

Article

Evaluating Consolidation Centers of an Integrated Transportation Network under the Belt and Road Initiative

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Abstract: Following the Belt and Road, the Air Silk Road has also been proposed. The coordinated development of multiple transportation modes, including air, land, and water, will create a strong transportation force in node cities. However, the current insufficient supply of cargo in various regions and the lack of integration among different transportation modes result in low transportation efficiency, which in turn affects the further advancement of the Belt and Road. To investigate these issues and attempt to find a solution, we selected 44 candidate cities from the prefecture-level cities in China as nodes based on relevant government policies, and constructed an integrated transportation network. For each node city, we first calculated the values of six classical indicators and then used the CRITIC to assign weights to each indicator. Subsequently, we employed the TOPSIS method combined with Grey Relational Analysis (GRA) to compute the comprehensive score for each node city. Based on the spatial layout and government policies under the BRI, eight cities, including Wuhan, Chongqing, Tianjin, Shanghai, Guangzhou, Lianyungang, Hefei, and Dalian, were finally recommended as the consolidation centers of the integrated transportation network. It is hoped that the results of this analysis can provide some insights for the government to outline and build the consolidation centers of the integrated transportation network composed of railway, air, highway, and water routes, which in turn can offer insights for elevating the Belt and Road Initiative (BRI) to a new level.



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Keywords: complex network theory; consolidation center; integrated transportation network; BRI

1. Introduction

The cooperative initiative of establishing the Belt and Road was proposed by Xi Jinping, President of the People's Republic of China, in Kazakhstan and Indonesia in 2013, respectively, which aims to establish the world's biggest economic cooperation platform covering Asia, Europe, and sub-regions of Africa and enhance the interconnectivity among countries. Currently, China Railway Express (CR Express), with active participation from local governments, has connected 108 Chinese cities and reached 208 cities in 25 European countries through ports such as Manzhouli, Erenhot, and Alashankou [1]. Meanwhile, as of September 2022, there are 94 routes along Maritime Silk Road, connecting 108 ports in 31 countries [2]. The in-depth development of the transportation network has greatly shortened the time and space distance between China and Europe. Currently, the Chinese local governments are faced with various issues in the process of promoting the in-depth development of the BRI, such as uneven supplies of goods, disordered competition, and inefficient coordination mechanism [3,4]. On the other hand, the Chinese domestic transportation network is a relatively independent development of various transportation modes, which lacks global optimization and integration of transportation resources. To address the above-mentioned issues, constructing consolidation centers through top-level government design is a promising solution to provide rational cargo allocation. This is

because the rational location and layout of the consolidation centers can reduce logistics costs through economies of scale, as well as maximize service quality and transportation efficiency within multimodal networks [5,6].

Therefore, the issue of transportation hubs along the Belt and Road has been discussed by many scholars from different perspectives in the past few years. Zhang et al. applied the TOPSIS to sort out the logistics nodes and select the optimal nodes of CR Express under the BRI [7]. Li et al. applied contest theory to validate the number of multimodal transportation network hubs based on local government subsidies under the BRI [8]. Wan et al. used the TOPSIS to identify essential ports in the maritime silk network when encountering severe disasters [9]. By analyzing the quantitative and qualitative factors influencing the location of global logistics centers in the existing literature, Lee et al. proposed the eight locations of global LDCs [10]. Li et al. considered the government policies and operational experience from the BRI, and used the improved entropy TOPSIS to select imported grain distribution centers across railway, highway, and water transportation networks [11]. The TOPSIS was employed by Aljohani et al. to conduct an assessment and ranking of 20 candidate consolidation centers within the city of inner Melbourne, Australia, based on 11 decision criteria, and found that the most suitable locations for the consolidation centers are in economically viable industrial areas [12]. Muerza et al. used ANP technology to evaluate and rank five locations in Europe for establishing international consolidation centers based on 25 standards to support the choices of decision makers [13].

Furthermore, during a meeting with the leader of Luxembourg in June 2017, President Xi Jinping first proposed to build the Air Silk Road between Zhengzhou and Luxembourg. With the gradual integration of the civil aviation industry into the BRI, the Chinese government released an Implementation Plan of the Air Silk Road in May 2022, aiming to promote its in-depth development [14]. Meanwhile, scholars have begun to address the issues of the air transportation network. Zhou et al. employed local centrality and global centrality to research the hub problem of the integration of rail ports, airports, and maritime ports in the Belt and Road countries [15]. Derudder et al. applied the centrality indicator to study the ranking of connectivity of three-layer transportation network node cities for air and highway routes along the Belt and Road [16].

However, the above-mentioned scholars are only concerned about a single mode or a combination of two or three transport modes, and there is less research on the integration of railway, air, highway, and water transportation. Additionally, the whole layout of the integrated transportation network has not been formed at the national level, which cannot effectively fit in with the development of the BRI, making it difficult to effectively achieve the orderly linking up of the multi-tiered integrated transportation network consisting of water, land, and air transportation. Hence, this paper addresses the ranking and selection of node cities as the candidate consolidation centers of an integrated transportation network composed of highway, railway, air, and water routes under the BRI to provide a reference for the government in building the consolidation centers.

A total of 44 Chinese cities were selected as the candidate consolidation centers under the BRI. Then, the integrated transportation network was formed based on the links of transportation modes among these 44 Chinese cities. It should be noted that the evaluation of consolidation centers in this study was based on the consideration of the above issues of cargo transportation at the national level of China under the BRI. Consequently, each city was viewed as a node in the network without delving into the specific logistic activities within it.

Complex network theory has been widely employed in transportation network research in recent years [17,18]; extensive study has been implemented on single-mode transportation networks, including railway networks [11], subway networks [19,20], bus networks [21,22], water networks [23,24], road networks [25], and air networks [26]. Currently, complex network theory is employed by some scholars to study the single-mode transportation networks under the BRI. Zhao et al. used the TOPSIS method combined with complex network theory to select 10 cities from 27 candidate cities as consolidation

centers of CR Express [27]. Sun et al. applied the TOPSIS method to select 10 cities from 48 candidate cities of CR Express as consolidation centers using some qualitative indicators [28]. Feng et al. applied the improved TOPSIS method to select the key node of CR Express through multiple centrality evaluation indicators [29]. The entropy weight TOPSIS method was used by Yin et al. [30] to choose eight inner cities as trans-shipment consolidation centers from the regional integration standpoint. Additionally, there are some studies on the impact of consolidation centers. Van Heeswijk et al. applied agent-based data simulation to verify that the urban consolidation center in Copenhagen can reduce truck mileage by about 65% and emissions by about 70% [31]. On the one hand, there is a lack of studies on the integration of various modes such as air, water, railway, and highway transportation in the aforementioned research. On the other hand, the multi-attribute indicators of transportation networks are rarely considered, which makes it difficult to comprehensively evaluate consolidation centers. Consequently, this study employed complex network theory to integrate various transportation modes—including air, water, highway, and railway—with the aim of constructing an integrated transportation network aligned with the BRI. Using this network, we evaluated the comprehensive scores of candidate node cities as potential consolidation centers.

