting principal components with cumulative variance greater than 85\% in the principal component analysis.

Screening based on information substitutability.

Step 4. Calculate the Pearson correlation coefficient \( (r_{jk})_{l \times l} \) amongst \( l \) indicators. This coefficient reflects the degree of information overlap between indicators \( j, k \).

\[
r_{jk} = \frac{\sum_{i=1}^{n} (x_{ij} - \overline{x}_j)(x_{ik} - \overline{x}_k)}{\sqrt{\sum_{i=1}^{n} (x_{ij} - \overline{x}_j)^2(x_{ik} - \overline{x}_k)^2}},
\]

where \( \overline{x}_j = \sum_{i=1}^{n} \frac{x_{ij}}{n}, \overline{x}_k = \sum_{i=1}^{n} \frac{x_{ik}}{n} \).

Step 5. Calculate the information substitutability \( s_j \) of index \( j \) that reflects the substitutability degree of the index by the remaining \( l-1 \) indicators.

\[
s_j = \frac{1}{l-1} \sum_{x_j \in D_{j,(l-1)}} r_{jk}^2.
\]

In accordance with the idea of class average to measure the similarity between two indicators in cluster analysis, \( s_j \) is the correlation degree between subclass \( D_{j,(l-1)} \), which is index \( j \), and the remaining \( l-1 \) indicators.

Step 6. Remove the indicators with large substitutability. If the substitutability \( s_j \) of index \( j \) is greater than the average substitutability \( \overline{s} \), \( s_j > \overline{s} \), then index \( j \) should be deleted, i.e., \( \overline{s} = \frac{\sum_{j=1}^{l} s_j}{l} \).

Reliability judgment of the evaluation index system.

Step 7. Reliability analysis. Reliability analysis is an effective measurement tool to evaluate the stability and reliability of an evaluation index system. Cronbach’s alpha coefficient is commonly used to perform a reliability analysis of an index system.

\[
\alpha = \frac{l \left( \frac{\text{cov}}{\text{var}} \right)}{1 + (l - 1) \left( \frac{\text{cov}}{\text{var}} \right)},
\]

where \( l \) is the number of indicators and \( \text{cov}, \text{var} \) are the average of covariance and variance between indicators, respectively. Generally, \( \alpha > 0.8 \) indicates that the result is good.

3.3. Comprehensive evaluation model. Classical MCDM methods seldom consider the impact of DMs on the results in the evaluation process. However, considering that DMs are not completely rational, they take different attitudes towards gains and losses when facing decision-making, which exert a great impact on
the decision-making results. Therefore, this study combines prospect theory with MCDM to make the evaluation results objective, accurate and reliable. A detailed description of these methods is provided below.

3.3.1. Prospect theory. The evaluation results of MCDM problem are largely related to the evaluation indicators and methods selected by DMs; thus, MCDM is actually an uncertainty problem. Prospect theory can solve such a problem by considering the experience and knowledge of DMs under uncertain conditions [27]. MCDM based on prospect theory can introduce the personal preference of psychological behaviour into the decision-making process.

Let \( X = (x_{ij})_{n \times m} \) be the evaluation matrix, where \( x_{ij} \) represents the value of the \( i-th \) sample for the \( j-th \) index. The value function is expressed in the form of a power law according to the following expression.

\[
v(\Delta x_{ij}) = \begin{cases} (\Delta x_{ij})^\alpha, & \Delta x_{ij} \geq 0, \\ -\theta(-\Delta x_{ij})^\beta, & \Delta x_{ij} < 0, \end{cases}
\]

where \( \alpha \) is the risk-seeking coefficient and \( \beta \) is the risk-averse coefficient. \( \theta \) is the loss-averse coefficient, and \( \theta > 1 \) means that DM is more sensitive to losses than to equal gains. \( \Delta x_{ij} \) is a variable related to the reference point, \( \Delta x_{ij} \geq 0 \) represents the gains and \( \Delta x_{ij} < 0 \) represents the losses. In this study, we regard the average value of all samples for the same attribute as the reference point, i.e. \( \Delta x_{ij} = x_{ij} - \frac{1}{n} \sum_{i=1}^{n} x_{ij} \).

Fig. 1 shows the prospect value function with convex and concave S shapes for losses and gains, respectively.

![Value function](image)

**Figure 1.** Value function

The prospect value of each node is calculated by the value and weight functions.

\[
V(f_i) = V(f^+_i) + V(f^-_i),
\]

\[
V(f^+_i) = \sum_{j=1}^{h} w_j v_{ij},
\]

\[
V(f^-_i) = \sum_{j=h+1}^{m} w_j v_{ij},
\]

where \( V(f_i), V(f^+_i), V(f^-_i) \) denote the total, yield and loss prospect values of node \( i \), respectively, and \( h \) is the number of indicators of the yield prospect value. The
prospect matrix $R = (r_{ij})_{n \times m}$ is calculated by the value and weight functions, $r_{ij} = w_j v_{ij}$, and $w_j$ is the weight of index $j$, which is obtained with the maximum deviation-entropy method.

The maximum deviation-entropy method is an objective weighting approach that can avoid the influence of subjectivity on weight calculation \[41\]. In practice, due to the complexity of the environment and the limitations of people’s understanding, the real weight of the index is a random variable with uncertainty. When determining the index weight, to eliminate the weight differences between index values and increase the certainty, according to the maximum information entropy principle, when the entropy of each index weight is the largest, the weight differences is the smallest. Therefore, this study uses the maximum deviation-entropy method, which can consider the differences between the index values and the uncertainty of the weight, to determine the index weight.

Suppose that the normalised evaluation matrix of $X = (x_{ij})_{n \times m}$ is $Y = (y_{ij})_{n \times m}$. Let the weight vector of $m$ indexes be $w = (w_1, w_2, ..., w_m)^T$ and satisfy the constraint $\sum_{j=1}^{m} w_j = 1$, $w_j \geq 0$. For index $j$, the deviation between scheme $i$ and other evaluation schemes is expressed by $f_{ij}(w) = \sum_{k=1}^{n} w_j |y_{ij} - y_{kj}|$, and the total deviation amongst all evaluation schemes is represented by $f_j(w) = \sum_{i=1}^{n} f_{ij}(w) = \sum_{i=1}^{n} \sum_{k=1}^{n} w_j |y_{ij} - y_{kj}|$.

The evaluation is conducted to determine the reasonable index weight for maximising the total deviation of all evaluation indexes to all evaluation schemes.

$$\max \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{n} w_j |y_{ij} - y_{kj}|,$$

s.t. $\sum_{k=1}^{n} w_j = 1$, $w_j \geq 0$. \hspace{1cm} (8)

The real weight of the index is uncertain and can be expressed by Shannon entropy $H = -\sum_{j=1}^{m} w_j ln w_j$ ($w_j$ can be understood as the proportion of the $j$–th index in the index set). The other purpose of the evaluation is to eliminate the uncertainty of index weight (maximise the entropy of each index weight). According to the principle of Jaynes maximum entropy, the index weight should maximise the Shannon entropy:

$$\max H = -\sum_{j=1}^{m} w_j ln w_j,$$

s.t. $\sum_{j=1}^{m} w_j = 1$, $w_j \geq 0$. \hspace{1cm} (9)

The two optimisation objectives above can be transformed into the following optimisation problem-solving weights.

$$\max \delta \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{n} w_j |y_{ij} - y_{kj}| - \delta \sum_{j=1}^{m} w_j ln w_j,$$

s.t. $\sum_{j=1}^{m} w_j = 1$, $w_j \geq 0$. \hspace{1cm} (10)
where $\delta \in [0, 1]$ represents the balance coefficient between the two targets, and $\delta = 0.5$ is usually applied [41]. Through a reasonable adjustment of balance coefficient $\delta$, the subjective weight of the index can be determined flexibly.