The TOPSIS is a traditional multi-attribute decision-making approach. However, the TOPSIS cannot accurately reflect the similarity of data curves, making it difficult to accurately assess the optimal results. In this study, the TOPSIS combined with Grey Relational Analysis (GRA) was applied, which not only retains the objective advantage of the TOPSIS method but also takes the advantages of the similarity and dynamicity of GRA to make up for the shortcoming of the TOPSIS method. Finally, the ranking results of the candidate consolidation centers are obtained based on the combination of the TOPSIS and GRA.

This paper makes the following contributions. Firstly, the consolidation centers of an integrated transportation network, which includes highway, railway, air, and water routes, is considered as the research target under the BRI to attempt to solve the high logistics costs resulting from disorderly competition, poor efficiency, and so on among the different transportation modes. Secondly, considering the links among the candidate consolidation centers, the TOPSIS and GRA are combined to comprehensively evaluate the ranking of candidate consolidation centers within the integrated transportation network constructed based on complex network theory. Thirdly, the local and global evaluation indicators were integrated to evaluate the candidate consolidation centers of the integrated transportation network.

The remaining sections are as follows: Section 2 introduces the criteria and the steps for selecting node cities. Section 3 establishes transportation networks of air, water, railway, and highway routes. The related evaluation indicators are selected in Section 4. The related approach is depicted in Section 5. A case application is analyzed in Section 6. Section 7 implements a comparative analysis. Finally, Section 8 is the conclusions.

2. Criteria and Procedure for Selecting Consolidation Centers

2.1. Screening Criteria

The Chinese government has issued various documents with regard to the layout of Chinese logistics center cities over recent years. These documents include: “a plan to develop modern logistics during the 14th Five-Year Plan period (2021–2025)” (https://www.gov.cn/zhengce/content/2022-12/15/content_5732092.htm, accessed on 15 January 2023), “Outline of National Comprehensive Three-Dimensional Transportation Network Plan (2021–2035)” (<http://finance.people.com.cn/n1/2021/0224/c1004-32036071.html>, accessed on 15 January 2023), “Outline of Building a Strong Transportation Nation (2020–2035)” (https://www.gov.cn/zhengce/2019-09/19/content_5431432.htm, accessed on 16 January 2023), “Outline of the 14th Five-Year Plan (2021–2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035” (https://www.gov.cn/xinwen/2021-03/13/content_5592681.htm, accessed on 17 January 2023), “Implementation Plan for Promoting the High-Quality Development of the ‘Air Silk Road’

during the 14th Five-Year Plan Period (2021–2025)” (http://www.caac.gov.cn/PHONE/XXGK_17/XXGK/SYZCFBJD/202205/t20220506_213121.html, accessed on 17 January 2023), and so on. The publication of these different transportation plans provides policy support for the construction of transportation networks. However, these documents are primarily formulated for a single transportation mode and lack comprehensive planning for the integration of multiple modes.

Due to factors such as economic scale, geography, and population, not every city in China is suitable as a consolidation center [11,18]. This study constructed rules for screening the consolidation centers considering Chinese government documents, the geographical location, and the accessibility of transportation modes. Meanwhile, cities in Xizang, considering the population and economic scale, as well as Hainan, Taiwan, Hong Kong, and Macau, considering the geography and political factors, were excluded. This not only enhances the accuracy of the evaluation of the consolidation centers but also narrows down the selected cities. Considering the above-mentioned factors, with reference to [27] and [32], the specific screening criteria were formulated as follows:

Criterion 1: Node cities linked by CR Express, highway, domestic air, and/or water transportation modes.

Criterion 2: National- or regional-level logistics node cities.

Criterion 3: Provincial capital city.

Criterion 1 mainly reflects the cumulative advantages of the transportation mode of the comprehensive transportation network. Criterion 2 presents the national logistic layout, and Criterion 3 selects provincial capitals to demonstrate the support of local governments.

2.2. Screening Procedure

To screen out the candidate node cities, the following screening steps were formulated based on the criteria.

Step 1: Priority is given to cities that simultaneously meet all three criteria.

Step 2: If provinces do not have any candidate cities after Step 1, preference will be given to cities that meet 2 criteria. In particular, the order of precedence was ① Criteria 1 and 2; ② Criteria 2 and 3; and ③ Criteria 1 and 3.

Step 3: If provinces do not have any candidate cities after Steps 1 and 2, cities that meet the following order of criteria can be selected: Criterion 1, Criterion 2, and Criterion 3.

Simultaneously, national- or regional-level logistics cities are shown in Table A1, node cities of CR Express are shown in Table A2, node cities of water transportation are shown in Table A3, node cities of air transportation are shown in Table A4, and provincial capitals are shown in Table A5, which are appended in Appendix A. Based on the above-mentioned screening criteria and procedure, by searching government documents, relevant government websites, or industry websites, 44 node cities were ultimately screened as candidate consolidation centers for the integrated transportation network under the Belt and Road Initiative, as shown in Table 1 and Figure 1.

Table 1. Candidate consolidation centers.

Number	City	Number	City	Number	City	Number	City
1	Chongqing	12	Urumqi	23	Xining	34	Hohhot
2	Wuhan	13	Harbin	24	Tianjin	35	Hangzhou
3	Zhengzhou	14	Lanzhou	25	Taiyuan	36	Fuzhou
4	Suzhou	15	Qingdao	26	Shenzhen	37	Guiyang
5	Guangzhou	16	Kunming	27	Jinan	38	Beijing
6	Xi’an	17	Xiamen	28	Shanghai	39	Xuzhou
7	Hefei	18	Changchun	29	Tangshan	40	Quanzhou
8	Shenyang	19	Nanchang	30	Shijiazhuang	41	Jiujiang
9	Ningbo	20	Dalian	31	Chengdu	42	Yantai
10	Changsha	21	Dongguan	32	Yinchuan	43	Liuzhou
11	Lianyungang	22	Nanjing	33	Nanning	44	Wuxi

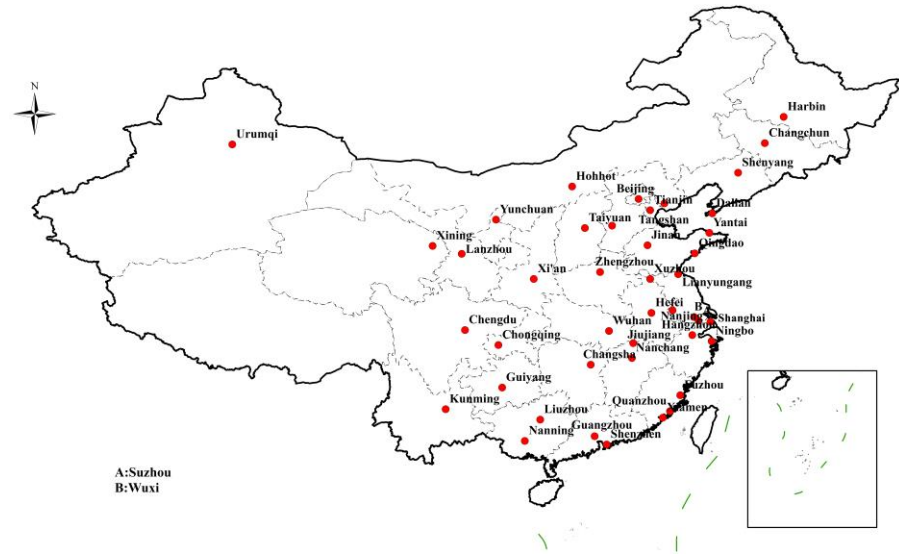


Figure 1. Map of candidate consolidation centers.