**Theorem 3.1.** The optimisation problem of the above-mentioned formula has a unique solution $w = \left(\frac{s_1}{\sum_{j=1}^{m} s_j}, \frac{s_2}{\sum_{j=1}^{m} s_j}, \ldots, \frac{s_m}{\sum_{j=1}^{m} s_j}\right)^T$ with $s_j = \exp\left[\frac{\delta}{1-\delta} \sum_{i=1}^{n} \sum_{k=1}^{n} |y_{ij} - y_{kj}| - 1\right]$. 

**Proof.** Constructed Lagrange function:

$$L(w, \lambda) = \delta \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{n} w_j |y_{ij} - y_{kj}| - (1 - \delta) \sum_{j=1}^{m} w_j \ln w_j - \lambda \left(\sum_{j=1}^{m} w_j - 1\right).$$

(11)

In accordance with the necessary conditions for the existence of the extremum, the following formula is obtained.

$$\frac{\partial L}{\partial w_j} = \delta \sum_{i=1}^{n} \sum_{k=1}^{n} |y_{ij} - y_{kj}| - (1 - \delta) (\ln w_j + 1) - \lambda = 0,$$

$$\frac{\partial L}{\partial \lambda} = \sum_{j=1}^{m} w_j - 1 = 0.$$  

(12)

The formula above is simplified as follows:

$$w_j = \exp\left[\frac{\delta}{1-\delta} \sum_{i=1}^{n} \sum_{k=1}^{n} |y_{ij} - y_{kj}| - 1\right],$$

$$\exp\left[\frac{\lambda}{1-\delta}\right] = \sum_{j=1}^{m} \exp\left[\frac{\delta}{1-\delta} \sum_{i=1}^{n} \sum_{k=1}^{n} |y_{ij} - y_{kj}| - 1\right].$$  

(13)

Hence, $w_j = \frac{s_j}{\sum_{j=1}^{m} s_j}$ with $s_j = \exp\left[\frac{\delta}{1-\delta} \sum_{i=1}^{n} \sum_{k=1}^{n} |y_{ij} - y_{kj}| - 1\right]$.

### 3.3.2. eGRA-TOPSIS method.

The TOPSIS method, as one of the most popular MCDM approaches, can sort through the closeness of a limited number of evaluation objects and idealised goals, allowing it to analyse the relative merits of the evaluation objects. It can be easily modified to account for different weighting methods or expanded to account for additional indexes. However, TOPSIS can only use the perspective of distance to reflect the closeness of the samples and cannot adapt to the complex diversification of an evaluation index system [24]. GRA, a portion of grey system theory based on grey space, proposed and developed by Deng [9], a method used to measure the degree of similarity of curve shapes between sequences, can intuitively present the nonlinear relationship between sequences and reflect the degree of affinity existing between system factors. GRA has significant advantages in addressing complex decision-making problems marked by vague, incomplete and inaccurate information [4], besides it only requires small sample data, and simple calculation, and has been widespread applied in addressing kinds of real-world application problems in decision-making, data processing and systems analysis [25, 42]. Thus, it can make up for the deficiency of the TOPSIS method. Therefore, the GRA-TOPSIS method (combination of TOPSIS and GRA) has been adopted in multiple decision-making fields.

However, classical GRA-TOPSIS has two limitations. Firstly, the vertical line nodes in the positive ideal solution (PIS) and negative ideal solution (NIS) cannot be distinguished effectively by Euclidean distance, and the actual results have errors.
Relative entropy satisfies the following properties:

Let \( d \) be the relative entropy, also known as Kullback-Leibler divergence, is the asymmetrical measure of the difference between two probability distributions. This study uses relative entropy to express the closeness of the evaluation scheme to PIS and NIS.

Secondly, the grey relational degree only measures the shape similarity between sequences and does not consider the numerical proximity of sequences. For example, when two sequences are parallel, even though the distance between them is large, the relational degree is 1, which is inconsistent with the actual situation. This study improves these two shortcomings. The specific steps are as follows:

**Step 1.** Construct the decision matrix \( R = (r_{ij})_{n \times m} \). \( x_{ij} \) represents the value of the \( i - th \) sample for the \( j - th \) index. Considering the influence of DMs’ experience and knowledge on the evaluation results, this study takes the prospect value as the attribute value \( r_{ij} \).

**Step 2.** Determine the PIS and NIS \( r^+, r^- \) for the evaluation indicator.

\[
\begin{align*}
r^+ &= \{r^+_{i1}, r^+_{i2}, \ldots, r^+_{im}\} = \{\max_{1 \leq i \leq n} r_{ij} | j \in m^+, \min_{1 \leq i \leq n} r_{ij} | j \in m^-\}, \\
&= \{r^+_{i1}, r^+_{i2}, \ldots, r^+_{im}\} = \{\min_{1 \leq i \leq n} r_{ij} | j \in m^+, \max_{1 \leq i \leq n} r_{ij} | j \in m^-\},
\end{align*}
\]

where \( m^+, m^- \) are the set of profitable and cost indicators, respectively.

**Step 3.** Calculate the weighted distances \( d^+_i, d^-_i \) from the evaluation scheme to PIS and NIS.

This study adopts relative entropy to improve \( d^+_i, d^-_i \). Relative entropy, also known as Kullback-Leibler divergence, is the asymmetrical measure of the difference between two probability distributions. This study uses relative entropy to express the closeness of the evaluation scheme to PIS and NIS.

\[
\begin{align*}
d^+_i &= \sum_{j=1}^{m} r^+_i \log \left( \frac{r^+_j}{r_{ij}} \right) + (1 - r^+_i) \log \left( \frac{1 - r^+_j}{1 - r_{ij}} \right), \\
d^-_i &= \sum_{j=1}^{m} r^-_i \log \left( \frac{r^-_j}{r_{ij}} \right) + (1 - r^-_i) \log \left( \frac{1 - r^-_j}{1 - r_{ij}} \right).
\end{align*}
\]

If \( d^+_i \) is small, then the difference between the \( i - th \) object and PIS is also small. Moreover, if \( d^-_i \) is small, then the difference between the \( i - th \) object and NIS is small.

**Theorem 3.2.** Relative entropy satisfies the following properties:

1. \( d^+_i \geq 0, d^-_i \geq 0 \);
2. \( d^+_i = 0 \), if and only if \( r_i = r^+ \);
3. \( d^-_i = 0 \), if and only if \( r_i = r^- \).

**Proof.** Let \( d^+_i = \sum_{j=1}^{m} g^+_i \).

\[
\begin{align*}
g^+_i &= r^+_i \log \left( \frac{r^+_j}{r_{ij}} \right) + (1 - r^+_i) \log \left( \frac{1 - r^+_j}{1 - r_{ij}} \right), \\
&= r^+_i \log \left( \frac{r^+_j}{r^+_i} \right) + (1 - r^+_i) \log \left( \frac{1 - r^+_j}{1 - r^+_i} \right), \\
&\leq \log \left( \frac{r^+_j}{r^+_i} \right) + (1 - r^+_i) \left( \frac{1 - r^+_j}{1 - r^+_i} \right), \\
&= \log (r_{ij} + (1 - r_{ij})),
\end{align*}
\]
Equation (16) can be derived from Jensen inequality. Given that $\log$ is a strictly concave function, if and only if $r_i = r^+$ does the equal sign holds. Therefore, $g_{i1}^+ = 0$ if and only if $r_{i1} = r_1^+$. Similarly, $g_{i2}^+ = 0, \ldots, g_{im}^+ = 0$, if and only if $r_{i2} = r_2^+, \ldots, r_{im} = r_m^+$. Hence, $d_i^+ \geq 0$ if and only if $r_i = r^+$, and the equal sign holds.

Similarly, $d_i^- \geq 0$, if and only if $r_i = r^-$, and the equal sign holds.

This completes the proof.

**Step 4.** Calculate the improved grey relational coefficients $q_{ij}^+, q_{ij}^-$ (used to determine how close each of the alternative is to the ideal solution, including PIS and NIS) and grey relational degree $q^+_i, q^-_i$ (the mean of the grey relational coefficient).

The classical grey relational coefficients on the shape change in the GRA-TOPSIS method are as follows:

\[
q_{ij}^+ = \min_{i, j} \left( \frac{|r_i^+ - r_{ij}| + \rho \max_j |r_i^+ - r_{ij}|}{|r_i^+ - r_{ij}| + \rho \max_j |r_i^+ - r_{ij}|} \right),
\]

\[
q_{ij}^- = \min_{i, j} \left( \frac{|r_i^- - r_{ij}| + \rho \max_j |r_i^- - r_{ij}|}{|r_i^- - r_{ij}| + \rho \max_j |r_i^- - r_{ij}|} \right),
\]

where $\rho \in [0, 1]$ is the distinguishing coefficient; $\rho = 0.5$ is usually applied following the rule of least information [42, 2].

In this study, the shape similarity and numerical proximity between sequences are considered from the shape and distance of sequences. Moreover, an improved grey correlation coefficient is constructed by using the multiplication rule.

The absolute deviation $\Delta_{ij}$ between the ideal solution sequence and the evaluation sequence is $\Delta_{ij}^+ = |r_i^+ - r_{ij}|, \Delta_{ij}^- = |r_i^- - r_{ij}|$.

With the absolute deviation, Equation 17 can now have Equation 18, as follows:

\[
q_{ij}^+' = \min_{i, j} \left( \frac{\Delta_{ij}^+ + \rho \max_j \Delta_{ij}^+}{\Delta_{ij}^+ + \rho \max_j \Delta_{ij}^+} \right),
\]

\[
q_{ij}^-' = \min_{i, j} \left( \frac{\Delta_{ij}^- + \rho \max_j \Delta_{ij}^-}{\Delta_{ij}^- + \rho \max_j \Delta_{ij}^-} \right),
\]

The proximity between sequences is related to the absolute deviation and relative error $E_j(E_j^+, E_j^-)$.

\[
E_j^+ = \frac{\Delta_{ij}^+}{T_{ij}^+} + \frac{\Delta_{ij}^-}{T_{ij}^-},
\]

\[
E_j^- = \frac{\Delta_{ij}^-}{T_{ij}^+} + \frac{\Delta_{ij}^+}{T_{ij}^-},
\]

where $T_j(T_j^+, T_j^-)$ is related to the value of points on the ideal solution sequence. Given the similar proximity between the evaluation sequence symmetrical on both
The improved grey correlation coefficient satisfies the four axioms in the grey system.

Theorem 3.3. The improved grey correlation coefficient satisfies the four axioms in the grey system.

Proof. 1. Normative:
If \( \Delta_{ij} = 0 \), then \( q_{ij} = 1 \), and if \( \Delta_{ij} > 0 \), \( 0 < (q_{ij}')^\mu < 1 \), \( E_j > 0 \) and \( 0 < (e^{-E_j})^\nu < 1 \), then \( 0 < q_{ij} < 1 \). For \( \Delta_{ij} \geq 0 \), \( q_{ij} \in (0, 1] \); thus, the normative aspect is proven.

2. Integrity:
If \( r = \{r_s|s = 0, 1, ..., n; n \geq 2 \} \), for \( \forall r_{s1}, r_{s2} \in r, r_{s1} \neq r_{s2} \), generally, \( max_j \Delta s_{1j} \neq max_j \Delta s_{2j} \), \( q_{s1s2} < q_{s2s1} \) when \( \Delta s_{1j} \neq \Delta s_{2j}, e^{-<E_j>_{s1}} \neq e^{-<E_j>_{s2}} \). Consequently, \( q_{s1j} \neq q_{s2j} \); thus, the integrity aspect is proven.

3. Even Symmetry:
If \( r = \{r_{s1}, r_{s2} \}, \Delta s_{1s2} = \Delta s_{2s1} \) and \( max_j \Delta s_{1j} = max_j \Delta s_{2j} \), then \( q_{s1s2} = q_{s2s1}, (T_j)_{s1s2} = (T_j)_{s2s1} \) and \( e^{-<E_j>_{s1}} = e^{-<E_j>_{s2}} \). Consequently, \( q_{s1s2} = q_{s2s1} \), and the even symmetry is proven.

4. Proximity:
If \( \Delta_{ij} \to 0 \), then \( e^{-E_j} \to 1 \), and if \( \Delta_{ij} \to \infty \), then \( e^{-E_j} \to 0 \). Thus, \( (e^{-E_j})^\nu \) satisfies the proximity condition, and \( (q_{ij}')^\mu \) satisfies the proximity in the grey system. Correspondingly, the proximity aspect is proven.

Therefore, the improved grey relational degree can be obtained as

\[
\begin{align*}
t_j^+ &= \frac{\sum_{j=1}^{m} q_{ij}^+}{m}, \\
t_j^- &= \frac{\sum_{j=1}^{m} q_{ij}^-}{m}.
\end{align*}
\]
Step 5. Apply non-dimensional treatment of weighted distances $d_i^+, d_i^-$ and grey correlation degree $q_i^+, q_i^-$.  

\[ D_i^+ = \frac{d_i^+}{\max d_i^+}, \]
\[ D_i^- = \frac{d_i^-}{\max d_i^-}, \]
\[ Q_i^+ = \frac{q_i^+}{\max q_i^+}, \]
\[ Q_i^- = \frac{q_i^-}{\max q_i^-}. \]  

(23)

Step 6. Integrate the results of the dimensionless distance and grey relational degree as follows:  

\[ S_i^+ = \varphi D_i^- + (1 - \varphi)Q_i^+, \]
\[ S_i^- = \varphi D_i^+ + (1 - \varphi)Q_i^-, \]  

(24)

where $\varphi \in [0, 1]$ is the preference coefficient, which represents the evaluator’s preference for the curve position and shape.

Step 7. Calculate relative closeness $C_i$ and rank the alternatives.  

\[ C_i = \frac{S_i^+}{S_i^+ + S_i^-}. \]  

(25)

If the relative closeness value is large or small, then the evaluation object will be good or bad, respectively.

3.4. Location decision framework for CICMHs. As logistics nodes will increasingly be set up as CICMHs in the future, DMs will face the problem of selecting multiple alternative locations. A reasonable and effective site selection framework can improve the efficiency of decision-making. This section presents the establishment of a location decision framework for CICMHs (Fig. 2). The decision-making process consists of three main phases, namely, preliminary preparation, location evaluation and discussion analysis.