3. Construction of Integrated Network

The topology of the integrated transportation network consisting of railway, road, water, and air routes is a complex network, denoted as $HG = (V, E, A)$. Here, $V = \{v_1, v_2, \dots, v_n\}$ and $E = \{e_1, e_2, \dots, e_q\}$ denote the link set and the node set of the network, respectively. $A = (a_{ij})_{n \times n}$ denotes the adjacency matrix where the number of nodes is n , and a_{ij} represents the following meaning:

$$a_{ij} = \begin{cases} 1, & \text{if } i \text{ and } j \text{ is adjacent} \\ 0, & \text{if } i \text{ and } j \text{ is not adjacent} \end{cases} \quad (1)$$

In other words, the transportation network G is defined as an undirected transportation network with n nodes and q links [26,33]. In this paper, a node denotes a city; meanwhile, a city also represents a candidate consolidation center and a link connects two cities by transportation modes such as railway, highway, water, or air. These network nodes are linked to establish an integrated transportation network, which is displayed in Figure 2.

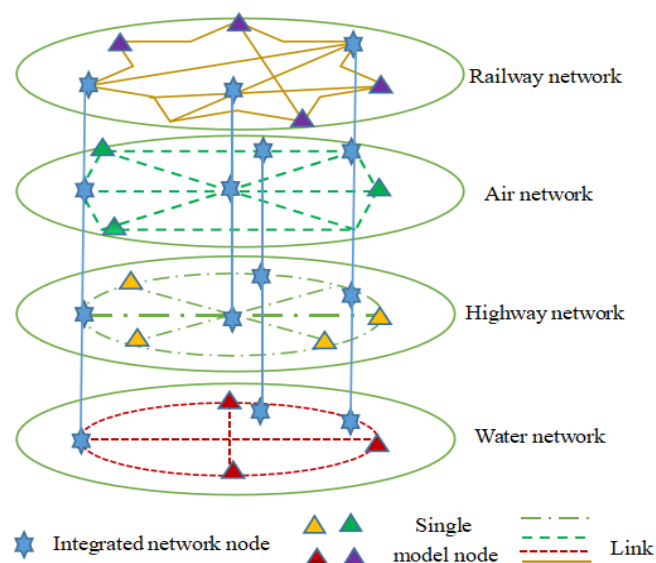


Figure 2. Map of integrated transportation nodes and links.

In Figure 2, triangles of different colors indicate the nodes of a single transportation mode; the red triangles indicate the city nodes of the water transportation network, and the links of the same color denote the links among. Similarly, the yellow triangles, green triangles, and purple triangles indicate the city nodes of the highway network, air network, and railway network, respectively. Simultaneously, the links of the same color denote the links between cities that can be reached by highway, air, and railway modes, respectively. The blue hexagons denote the nodes of the integrated transportation network, and the links of the same color indicate multiple transportation modes passing through the same node city.

3.1. Establishment of the Railway Network

In this study, a railway transportation network connected by 277 railway lines was established between 44 node cities according to data from the China Railway website (<https://ec.95306.cn/hycp/?active=0>, accessed on 7 February 2023) and domestic cities serviced by CR Express. Figure 3 shows a topological map of the railway transportation network drawn using ArcGIS 10.2 software based on data from 277 railway transportation lines among the 44 node cities, which demonstrates the link network among cities serviced by CR Express or freight trains.

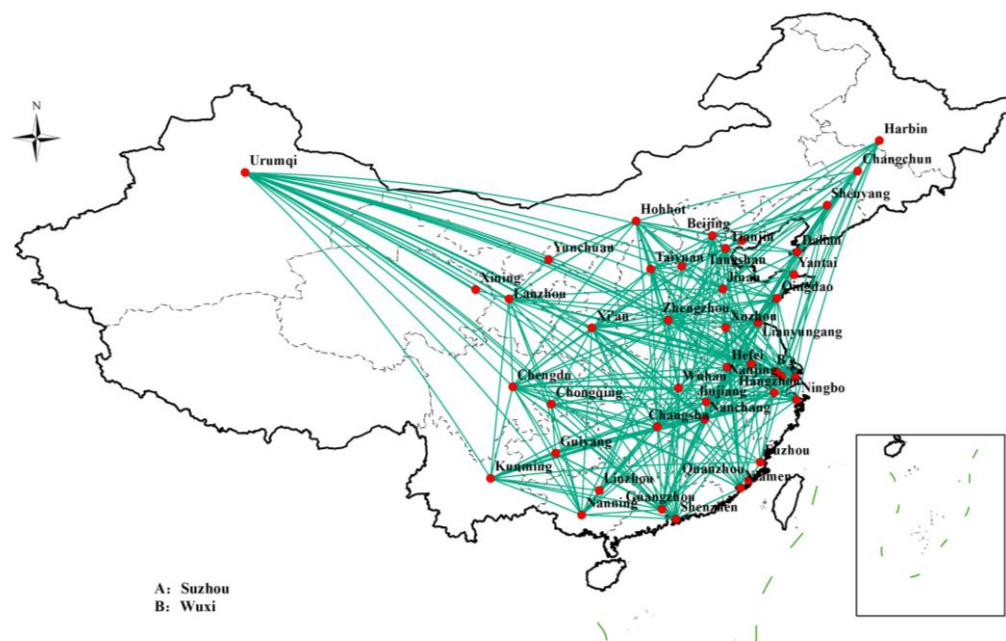


Figure 3. Topological map of the railway transportation network.

3.2. Establishment of the Highway Network

To simplify the processing of the transportation network data and align with the reality of freight transportation, the expressway was primarily considered in this study. At present, the expressway network in China is laid out with radial lines and vertical and horizontal grids, which are composed of 7 radial lines starting from Beijing, as well as 9 north–south vertical lines and 18 east–west horizontal lines [34]. Compared with the railway transportation network, only cities directly connected by expressways are considered as the nodes of the highway network. Therefore, the cities connected by expressways are divided into segments. For example, the expressway between Beijing and Harbin passing through multiple node cities is divided into many subsections, such as Beijing–Tangshan, Tangshan–Shenyang, Shenyang–Changchun, and Changchun–Harbin. In addition, Dongguan is not connected by highway. Therefore, in this study, based on the above-mentioned factors, 79 connections among 43 node cities were identified. By using ArcGIS 10.2 software, a topological map of the expressway transportation network

was drawn based on the 79 connections among the 43 node cities, as shown in Figure 4, which indicates the highway link network among the 43 node cities connected by the highway network.