4. Application of the proposed model.

4.1. Data sources. Most of the index data in the evaluation index system were extracted from the Statistics Bulletin of the National Economic and Social Development, Statistical Yearbook and the Government Work Report for the cities studied. The index data at the hub station were from the official website of the international land-port companies.

The transport time between the evaluated city and other domestic cities was calculated based on distance and speed. The distance was obtained by considering the transport networks (freight railways and highway, Fig. 3) that were constructed based on the Medium- and Long-term Railway Network Plan 2016-2025 and Highway Network Planning 2013 -2030. The speed was obtained from the Code for Design of Railway Line and Technical Standard of Highway Engineering.

The transport time of the CRexpress to Europe was derived from the statistics published by the top 10 international land-port companies (Chongqing, Chengdu,
**Figure 2. Location decision framework for CICMHs**

- **Phase I**
  - **Preliminary preparation**
    - Study object
    - Screening of research objects
    - Index screening
    - Screening criteria
    - Screening method
    - Comprehensive evaluation model
  - **Method**
    - Information contribution rate
    - Information substitutability
    - Reliability judgment
    - Prospect theory
    - Maximum Deviation-Entropy
    - eGRA-TOPSIS

- **Phase II**
  - **Location evaluation**
    - Data processing
    - Construction of evaluation index system
    - Index weight calculation
    - Comprehensive evaluation & Ranking
    - Determination of final location
  - **Method**
    - Selection of primary indicators
    - Determination of index system
    - Maximum Deviation-Entropy method
    - eGRA-TOPSIS/Prospect theory
    - eGRA-TOPSIS/GRA-TOPSIS/TOPSIS/GRA
    - Discrimination approach

- **Phase III**
  - **Discussion analysis**
    - Screening analysis of hubs
    - Sensitivity analysis
    - Comparative analysis
  - **Method**
    - Discussion on qualitative screening
    - Fluctuation of index weight
    - Fluctuation of loss-averse coefficient \( \theta \)
    - Fluctuation of preference coefficient \( \varphi \)
    - eGRA-TOPSIS/GRA-TOPSIS/TOPSIS/GRA
    - Discrimination approach

**Figure 3. Transport networks in China**
The shipping time from China’s top 10 seaports (Shanghai, Ningbo-Zhoushan, Shenzhen, Guangzhou, Qingdao, Tianjin, Xiamen, Dalian, Yingkou and Lianyungang) to Europe was extracted from the official website of the world’s top 10 liner companies (Maersk Line, MSC, COSCO, CMA CGM, Hapag-Lloyd, ONE, Evergreen, Yang Ming Marine, PIL and Hyundai M.M.).

4.2. Construction of the evaluation index system.

4.2.1. Selection of primary indicators. This study combines regional economics, sociology and urban geography and selects indicators from multiple perspectives in accordance with the principles of sustainability, systematicness, comprehensiveness and feasibility. The objective is to fully reflect the comprehensive strength and development potential of a city as a multimodal hub and its influence on the surrounding areas. Four dimensions were used as the criteria layer. (1) The scale-quality dimension indicates the logistics trade and transhipment capacity for international goods and the handling and service level at the hub station. (2) The transport-geography dimension reflects the location accessibility/connectivity and transport convenience in space and time and the centrality in the logistics network. (3) The economic-social dimension provides basic support (including financial, policy and source of goods) for hub construction and daily operation. (4) The resource-environment dimension represents the comprehensive competitiveness in infrastructure and the potential for sustainable development. The second layer is the sub-criteria layer, and the third layer is the index layer, which contains 49 specific indicators (Fig. 4).

Interpretation of several indicators:

The convenience of multimodal transport refers to the transfer capacity of various transport modes, including highway, railway, waterway and aviation. If the city has \( n (n = 1, 2, 3, 4) \) modes, then the value is . The number of operating routes of trains includes CRexpress and rail-sea intermodal trains that have been stably operated. The average railway/highway time to all domestic cities considers the 333 prefecture-level cities in mainland China. The average CRexpress time to EU statistics considers China’s top 10 CRexpress cities through three exit ports (Alashankou, Erenhot and Manzhouli) to Europe. The average rail-sea intermodal time to EU includes the domestic railway transport to China’s top 10 container seaports, followed by shipping to Europe. The network centrality index is calculated according to the meaning of the index in a complex network \([36]\) constructed by a freight railway/highway network. Policy support refers to the frequency of a hub appearing in five documents (APLH, LPLN, APLC, DPCT and NCNLH). If the hub does not appear in any document, then the value is 0. If it appears in \( n (n = 1, 2, 3, 4, 5) \) documents, then the value is \( n \).

4.2.2. Determination of the evaluation index system. This study screened the primary indicators according to the indicator screening method to avoid inaccurate results caused by a repeated discussion of similar indicators in the evaluation process. The indicators remaining after screening were used to construct the final evaluation index system, which included 4 criteria, 5 sub-criteria and 13 specific indicators (Fig. 5).

Reliability judgement: The Cronbach’s alpha of the 49 primary indicators was 0.841, indicating that the credibility of the index system is high. The Cronbach’s alpha of the 13 screened indicators was 0.816. Although the reliability was lower
Figure 4. Preliminary evaluation index system
than that of the primary indicators, the result was still high (> 0.8). This finding shows that the screening index can reduce the influence of redundant information on the evaluation results and greatly decrease the calculation amount and error caused by the tedious evaluation process. Therefore, the evaluation index screened by information contribution rate-information substitutability is suitable for the location evaluation of CICMHs.

4.3. Location evaluation of CICMHs. From index data processing, the weights of the 13 evaluation indicators were obtained and are shown in Table 2 through the application of the maximum deviation-entropy method.

| Index     | A1   | A2   | A3   | A4   | A5   | B1   | B2   | B3   | C1   | C2   | C3   | D1   | D2   |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Weight    | 0.0888 | 0.1615 | 0.1163 | 0.0998 | 0.0554 | 0.03 | 0.1037 | 0.0237 | 0.1163 | 0.0349 | 0.0348 | 0.0701 | 0.0647 |

Table 2. Weight of the evaluation index

Table 2 shows that the logistics trade scale has the largest weight, and urban infrastructure has the smallest weight. Given that the hub studied is mainly used for the transshipment, consolidation and distribution of goods, the location and layout of CICMHs are largely influenced by the freight turnover volume and export volume to EU. The socio-economic support is average because the differences in economic and social development conditions in China are not evident. Although the transport location advantages have a low weight, the location conditions need to be considered when further optimising the site for the balance and rationality of the hub layout. The freight turnover volume, foreign trade volume and transport facilities investment should be considered in the location and layout of the hub.

The eGRA-TOPSIS combining prospect theory was then used to evaluate the 23 alternative CICMHs to obtain the distance, grey correlation degree and relative closeness of the evaluation object. The parameters of DM’s preference in prospect theory were \( \theta = 2.25, \alpha = \beta = 0.88 \) based on the experiment of Tversky and Kahneman [40]. Table 3 shows the calculation results and the order of the alternative sites.
Table 3 shows that a high ranking of a CICMH indicates a large capacity of container transhipment, consolidation and distribution, rendering the city highly suitable to serve as a multimodal hub. Referring to the planning policies of national logistics node cities, this study selected 10 cities as CICMHs based on the overall layout and planning of hubs, including the agglomeration and scale effect of resources. The number of hubs can be adjusted according to the actual situation and the preference of planning departments and DMs. Table 3 shows the top 10 CICMHs, namely, Chongqing, Guangzhou, Shanghai, Wuhan, Chengdu, Xi’an, Nanjing, Tianjin, Zhengzhou and Dalian.

Fig. 6 shows the location and distribution of the top 10 CICMHs. Amongst them, Chongqing and Chengdu in the southwest region, Zhengzhou and Wuhan in the central region and Xi’an in the northwest region are the Chinese cities with the largest container volumes carried by CRExpress and intermodal transportation modes (in the corresponding regions) and convenient geography. They enable a connection with the other regions in China. Guangzhou, Shanghai, Tianjin and Dalian, which are distributed in the coastal areas of China, are the port cities with the largest container throughput and exhibit an advanced handling capability for rail-sea intermodal transportation. Nanjing with a developed economy and large aggregation of goods is the core city of the Yangtze River Delta. To support this proposal, attention should be paid to the logistics trade scale, policy support, transportation facilities and overall spatial layout of the city. We recommend that the CICMHs should fully exploit their geographical advantages and improve their centrality in the comprehensive transportation network (railway, highway, waterway.

| Node      | $D^+_i$ | $D^-_i$ | $Q^+_i$ | $Q^-_i$ | $C_i$  | Ranking |
|-----------|---------|---------|---------|---------|--------|---------|
| Chongqing | 0.0681  | 1.0000  | 1.0000  | 0.8495  | 0.6855 | 1       |
| Chengdu   | 0.3259  | 0.7244  | 0.9498  | 0.8952  | 0.5783 | 5       |
| Zhengzhou | 0.3362  | 0.5597  | 0.9166  | 0.9241  | 0.5395 | 9       |
| Xi’an     | 0.3269  | 0.6633  | 0.9347  | 0.9069  | 0.5643 | 6       |
| Suzhou    | 0.55    | 0.6076  | 0.9219  | 0.9297  | 0.5083 | 13      |
| Wuhan     | 0.1838  | 0.6908  | 0.9257  | 0.9024  | 0.5981 | 4       |
| Changsha  | 0.3888  | 0.4129  | 0.888   | 0.9572  | 0.4915 | 14      |
| Hefei     | 0.5098  | 0.4152  | 0.8817  | 0.9553  | 0.4696 | 18      |
| Lanzhou   | 0.3519  | 0.3349  | 0.8713  | 0.9851  | 0.4743 | 17      |
| Shenyang  | 1.0000  | 0.2845  | 0.858   | 1.0000  | 0.3636 | 22      |
| Harbin    | 0.6944  | 0.3196  | 0.8673  | 0.9899  | 0.4134 | 21      |
| Nanjing   | 0.2759  | 0.5634  | 0.9055  | 0.9244  | 0.5503 | 7       |
| Hangzhou  | 0.43    | 0.5315  | 0.9036  | 0.9367  | 0.5122 | 11      |
| Nanning   | 0.6054  | 0.3407  | 0.8685  | 0.9785  | 0.4329 | 20      |
| Urumqi    | 0.5853  | 0.3767  | 0.8791  | 0.993   | 0.4431 | 19      |
| Shanghai  | 0.2839  | 0.8857  | 0.9707  | 0.8955  | 0.6115 | 3       |
| Ningbo    | 0.3697  | 0.4831  | 0.8877  | 0.9444  | 0.5106 | 12      |
| Guangzhou | 0.2633  | 0.883   | 0.9686  | 0.8883  | 0.6166 | 2       |
| Tianjin   | 0.3155  | 0.5932  | 0.9154  | 0.9222  | 0.5493 | 8       |
| Qingdao   | 0.4115  | 0.4219  | 0.8826  | 0.9526  | 0.4888 | 15      |
| Dalian    | 0.4104  | 0.545   | 0.896   | 0.9515  | 0.5141 | 10      |
| Xiamen    | 0.4029  | 0.3858  | 0.8699  | 0.9767  | 0.4765 | 16      |

Table 3. Weight of the evaluation index
and aviation). Furthermore, the CICMHs should fully utilise their functionalities for cargo accumulation and transhipment and as a hub connecting various modes of transportation organically in the multimodal network.

![Figure 6. Results of the location evaluation of CICMHs](image)

5. Discussion.

5.1. Screening of hubs. The screening of hubs has a certain impact on the location evaluation of multimodal hubs. Different screening principles generate different numbers of hubs. If the number is too large, then the importance of individual nodes will be weakened, which does not conform to the agglomeration and scale effect of resources. Meanwhile, if too few hubs are generated, then the international goods from all regions of a country will be transhipped through these hubs, thereby increasing the total delivery cost/distance/time and reducing the overall transport efficiency.

The government has issued only few policies that are related to international multimodal hubs. Therefore, screening such hubs has strong subjectivity. Different researchers may screen out various sets of hubs. With the opening and operation of CRexpress and rail-sea intermodal trains in numerous cities and the issuance of policies related to logistics node planning, the preliminary screening of hubs becomes extremely necessary. Moreover, additional factors (e.g. geographical location, transport convenience, infrastructure and environment) and various types of hubs (e.g. dry port, airport, seaport and service-oriented types of hubs) should be considered in future screenings.
5.2. Sensitivity analysis. A sensitivity analysis was conducted for the parameters, including the index weights, loss-averse coefficient $\theta$ of DMs and preference coefficient $\phi$, in eGRA-TOPSIS to examine the robustness and stability of the proposed framework and evaluation results.

**Part 1: Adjust the index weight**

The constructed model belongs to a comprehensive evaluation of MCDM, and its calculation principle is based on index weight. Therefore, the index weight must be changed to verify the stability of the model. The 13 indicators were classified into four groups based on the final evaluation index system. The weights of the 13 indicators fluctuated by $\pm 10\%$ and $\pm 20\%$ to reflect the change in index weight. The influence of the weight change of each index was expressed intuitively in the form of images.

![Figure 7. Sensitivity analysis of the sub-criteria in logistics trade scale and service quality of hub stations](image)

![Figure 8. Sensitivity analysis of the sub-criteria in transport location advantages](image)

Figs. 7-10 depict that under the fluctuation of the weights of the 13 indicators, the trend of the curve is parallel to the X-axis without evident fluctuation, which indicates that the fluctuation of index weight has a limited effect on the results. The ranking results of the 10 alternative sites are stable. The ranking score of Chongqing is always the highest, and it is the most suitable city for the location of CICMH. Dalian exhibits the lowest suitability. Notably, A2 is highly sensitive although the ranking results remain constant. The scores of Guangzhou, Shanghai and Dalian
increase slightly, whereas the scores of Chengdu, Xi’an and Zhengzhou decrease slightly with the increase in weight. The reason is that A2 (freight turnover volume) reflects the consolidation, transhipment and distribution capacity of the hub in the logistics network to a certain extent. Moreover, Guangzhou, Shanghai and Dalian are sensitive to A4 and B2, and a negative correlation exists between them. Overall, A2, A4, B2 and C1 are more sensitive factors than the other indicators, but they are not enough to change the sorting results.

According to the analysis, regardless of how the index weights change, the sorting results of the alternatives remain similar. Thus, the proposed eGRA-TOPSIS method is reasonable and has good stability and applicability.