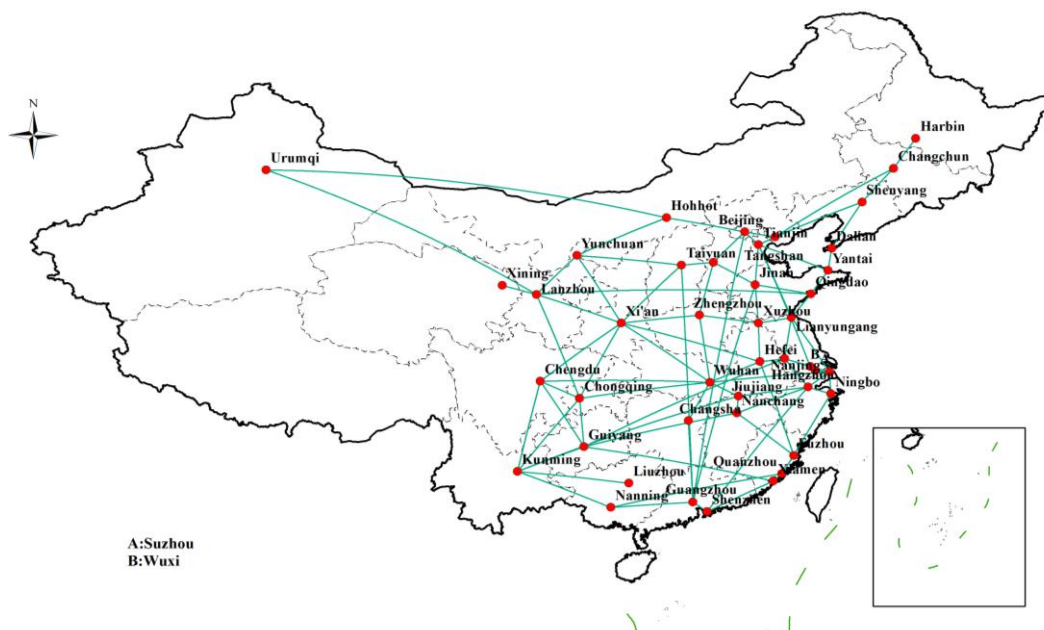


Figure 4. Topological map of the expressway transportation network.

3.3. Establishment of the Air Network

Most airports in China are now dual-use airports for passengers and cargo; therefore, in this study, only the connections between the nodes of the aviation network were considered; the volume and frequency of freight transportation between the nodes were not considered. The data on the air transportation network primarily came from the direct routes between cities listed in the “Catalogue of Domestic Routes with Market-Adjusted Prices” published by the Chinese government. Many of these cities only have one airport, but some cities have multiple airports; cities with multiple airports were represented by the city name. For example, Pudong and Hongqiao airports in Shanghai were represented by Shanghai. Only one airline route was reserved between each pair of cities, and repetitive routes were deleted. After screening, since there are no airports in Dongguan, Tangshan, Jiujiang, and Suzhou, 462 direct routes were selected among 40 node cities in the air transportation network. A topological map of the air transportation network was drawn using ArcGIS 10.2 software based on the data from the 462 direct links among the 40 node cities, as shown in Figure 5, which denotes the air transportation network among the 40 node cities connected by the air network.

3.4. Establishment of the Waterway Network

Compared with railway, air, and highway transportation networks, water transportation is limited by geographical factors and not every node city has a mode of water transportation. Water transportation is generally divided into coastal and inland river transportation, but this study mainly considered the connection between ports. Domestic water transportation in China mainly involves inland river transport in the Heilongjiang, Yangtze, and Pearl River basins, as well as the Beijing–Hangzhou Grand Canal, and coastal shipping in coastal areas. However, because the Heilongjiang River basin is affected by geographical and climatic factors and the shipping scope is small, the port cities in the Heilongjiang River basin were not considered. The data used in this study were sourced from relevant government websites (for example, <http://www.tcport.gov.cn/tcg/cjnh/zjgkwztt.sh-tml>, accessed on 9 February 2023) and shipping companies (for example,

<http://www.chinaports.com/>, accessed on 9 February 2023). Based on the above factors, 82 water transportation routes were identified among 27 port cities. Figure 6 is a topological map of the water transportation network drawn using ArcGIS 10.2 software based on the 82 water transportation links among the 27 port cities, which denotes the transportation network of direct water transportation links among the 27 port cities.

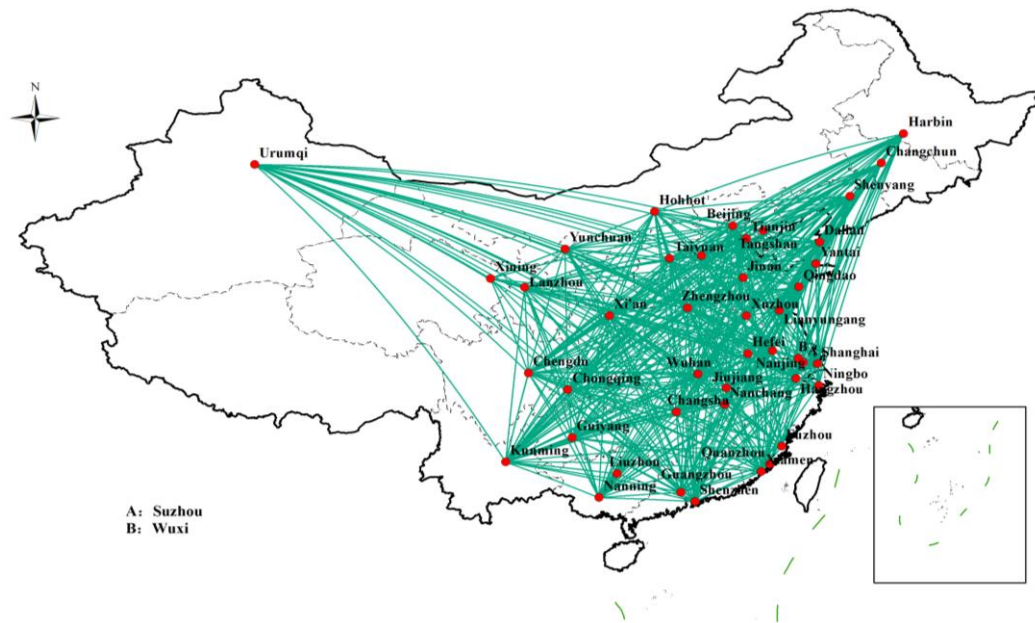


Figure 5. Topological map of the air transportation network.