Part 2: Adjust the loss-averse coefficient $\theta$

In CICMH site selection, different attitudes of DMs may result in different ranking orders. The loss-averse coefficient $\theta$ is a direct parameter used in prospect theory to characterise DMs to avoid risks and losses. Considering that $\theta > 1$ means that DM is more sensitive to losses than to equal gains and $\theta = 2.25$ is used at the most, we let $\theta = 1, 1.5, 2, 2.25, 2.5, 3, 3.5, 4$. This result indicates the DMs’ different attitudes to loss aversion, and the ranking orders of the alternatives were obtained correspondingly (Table 4, Fig. 11). L0, ..., L9 indicate Chongqing, Chengdu, Zhengzhou, Xi’an, Wuhan, Nanjing, Shanghai, Guangzhou, Tianjin and Dalian, respectively.

According to the results, regardless of how the value of $\theta$ changes, no change occurred in the ranking results. Chongqing always occupied the first place, and the worst alternative was Dalian. In addition, with the adjustment of $\theta$, we found that the evaluation scores were stable when $1 \leq \theta \leq 2.25$, and the evaluation scores of different alternatives showed different change trends when $2.25 < \theta \leq 4$. This result indicates that the psychological behaviour of DMs has an effect on the
Evaluation result. Therefore, the DMs’ psychology of avoiding risks and losses must be considered. The uniform change in the preference coefficient has no substantial effect on the final results. The robustness and stability of the proposed framework are verified.

**Part 3: Adjust the preference coefficient** $\varphi$

The coefficient $\varphi = 0.5$ was mostly used in extant studies, indicating that decision-makers exhibit the same preference for curve position (in TOPSIS) and shape (in GRA) to calculate the relative closeness. However, this setting does not correspond to the actual situation, in which different evaluators have different preferences. Therefore, in this work, $\varphi = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9$ was set to explore the changes in the final results (Fig. 12).

Fig. 12 indicates that the ranking results changed slightly compared with the original settings. A small $\varphi$ corresponded to a large change in the ranking. The evaluation results of the different alternatives showed different change trends when $0.5 < \varphi \leq 1$. As $\varphi$ increased, the gap between the schemes was enlarged, although the sorting results were unaffected. Overall, Chongqing was always the optimal site, and Dalian was the worst alternative. The evaluator’s preference had little effect on the evaluation result. These findings demonstrate the robustness of the eGRA-TOPSIS method in determining the optimal location from multiple alternatives.

### 5.3. Comparative analysis

A comparison was performed with classical ranking methods to demonstrate the rationality and feasibility of the proposed framework. The GRA-TOPSIS method is the core part used in the multi-criteria evaluation model eGRA-TOPSIS constructed in this study. TOPSIS and TODIM are mature methodologies, and the basic MCDM method is generally used to solve the location decision problem. Table 5 shows the comparison results.

| θ | L0 | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---------|
| 1 | 0.6865 | 0.5813 | 0.5418 | 0.5677 | 0.6011 | 0.5544 | 0.6096 | 0.6152 | 0.5529 | 0.5143 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 1.5 | 0.6861 | 0.5801 | 0.5421 | 0.5664 | 0.5999 | 0.529 | 0.6103 | 0.6157 | 0.5515 | 0.5141 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 2 | 0.6857 | 0.5786 | 0.5406 | 0.5587 | 0.586 | 0.5512 | 0.6111 | 0.6162 | 0.5501 | 0.5141 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 2.25 | 0.6855 | 0.5781 | 0.5395 | 0.5588 | 0.5861 | 0.5501 | 0.6115 | 0.6166 | 0.5493 | 0.5141 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 2.5 | 0.6853 | 0.5776 | 0.5384 | 0.5606 | 0.5875 | 0.5491 | 0.612 | 0.6161 | 0.5485 | 0.5142 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 3 | 0.6847 | 0.5761 | 0.5382 | 0.5607 | 0.5871 | 0.5475 | 0.6132 | 0.6178 | 0.5469 | 0.5146 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 3.5 | 0.6842 | 0.5746 | 0.5374 | 0.5603 | 0.5846 | 0.5455 | 0.6146 | 0.6189 | 0.5451 | 0.5154 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |
| 4 | 0.6835 | 0.5729 | 0.5364 | 0.5594 | 0.5803 | 0.5432 | 0.6163 | 0.6204 | 0.5432 | 0.5168 | L0>L7>L6>L4>L1>L3>L5>L8>L2>L9 |

**Table 4.** Ranking orders with different $\theta$
Table 5 shows that the ranking results obtained by the four methods were generally consistent. The reasonable ranking is obtained by ranking the sum of the ranking results obtained using the four methods. Chongqing, Guangzhou and Shanghai were always the optimal alternatives for the location of CICMHs. On the contrary, Dalian and Zhengzhou were the least suitable sites. The other alternatives had different orders under the various methods because these methods are based on different core ideas. Specifically, eGRA-TOPSIS pays additional attention to the difference (loss) between schemes under each evaluation index. TOPSIS places considerable emphasis on the distance between the alternative and optimal reference scenarios, and the results of TODIM vary with the preference of DMs for losses and risk psychology. GRA-TOPSIS considers the distance between alternatives and the connections between criteria. Overall, the comparative results reveal the rationality of the proposed method in this study.

Additionally, the reliability of the proposed method is further verified. The reliability of evaluation methods refers to the methods’ distinguishing capacity, such that the evaluation results reveal the actual level of evaluation objects and are measured based on the discrimination approach [23]. Table 6 shows the discrimination of the four methods, and Fig. 13 shows the scatter diagrams of the evaluation values of each method after normalisation and the serial numbers.

Table 6 shows that GRA-TOPSIS exhibited the best discrimination capability. However, Fig. 13(c) illustrates that except for the distance between the three points in the upper-left corner and the other points, the distances between most of the
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| Method     | TOPSIS | TODIM  | GRA-TOPSIS | eGRA-TOPSIS |
|------------|--------|--------|------------|-------------|
| Discrimination | 1.0422 | 1.0775 | 1.0922     | 1.0817      |

**Table 6.** Weight of the evaluation index

This result shows that discrimination is mainly caused by the large distance between the three cities that are most suitable as CICMHs and the other cities. This finding does not mean that GRA-TOPSIS has the highest reliability. On the basis of the discrimination capability, the evaluation method reliability ranking is eGRA-TOPSIS > TODIM > TOPSIS. The dot pitch between the upper-left and lower-right points is relatively large, as shown in Fig. 13, indicating that the superior and inferior CICMHs can be easily distinguished.

6. **Conclusions.** This study proposed a decision framework for the location and selection of CICMHs under BRI based on evaluation index screening, prospect theory and the eGRA-TOPSIS method. Firstly, we screened 22 candidate CICMHs as the research objects according to the current operations of China’s trade transportation. Secondly, we constructed an evaluation index system that includes four dimensions of scale-quality, transport-geography, economic-social and resource-environment of the candidate CICMHs. The information contribution rate-information substitutability method was used to screen indicators from the preliminary index system. Furthermore, we proposed an eGRA-TOPSIS method combining prospect theory to evaluate the comprehensive performance of the CICMHs. Prospect theory was utilised to consider the DMs’ preference for risk and loss avoidance, and the index weight was determined through the maximum deviation-entropy method. GRA-TOPSIS was improved by introducing relative entropy and considering the shape similarity and numerical proximity between sequences. The results showed that the top 10 CICMHs are Chongqing, Guangzhou, Shanghai, Wuhan, Chengdu, Xi’an, Nanjing, Tianjin, Zhengzhou and Dalian. Lastly, this
study performed a sensitivity analysis by adjusting the index weights and the loss-averse and preference coefficient. The results revealed that the proposed method has good stability and robustness. For the comparative analysis, this study adopted GRA-TOPSIS, TOPSIS and TODIM methods to reorder the alternative sites, and the results showed that the proposed method has good applicability and reliability.