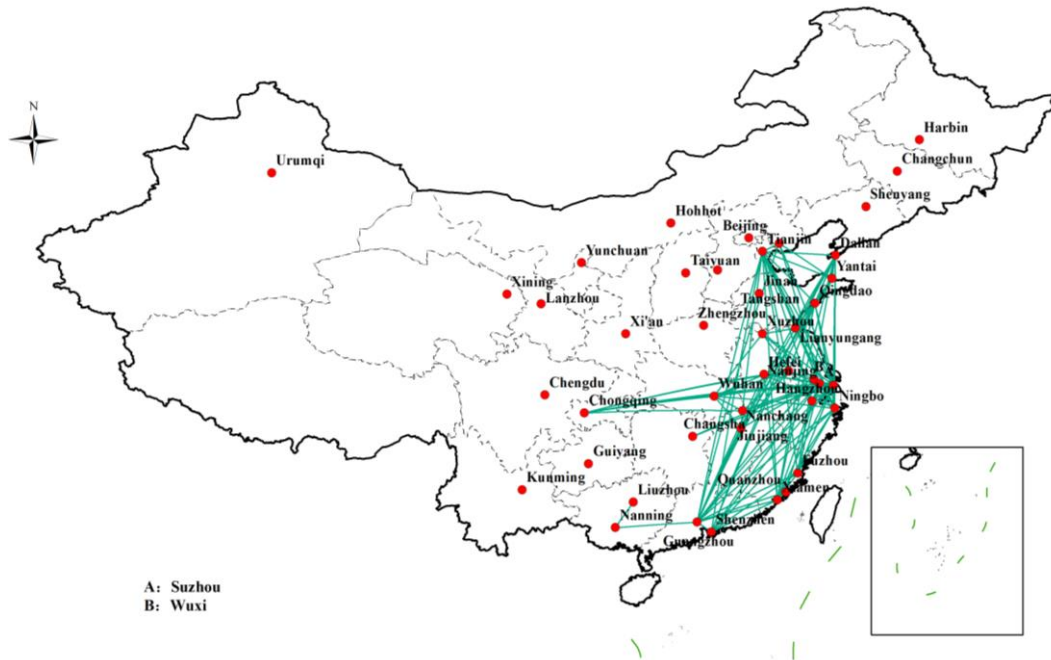


Figure 6. Topological map of the water transportation network.

4. Evaluation Indicators

Given the complexity and diversity of evaluation factors, the impact of different evaluation indicators on the evaluation results is also different; therefore, the reasonable selection and use of evaluation indicators are crucial for obtaining scientific evaluation results. Considering the advantages and disadvantages of different evaluation indicators, based on references [25,27], this study selected six classic evaluation indicators from global

and local perspectives, including closeness centrality, degree centrality, network constraint coefficient, betweenness centrality, clustering coefficient, and eigenvector centrality. The following are the six evaluation indicators:

(1) Degree centrality

The centrality indicator degree centrality (DC_i) measures the node's influence, which is an essential parameter for studying the topology of complex networks. The number of the connection of individual node i is denoted as d_i , that is, the number of links connected between node i and other nodes within the entire network. The maximum number of possible connections within the entire network is $n - 1$. The degree centrality indicates the ratio of d_i to $n - 1$, as shown in Equation (2) [19,33].

$$DC_i = \frac{d_i}{n - 1}, \tag{2}$$

where n is the number of nodes in the network. Generally, a node with a higher DC_i is directly connected to more nodes, thus occupying a more important position within the network.

(2) Betweenness centrality (BC_i)

BC_i is the number of the shortest paths between the node and node d passing through an intermediate node i [13]. BC_i can be obtained from Equation (3):

$$BC_i = \frac{2}{n^2 - 3n + 2} \sum_{s < d} \frac{g_{sd(i)}}{g_{sd}}, \tag{3}$$

where g_{sd} denotes the total number of shortest paths between node s and node d , and $g_{sd(i)}$ indicates the number of shortest paths between node s and d passing through node i . The higher the BC_i is, the more important vertex i is.

(3) Closeness centrality (CC_i)

CC_i represents the reciprocal of the average distances of the shortest path between node i and all other nodes [33,35], which is defined as follows:

$$CC_i = \frac{n - 1}{\sum_{j=1}^n d_{ij}}, \tag{4}$$

where d_{ij} is the minimum distance between node i and node j . The closer node i is to the network center, the greater CC_i becomes.

(4) Eigenvector centrality (EC_i)

EC_i indicates the linear relationship between the centrality indicator of vertex i and the centrality metrics of the neighboring nodes [33], which is defined as follows:

$$EC_i = \frac{1}{\theta} \sum_{j=1}^n a_{ij} EC_j, \tag{5}$$

where proportionality constant θ is the maximum eigenvalue of the n th-order adjacent matrix $A = (a_{ij})$. $EC_j = [EC_1 EC_2 EC_3 \cdots EC_n]^T$ denotes the center vector of all vertices. The larger EC_i is, the more import node i is.

(5) Clustering coefficient (CLC_i)

CLC_i reflects the tendency of node i to form clusters with its neighboring nodes, as shown in Equation (6). In general, only nodes with relatively low clustering coefficient values can become structural hole nodes [25].

$$CLC_i = \frac{2e(i)}{d_i[d_i - 1]}, \tag{6}$$

where $e(i)$ denotes the links number from node i to its neighboring nodes. d_i is the degree of node i .

(6) Network constraint coefficient (RC_i)

Burt put forward structural hole theory in 1992. The network constraint coefficient is an indicator used by Burt to reflect the number of structural holes and the extent of their impact on the information flow [36]. RC_{ij} is defined as the influence of an individual node:

$$RC_{ij} = \left(P_{ij} + \sum_q P_{iq}P_{qj} \right)^2, \tag{7}$$

where q indicates the common adjacent node between node i and $j, q \neq i, j$. The proportional strength of node j out of all the connections to node i is denoted as P_{ij} . The sum of the proportions of indirect connections between node i and j is $\sum_q P_{iq}P_{qj}$. The network constraint coefficient RC_i is defined as follows:

$$RC_i = \sum_j RC_{ij}. \tag{8}$$

The higher RC_i is, the greater the probability that node i will become the central node.

5. The Integrated Evaluation Method

The TOPSIS is a multi-attribute decision-making approach employed by many scholars. However, it has some limitations. One limitation is that the accuracy of Euclidean distances is affected by the correlation between indicators. Another limitation is that it cannot accurately reflect the similarity of data curves. The GRA approach can not only capture non-linear relationships between sequences but also determine the level of closeness between system indicators. Therefore, the simplicity of the calculation of the TOPSIS approach and the similarity of the GRA approach were integrated into the multi-attribute decision approach. Moreover, the experience and knowledge of decision makers are seldom considered in the applications of the TOPSIS approach. Given these, this paper introduces Criteria Importance through the Intercriteria Correlation (CRITIC) objective weighting method into the combination of the TOPSIS and GRA. Then, this approach was combined with the indicators to assess the candidate consolidation centers of the integrated transportation network. The specific evaluation process is shown below.

Step 1: Construction of indicator matrix

It is assumed that m indicators are employed to assess the importance of n nodes in the integrated transportation network. $x_{ij}(i = 1, 2, \dots, n; j = 1, 2, \dots, m)$ is the indicator value of each node. Here, i and j indicate the i -th node and j -th indicator separately, and the initial indicator matrix $U = (x_{ij})_{n \times m}$ is shown in Equation (9):

$$U = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix}. \tag{9}$$

Step 2: Construction of normalized indicator matrix

Due to the presence of the evaluation indicators with different scales, the dimensionless indicator matrix $F'_{ij} = (x'_{ij})_{n \times m}$ is obtain by normalization.

$$F'_{ij} = \begin{bmatrix} x'_{11} & x'_{12} & \dots & x'_{1m} \\ x'_{21} & x'_{22} & \dots & x'_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x'_{n1} & x'_{n2} & \dots & x'_{nm} \end{bmatrix} (i = 1, 2, \dots, n; j = 1, 2, \dots, m), \tag{10}$$

where

$$x'_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}} (i = 1, 2, \dots, n; j = 1, 2, \dots, m). \tag{11}$$

Step 3: Construction of indicator weight

To avoid the influence of individual preferences of evaluators on indicator weights, the CRITIC method proposed in [37] was employed in this study, and the concrete process is shown below.