This study provides a practical evaluation framework that combines index screening, prospect theory and MCDM methods for the location and selection and overall layout of CICMHs under BRI. It therefore enriches the application fields of MCDM methods, such as distribution hubs in metro-integrated logistics system, electric vehicle charging stations and offshore wind power plants. The proposed method has a wide range of applications, which are not limited to China; the method can be applied to other countries and regions. The reason is that the location decision method constructed in this study is universally applicable. However, this study still has several limitations due to the practical experience of the authors. On the basis of this study, we will continue to investigate the MCDM method from the preference of DMs’ psychological behaviour and integrate it with other novel decision methods. Moreover, future research could consider the logistics transportation networks in China-Europe (including CRexpress, rail-sea intermodal and aviation transportation) when establishing a model for optimising the location and layout of CICMHs.

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REFERENCES

[1] R. P. Brooker and N. Qin, Identification of potential locations of electric vehicle supply equipment, Journal of Power Sources, 299 (2015), 76–84.

[2] J. W. K. Chan and T. K. L. Tong, Multi-criteria material selections and end-of-life product strategy: Grey relational analysis approach, Materials & Design, 28 (2007), 1539–1546.

[3] G. Chen, W. Cheung, S.-C. Chu and L. Xu, Transshipment hub selection from a shipper’s and freight forwarder’s perspective, Expert Systems with Applications, 83 (2017), 396–404.

[4] M.-F. Chen and G.-H. Tzeng, Combining grey relation and TOPSIS concepts for selecting an expatriate host country, Mathematical and Computer Modelling, 40 (2004), 1473–1490.

[5] S. K. Das, M. Pervin, S. K. Roy and G.-W. Weber, Multi-objective solid transportation-location problem with variable carbon emission in inventory management: A hybrid approach, Annals of Operations Research, (2021).

[6] S. K. Das and S. K. Roy, Effect of variable carbon emission in a multiobjective transportation-p-facility location problem under neutrosophic environment, Computers & Industrial Engineering, 132 (2019), 311–324.

[7] S. K. Das, S. K. Roy and G.-W. Weber, Application of type-2 fuzzy logic to a multi-objective green solid transportation-location problem with dwell time under carbon tax, cap and offset policy: Fuzzy vs. non-fuzzy techniques, IEEE Transactions on Fuzzy Systems, 28 (2020), 2711–2725.

[8] S. K. Das, S. K. Roy and G.-W. Weber, Heuristic approaches for solid transportation-p-facility location problem, CEJOR Cent. Eur. J. Oper. Res., 28 (2020), 939–961.

[9] J. Deng, Control problems of grey systems, Systems and Control Letters, 1 (1982), 288–294.

[10] J. Deng, Introduction to grey theory system, J. Grey System, 1 (1989), 1–24.

[11] B. Dey, B. Bairagi, B. Sarkar and S. K. Sanyal, Group heterogeneity in multi member decision making model with an application to warehouse location selection in a supply chain, Computers & Industrial Engineering, 105 (2017), 101–122.
I. Essaadi, B. Grabot and P. Féniès, Location of global logistic hubs within Africa based on a fuzzy multi-criteria approach, Computers & Industrial Engineering, 132 (2019), 1–22.

Y.-P. Hu, X.-Y. You, L. Wang and H.-C. Liu, An integrated approach for failure mode and effect analysis based on uncertain linguistic GRA-TOPSIS method, Soft Computing, 23 (2019), 8801–8814.

Y. Jiang, J.-B. Sheu, Z. Peng and B. Yu, Hinterland patterns of China Railway (CR) express in China under the Belt and road initiative: A preliminary analysis, Transportation Research Part E: Logistics and Transportation Review, 119 (2018), 189–201.

S. Khalilpourazari and A. Arshadi Khamseh, Bi-objective emergency blood supply chain network design in earthquake considering earthquake magnitude: A comprehensive study with real world application, Ann. Oper. Res., 283 (2019), 355–393.

S. Khalilpourazari, B. Naderi and S. Khalilpourazary, Multi-objective stochastic fractal search: A powerful algorithm for solving complex multi-objective optimization problems, Soft Computing, 24 (2020), 3037–3066.

S. Khalilpourazari, S. Soltanzadeh, G.-W. Weber and S. K. Roy, Designing an efficient blood supply chain network in crisis: Neural learning, optimization and case study, Ann. Oper. Res., 289 (2020), 123–152.

B. Kirubakaran and M. Ilangkumaran, Selection of optimum maintenance strategy based on FAHP integrated with GRA-TOPSIS, Ann. Oper. Res., 245 (2016), 285–313.

X. Li, X. Li, X. Li and H. Qiu, Multi-agent fare optimization model of two modes problem and its analysis based on edge of chaos, Phys. A, 469 (2017), 405–419.

D. Li, L. Zhao, C. Wang, W. Sun and J. Xue, Selection of China's imported grain distribution centers in the context of the belt and road initiative, Transportation Research Part E: Logistics and Transportation Review, 120 (2018), 16–34.

Y.-H. Lin, P.-C. Lee and T.-P. Chang, Practical expert diagnosis model based on the grey relational analysis technique, Expert Systems with Applications, 36 (2009), 1523–1528.

C.-C. Lin and S.-W. Lin, Two-stage approach to the intermodal terminal location problem, Comput. Oper. Res., 67 (2016), 113–119.

D. Liu, C. Liu, Q. Fu, T. Li, K. M. Imran, S. Cui and F. M. Abrar, ELM evaluation model of regional groundwater quality based on the crow search algorithm, Ecological Indicators, 81 (2017), 302–314.

D. Liu, X. Qi, Q. Fu et. al., A resilience evaluation method for a combined regional agricultural water and soil resource system based on Weighted Mahalanobis distance and a Gray-TOPSIS model, Journal of Cleaner Production, 229 (2019), 667–679.

S. Liu, N. Xie and J. Forrest, Novel models of grey relational analysis based on visual angle of similarity and nearness, Grey Systems: Theory and Application, 1 (2011), 8–18.

S. Long and S. E. Grasman, A strategic decision model for evaluating inland freight hub locations, Research in Transportation Business & Management, 5 (2012), 92–98.

M. Lu, Node importance evaluation based on neighborhood structure hole and improved TOPSIS, Computer Networks, 178 (2020), 107336.

C. Ma, Y. Yang, J. Wang, Y. Chen and D. Yang, Determining the location of a Swine farming facility based on grey correlation and the TOPSIS method, Transactions of the ASABE, 60 (2017), 1281–1289.

H. Mokhtar, A. A. N. P. Redi, M. Krishnamoorthy and A. T. Ernst, An intermodal hub location problem for container distribution in indonesia, Comput. Oper. Res., 104 (2019), 415–432.

D. Muravev, H. Hu, H. Zhou and D. Pamucar, Location optimization of CR express international logistics centers, Symmetry, 12 (2020), 143.

M. E. O’Kelly, The location of interacting hub facilities, Transportation Science, 20 (1986), 92–106.

X. Pan, L. Ning and L. Shi, Visualisation and determinations of hub locations: Evidence from China’s interregional trade network, Research in Transportation Economics, 75 (2019), 36–41.

P. Peng, Y. Yang, F. Lu, S. Cheng, N. Mou and R. Yang, Modelling the competitiveness of the ports along the Maritime Silk Road with big data, Transportation Research Part A: Policy and Practice, 118 (2018), 852–867.

H. Quan, S. Li, H. Wei and J. Hu, Personalized product evaluation based on GRA-TOPSIS and Kansei engineering, Symmetry, 11 (2019), 867.

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[12] I. Essaadi, B. Grabot and P. Féniès, Location of global logistic hubs within Africa based on a fuzzy multi-criteria approach, Computers & Industrial Engineering, 132 (2019), 1–22.

[13] Y.-P. Hu, X.-Y. You, L. Wang and H.-C. Liu, An integrated approach for failure mode and effect analysis based on uncertain linguistic GRA-TOPSIS method, Soft Computing, 23 (2019), 8801–8814.

[14] Y. Jiang, J.-B. Sheu, Z. Peng and B. Yu, Hinterland patterns of China Railway (CR) express in China under the Belt and road initiative: A preliminary analysis, Transportation Research Part E: Logistics and Transportation Review, 119 (2018), 189–201.

[15] S. Khalilpourazari and A. Arshadi Khamseh, Bi-objective emergency blood supply chain network design in earthquake considering earthquake magnitude: A comprehensive study with real world application, Ann. Oper. Res., 283 (2019), 355–393.

[16] S. Khalilpourazari, B. Naderi and S. Khalilpourazary, Multi-objective stochastic fractal search: A powerful algorithm for solving complex multi-objective optimization problems, Soft Computing, 24 (2020), 3037–3066.

[17] S. Khalilpourazari, S. Soltanzadeh, G.-W. Weber and S. K. Roy, Designing an efficient blood supply chain network in crisis: Neural learning, optimization and case study, Ann. Oper. Res., 289 (2020), 123–152.

[18] B. Kirubakaran and M. Ilangkumaran, Selection of optimum maintenance strategy based on FAHP integrated with GRA-TOPSIS, Ann. Oper. Res., 245 (2016), 285–313.

[19] X. Li, X. Li, X. Li and H. Qiu, Multi-agent fare optimization model of two modes problem and its analysis based on edge of chaos, Phys. A, 469 (2017), 405–419.

[20] D. Li, L. Zhao, C. Wang, W. Sun and J. Xue, Selection of China’s imported grain distribution centers in the context of the belt and road initiative, Transportation Research Part E: Logistics and Transportation Review, 120 (2018), 16–34.

[21] Y.-H. Lin, P.-C. Lee and T.-P. Chang, Practical expert diagnosis model based on the grey relational analysis technique, Expert Systems with Applications, 36 (2009), 1523–1528.

[22] C.-C. Lin and S.-W. Lin, Two-stage approach to the intermodal terminal location problem, Comput. Oper. Res., 67 (2016), 113–119.

[23] D. Liu, C. Liu, Q. Fu, T. Li, K. M. Imran, S. Cui and F. M. Abrar, ELM evaluation model of regional groundwater quality based on the crow search algorithm, Ecological Indicators, 81 (2017), 302–314.

[24] D. Liu, X. Qi, Q. Fu et. al., A resilience evaluation method for a combined regional agricultural water and soil resource system based on Weighted Mahalanobis distance and a Gray-TOPSIS model, Journal of Cleaner Production, 229 (2019), 667–679.

[25] S. Liu, N. Xie and J. Forrest, Novel models of grey relational analysis based on visual angle of similarity and nearness, Grey Systems: Theory and Application, 1 (2011), 8–18.

[26] S. Long and S. E. Grasman, A strategic decision model for evaluating inland freight hub locations, Research in Transportation Business & Management, 5 (2012), 92–98.

[27] M. Lu, Node importance evaluation based on neighborhood structure hole and improved TOPSIS, Computer Networks, 178 (2020), 107336.

[28] C. Ma, Y. Yang, J. Wang, Y. Chen and D. Yang, Determining the location of a Swine farming facility based on grey correlation and the TOPSIS method, Transactions of the ASABE, 60 (2017), 1281–1289.

[29] H. Mokhtar, A. A. N. P. Redi, M. Krishnamoorthy and A. T. Ernst, An intermodal hub location problem for container distribution in indonesia, Comput. Oper. Res., 104 (2019), 415–432.

[30] D. Muravev, H. Hu, H. Zhou and D. Pamucar, Location optimization of CR express international logistics centers, Symmetry, 12 (2020), 143.

[31] M. E. O’Kelly, The location of interacting hub facilities, Transportation Science, 20 (1986), 92–106.

[32] X. Pan, L. Ning and L. Shi, Visualisation and determinations of hub locations: Evidence from China’s interregional trade network, Research in Transportation Economics, 75 (2019), 36–41.

[33] P. Peng, Y. Yang, F. Lu, S. Cheng, N. Mou and R. Yang, Modelling the competitiveness of the ports along the Maritime Silk Road with big data, Transportation Research Part A: Policy and Practice, 118 (2018), 852–867.

[34] H. Quan, S. Li, H. Wei and J. Hu, Personalized product evaluation based on GRA-TOPSIS and Kansei engineering, Symmetry, 11 (2019), 867.
[35] C. Rao, M. Goh, Y. Zhao and J. Zheng, Location selection of city logistics centers under sustainability, Transportation Research Part D: Transport and Environment, 36 (2015), 29–44.
[36] C. Salavati, A. Abdollahpouri and Z. Manbari, Ranking nodes in complex networks based on local structure and improving closeness centrality, Neurocomputing, 336 (2019), 36–45.
[37] B. Sennaroglu and G. V. Celebi, A military airport location selection by AHP integrated PROMETHEE and VIKOR methods, Transportation Research Part D: Transport and Environment, 59 (2018), 160–173.
[38] J. B. Sheu and T. Kundu, Forecasting time-varying logistics distribution flows in the One Belt-One Road strategic context, Transportation Research Part E: Logistics and Transportation Review, 117 (2018), 5–22.
[39] W. Sun, L. Zhao, C. Wang, D. Li and J. Xue, Selection of consolidation centres for China railway express, International Journal of Logistics Research and Applications, 23 (2020), 417–442.
[40] A. Tversky and D. Kahneman, Advances in prospect theory: Cumulative representation of uncertainty, Journal of Risk and Uncertainty, 5 (1992), 297–323.
[41] Z. Y. Wang, A method of multi-object decision-making based on maximum deviations and entropy, Journal of PLA University of Science and Technology, 3 (2002), 93–95.
[42] W. Wu and Y. Peng, Extension of grey relational analysis for facilitating group consensus to oil spill emergency management, Ann. Oper. Res., 238 (2016), 615–635.
[43] X. Zhang, W. Zhang and P. T.-W. Lee, Importance rankings of nodes in the China railway express network under the belt and road initiative, Transportation Research Part A: Policy and Practice, 139 (2020), 134–147.
[44] L. Zhao, H. Li, M. Li, Y. Sun, Q. Hu, S. Mao, J. Li and J. Xue, Location selection of intra-city distribution hubs in the metro-integrated logistics system, Tunnelling and Underground Space Technology, 80 (2018), 246–256.
[45] J. Zhou, Y. Wu, C. Wu, F. He, B. Zhang and F. Liu, A geographical information system based multi-criteria decision-making approach for location analysis and evaluation of urban photovoltaic charging station: A case study in Beijing, Energy Conversion and Management, 205 (2020), 112540.

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