- (1) Calculate the difference between evaluation indicators

The difference between evaluation indicators was calculated based on the normalized matrix constructed according to Equation (10). The CRITIC method uses the standard deviation to estimate the differential fluctuation between indicators i and j , as shown in Equation (12):

$$\begin{cases} \bar{x}_j = \frac{1}{n} \sum_{i=1}^n x'_{ij}, \\ S_j = \sqrt{\frac{\sum_{i=1}^n (x'_{ij} - \bar{x}_j)^2}{n - 1}} \end{cases} \tag{12}$$

where \bar{x}_j denotes the average value of indicator j (column) and S_j represents the standard deviation of indicator j . When the standard deviation between j and i is larger, it means that the information contained by indicator j is larger, which indicates that the evaluation intensity of indicator j is higher. Therefore, it is necessary to assign greater weight to indicator j . If the reverse is true, it is necessary to assign a smaller weight to indicator j .

- (2) Calculate the conflict between evaluation indicators

Similarly, the conflict between evaluation indicators was calculated based on the normalized matrix constructed according to Equation (10). The CRITIC method applies the correlation coefficient to estimate the conflict between indicator i and j . The stronger the correlation is, the smaller the conflict is, indicating that there is more identical information between indicators. Correspondingly, the evaluation intensity of indicator j is weakened to some extent, and therefore, less corresponding weight is assigned to indicator j . If the reverse is true, more weight is given. The equation for calculating the conflict R_j between indicator j and other indicators is shown in Equations (13) and (14):

$$r_{jk} = \frac{\sum_{i=1}^n (x'_{ij} - \bar{x}_j)(x'_{ik} - \bar{x}_k)}{\sqrt{\sum_{i=1}^n (x'_{ij} - \bar{x}_j)^2 \sum_{i=1}^n (x'_{ik} - \bar{x}_k)^2}}, (i = 1, 2, \dots, n; j, k = 1, 2, \dots, m), \tag{13}$$

$$R_j = \sum_{k=1}^m (1 - r_{jk}), \tag{14}$$

where r_{jk} denotes the correlation coefficient of indicator j and k . \bar{x}_k indicates the average value of indicator k .

- (3) Calculate comprehensive information volume

The difference and conflict between indicators were calculated using Equations (12)–(14), and the information volume contained in the indicators was calculated using Equation (15) according to the difference and conflict.

$$I_j = S_j \sum_{i=1}^n (1 - r_{jk}) = S_j \times R_j. \tag{15}$$

Generally, the larger I_j is, the more the information contained in indicator j , and the more important it is. In such cases, more weight should be assigned to the indicator. If the reverse is true, less weight should be assigned to the indicator.

(4) Determine objective weight

The CRITIC was employed to determine the objective weight of the indicators in accordance with the comprehensive information on the differences and conflicts. Therefore, according to Equation (16), the indicator information volume contained in the j -th indicator is calculated to determine the corresponding weight W_j , and the equation of calculation is shown below:

$$W_j = \frac{I_j}{\sum_{j=1}^m I_j}, \tag{16}$$

where W_j is the weight of the indicator j .

Step 4: Calculate the weighted normalization matrix

To effectively evaluate the influence of each indicator on the evaluation result, the normalized matrix constructed using Equation (10) and the weight of each indicator obtained from Equation (16) can be multiplied to obtain the weighted normalized matrix Z , as shown in Equation (17):

$$H = (h_{ij})_{n \times m} = F'_{ij} \times W_j, \tag{17}$$

where z_{ij} represents the indicator value of the weighted normalized matrix, and F'_{ij} indicates the dimensionless matrix.

Step 5: Determine the ideal solutions

According to the weighted normalization matrix, the maximum and minimum of the various indicators are determined as the positive ideal solutions and the negative ideal solutions, H^+ and H^- , respectively.

$$H^+ = (h_1^+, h_2^+, \dots, h_m^+) = \max(h_{ij}, 1 \leq i \leq n; 1 \leq j \leq m), \tag{18}$$

$$H^- = (h_1^-, h_2^-, \dots, h_m^-) = \min(h_{ij}, 1 \leq i \leq n; 1 \leq j \leq m). \tag{19}$$

Step 6: Calculate the Euclidean distance

The weighted normalized matrix H was computed from Equation (17), and the positive ideal solution sets were obtained from Equation (18) and the negative ideal solution sets were obtained from Equation (19). Then, D_i^+ is labeled as the Euclidean distance of indicator j from the positive ideal solution, as shown in Equation (20). D_i^- is labeled as the Euclidean distance of indicator j from the negative ideal solution, as shown in Equation (21).

$$D_i^+ = \sqrt{\sum_{j=1}^m (h_{ij} - h_j^+)^2}, (i = 1, 2, \dots, n), \tag{20}$$

$$D_i^- = \sqrt{\sum_{j=1}^m (h_{ij} - h_j^-)^2}, (i = 1, 2, \dots, n). \tag{21}$$

Step 7: Grey Relational Analysis (GRA)

(1) Calculate grey relational coefficient

The grey relational coefficient is computed based on the weighted normalized matrix established by Equation (17). γ_{ij}^+ is expressed as the correlation coefficient between indicator j and the positive ideal sequence and γ_{ij}^- is expressed as the correlation coefficient between indicator j and the negative ideal sequence. The calculation equations are shown in Equations (22) and (23).

$$\gamma_{ij}^+ = \frac{\min_i \min_j |h_{ij} - h_i^+| + \rho \max_i \max_j |h_{ij} - h_i^+|}{|h_{ij} - h_i^+| + \rho \max_i \max_j |h_{ij} - h_i^+|}, \tag{22}$$

$$\gamma_{ij}^- = \frac{\min_i \min_j |h_{ij} - h_j^-| + \rho \max_i \max_j |h_{ij} - h_j^-|}{|h_{ij} - h_j^-| + \rho \max_i \max_j |h_{ij} - h_j^-|}, \tag{23}$$

where ρ is the resolution coefficient that controls the degree of discrimination of the grey relational coefficient, and the value of ρ ranges from 0 to 1. The smaller ρ is, the greater the degree of discrimination is. The greater ρ is, the smaller the degree of discrimination is. The value of ρ was set as 0.5 in this study.

(2) Calculate grey relational degree

According to the grey relational coefficient, B_i^+ is the grey relational degree between indicator j and the positive ideal solution, while B_i^- is the grey relational degree between indicator j and the negative ideal solution, which are expressed as Equations (24) and (25).

$$B_i^+ = \frac{1}{m} \sum_{j=1}^m \gamma_{ij}^+ (i = 1, 2, \dots, n; j = 1, 2, \dots, m), \tag{24}$$

$$B_i^- = \frac{1}{m} \sum_{j=1}^m \gamma_{ij}^- (i = 1, 2, \dots, n; j = 1, 2, \dots, m). \tag{25}$$

Step 8: Dimensionless processing of D_i^+, D_i^- and B_i^+, B_i^-

d_i^+, d_i^- and a_i^+, a_i^- are dimensionless values, and their specific calculations are shown in Equations (26)–(29).

$$d_i^+ = \frac{D_i^+}{\max D_i^+} (i = 1, 2, \dots, n), \tag{26}$$

$$d_i^- = \frac{D_i^-}{\max D_i^-} (i = 1, 2, \dots, n), \tag{27}$$

$$a_i^+ = \frac{B_i^+}{\max B_i^+} (i = 1, 2, \dots, n), \tag{28}$$

$$a_i^- = \frac{B_i^-}{\max B_i^-} (i = 1, 2, \dots, n). \tag{29}$$

Step 9: Calculate the close degree

R_i^+ and R_i^- were set as the proximity of the node i to the positive ideal solution and the negative ideal solution, respectively. Hence, the proximity of the node to the ideal solution was calculated in accordance with the dimensionless grey relational degree and dimensionless Euclidean distance. The calculation equations are shown in Equations (30) and (31):

$$R_i^+ = \varphi_1 a_i^+ + \varphi_2 d_i^-, \tag{30}$$

$$R_i^- = \varphi_1 a_i^- + \varphi_2 d_i^+, \tag{31}$$

where φ_1 and φ_2 are the preference coefficients, which indicate the degree of preference of the decision maker. Generally, $\varphi_1 + \varphi_2 = 1$ and the values of φ_1 and φ_2 are usually both 0.5.

Based on the above-mentioned comprehensive grey relational degree–Euclidean distance measure, the new measures obtained from Equations (30) and (31) were used to compute the relative closeness of each evaluation target. T_i represents the target’s response to both the positive and negative ideal solutions in changing situations, and the calculation equation is shown in Equation (32). Finally, the targets were sorted based on the closeness value.

$$T_i = \frac{R_i^+}{R_i^+ + R_i^-} (i = 1, 2, \dots, n). \tag{32}$$

The greater T_i is, the better the target’s evaluation is. Correspondingly, the smaller T_i is, the poorer the target’s evaluation is.

6. Case Study

The purpose of the BRI is to enrich the transportation network and promote connection and cooperation around the world. Based on this background, a case study of the consolidation centers of an integrated transportation network composed of railway, road, water, and air routes was conducted to evaluate the above-mentioned approach.

6.1. Scoring and Ranking of the Candidate Consolidation Centers for a Single Mode

Firstly, according to the complex network theory, the raw data of the 44 node cities of the railway transportation network was normalized using Equation (10) in Section 5 in this paper, and then the CRITIC was employed to obtain the weights of six indicators of the railway transportation network according to Step 3 in Section 5. The concrete values of each indicator were 0.1939, 0.1363, 0.2029, 0.1994, 0.1335, and 0.1339. Similar to the process described above, the weights of the six indicators for the four transportation modes were calculated and are shown in Table 2.

Table 2. Weights of indicators of railway, highway, air, and water networks.

Mode \ Weight	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient
Railway	0.1939	0.1363	0.2029	0.1994	0.1335	0.1339
Highway	0.1533	0.1979	0.1713	0.1681	0.1811	0.1283
Air	0.1746	0.1750	0.2092	0.1765	0.1489	0.1158
Water	0.1639	0.1504	0.1613	0.1771	0.1561	0.1911

Next, the weighted normalized matrix was obtained by multiplying the weights with the normalized matrix. Finally, the values of the six indicators for the 44 city nodes of the railway transportation network, including closeness centrality, eigenvector centrality, betweenness centrality, degree centrality, constraint coefficient, and clustering coefficient, were determined through the application of the combination of GRA and the TOPSIS. The concrete rankings are also shown in Table A6.

Similarly, the scores of the six indicators for the candidate consolidation centers of the highway, water, and air networks are also shown in Appendix B Tables A7–A9. Tables A6–A9 show the indicator values, scores, and rankings of the six indicators for each candidate consolidation center in the railway transportation network, highway transportation network, air transportation network, and water transportation network, respectively.

6.2. Evaluation of the Single Transportation Mode Networks

To reflect the changes between the integrated transportation network and the single transportation mode networks, the candidate consolidation centers of the single transportation mode network were first evaluated and analyzed.

It can be seen from the overall rankings of the railway transportation network from Table A6 that more connections among the candidate consolidation centers resulted in higher rankings, which is in line with the clustering effect of complex network theory. These cities are important nodes in the Chinese domestic railway transportation network, which plays an important role in railway cargo transportation. In addition, China Railway Express (CR Express) mainly passes through ports such as Manzhouli, Erenhot, and Alashankou to reach Europe. However, from the perspective of geographical area, only Shenyang in Northeast China is in the top 50% and Manzhouli has not played its corresponding role as a port of CR Express due to distance reasons. Correspondingly, Urumqi and Xi’an are ranked high in Northwest China, indicating that the northwest land ports are regarded as the important outbound ports by the cities that are serviced by CR Express in China. Chengdu was one of the earliest cities in China to be serviced by CR Express, and it is

also an important source of cargo consolidation centers. There are three cities in central China, Zhengzhou, Changsha, and Nanchang, which show the importance of the city's geographical location. Currently, these cities have been the important Chinese starting points of CR Express. However, Beijing is not in the top 50%, because its main task is passenger transportation as the capital of China, despite its well-developed rail network.

The corresponding rankings of the candidate consolidation centers of the air transportation network are displayed in Table A7. The relevant indicator values for Suzhou, Dongguan, and Jiujiang were set to 0 due to them not having airports operating in air transportation. Similar to the railway transportation network, the more connections there are among node cities, the higher the rankings are. According to the geographical distribution of these cities, one can see that no cities were selected in the northwest region. The reasons are the vast territory, sparse population, backward economic development, or low industrial concentration. In addition, there are a few exceptions. Shanghai and Xi'an are not in the top 50%, although there are more routes among node cities. The reason is that these cities are affected by the direct routes, and the values of structural holes of these direct routes and other indicators are relatively low, resulting in their low ranking.

Table A8 shows the corresponding rankings of the candidate consolidation centers of the highway transportation network. Based on the geographical distribution of these cities, the cities in Northeast China are all in the bottom 50%. The reason is that there are fewer national highway connections between cities in the northeast and cities in other regions. Additionally, the relevant indicator values for Dongguan were set to 0 because Dongguan is not connected by the national highway. However, Beijing is at the forefront of the ranking in the highway network because, as the capital of China, the highway network is centered around Beijing.

Due to the particularity of water transportation, the relevant indicator values for cities with no water transportation modes passing through were set to 0. Meanwhile, Harbin is an inland river transportation city with a relatively small freight volume, mainly connecting some ports in Russia and not directly connected with other Chinese domestic node cities. Therefore, the relevant indicator value for Harbin was also set to 0. Therefore, there were 27 node cities in the water transportation network. As shown in Table A9, the rankings of the 27 candidate consolidation centers were determined based on the indicator values. It can be seen from the ranking that there were no node cities in Northwest China and Northeast China due to the lack of water transportation. Correspondingly, most of the selected node cities are mainly located in the coastal areas and some selected cities are located in the Yangtze River basin. The node cities in coastal areas were relatively high in the overall ranking of the water transportation network.

6.3. Comprehensive Evaluation of the Integrated Transportation Network

This study evaluated and ranked the candidate consolidation centers in an integrated transportation network under the BRI. This ranking can supply a reference for optimizing the layout of these centers to some extent, thereby enhancing the efficiency of freight services in China. We assessed the overall conditions of various transportation modes in each node city following the evaluation obtained for each mode individually. A comprehensive evaluation was conducted on the transportation modes passing through the candidate consolidation centers to obtain the ranking of these cities under the BRI.

Given that freight volume is an important indicator of transportation business and industry linkage, this study referred to references [11] and [27] and the proportion of freight volume of different transportation modes to the total freight volume in 2022 published by the Chinese government as the weight of each transportation mode [38]. After calculation, the proportions of railway, highway, water, and air freight volumes to total freight volume were 0.097419, 0.733509, 0.168952, and 0.000120, respectively. The comprehensive score of each node city can be obtained based on these weights. Consequently, the comprehensive

score (C_s) of each node city of the integrated transportation network was calculated using Equation (33).

$$C_s = 0.097419x_r + 0.733509x_h + 0.168952x_w + 0.000120x_a, \tag{33}$$

where x_r, x_h, x_w , and x_a represent the comprehensive score for each city in the highway, railway, water, and air transportation networks, respectively.

In summary, 44 candidate consolidation centers were comprehensively evaluated based on each transportation mode within the integrated transportation network under the BRI with the freight volumes serving as the weights. The final comprehensive scores and rankings of the 44 node cities are displayed in Table 3.

Table 3. Comprehensive score and ranking of each node city.

Number	City	x_r	x_a	x_h	x_w	C_s	Ranking
1	Chongqing	0.468878	0.504407	0.551215	0.515338	0.537127	2
2	Wuhan	0.483948	0.507661	0.563992	0.500424	0.545447	1
3	Zhengzhou	0.495845	0.50155	0.480866	0	0.401084	34
4	Suzhou	0.481240	0	0.427225	0.532996	0.450306	24
5	Guangzhou	0.500474	0.498788	0.510489	0.547004	0.515681	5
6	Xi'an	0.506751	0.494832	0.571843	0	0.468879	19
7	Hefei	0.47762	0.48491	0.496015	0.505258	0.495783	9
8	Shenyang	0.480288	0.500712	0.475598	0	0.395705	37
9	Ningbo	0.483715	0.482786	0.455729	0.527235	0.470540	18
10	Changsha	0.504486	0.513417	0.434066	0.511659	0.454045	23
11	Lianyungang	0.454819	0.457044	0.500935	0.505318	0.497178	8
12	Urumqi	0.507032	0.489342	0.437345	0	0.370250	44
13	Harbin	0.454941	0.504578	0.477364	0	0.394531	38
14	Lanzhou	0.475377	0.497409	0.515617	0	0.424580	32
15	Qingdao	0.499621	0.525641	0.454680	0.538485	0.473226	16
16	Kunming	0.478006	0.508767	0.530426	0	0.435700	28
17	Xiamen	0.466563	0.490206	0.430196	0.524528	0.449684	25
18	Changchun	0.457503	0.489678	0.464427	0	0.385290	41
19	Nanchang	0.503	0.511331	0.464533	0.522685	0.478111	15
20	Dalian	0.458258	0.520965	0.493271	0.518903	0.494194	10
21	Dongguan	0.450085	0	0.416530	0.509409	0.435441	29
22	Nanjing	0.492756	0.505921	0.483643	0.529569	0.492293	11
23	Xining	0.45753	0.482772	0.477001	0	0.394515	39
24	Tianjin	0.495618	0.499631	0.542425	0.537336	0.537000	3
25	Taiyuan	0.476714	0.497693	0.472072	0	0.392770	40
26	Shenzhen	0.484054	0.512061	0.449829	0.524569	0.465798	20
27	Jinan	0.48326	0.48285	0.478785	0	0.398330	36
28	Shanghai	0.493701	0.49673	0.518560	0.542556	0.520190	4
29	Tangshan	0.455568	0.45325	0.487910	0.504278	0.487521	12
30	Shijiazhuang	0.458857	0.485398	0.449369	0	0.374376	43
31	Chengdu	0.509849	0.499575	0.524607	0	0.434533	30
32	Yinchuan	0.432786	0.485644	0.485985	0	0.398694	35
33	Nanning	0.481669	0.494052	0.493179	0.446181	0.484117	14
34	Hohhot	0.470704	0.485132	0.453534	0	0.378585	42
35	Hangzhou	0.466891	0.50555	0.507410	0.514296	0.504626	7
36	Fuzhou	0.42889	0.499014	0.453631	0.524839	0.463257	21
37	Guiyang	0.472797	0.504032	0.522408	0	0.429311	31
38	Beijing	0.471305	0.520587	0.504772	0	0.416231	33
39	Xuzhou	0.452254	0.456481	0.452537	0.487505	0.458418	22
40	Quanzhou	0.427987	0.476879	0.430582	0.510794	0.443887	27
41	Jiujiang	0.458679	0	0.484654	0.507533	0.485931	13
42	Yantai	0.46756	0.492713	0.511687	0.510318	0.507155	6
43	Liuzhou	0.46174	0.473039	0.480385	0.447931	0.473085	17
44	Wuxi	0.440172	0.455676	0.437343	0.482609	0.445269	26

Based on the spatial layout and government policies under the BRI, with reference to [11], five attributes were employed to analyze the selection of candidate consolidation centers, including service by CR Express, along inland river, along the coast, along the key railway, and the final comprehensive score. Finally, the ten major cities, including Wuhan, Chongqing, Tianjin, Shanghai, Guangzhou, Yantai, Hangzhou, Lianyungang, Hefei, and Dalian, were selected as consolidation centers of the integrated transportation network in this study. On the other hand, the straight-line distance from Yantai to Dalian is only 170 km, and Hangzhou is about 170 km away from Shanghai. Considering the related geographical factors, Shanghai was merged with Hangzhou and Yantai was merged with Dalian. Wuhan, Chongqing, Tianjin, Shanghai, Guangzhou, Lianyungang, Hefei, and Dalian were finally recommended as the consolidation centers of the integrated transportation network, and Figure 7 shows the final selection results. Additionally, one can see that the top node cities are located along the inland river or coastal areas from Table 3. Xi'an, ranked 19th, is the top-ranked inland city without water transport, which indicates that the absence of water transport weakens the competitiveness of inland cities in the integrated transportation network. In addition, by comparing the top-ranked cities in the integrated transportation network with those in the single-mode networks, it can be observed that many of the top cities in the integrated network ranking are also among the top cities in the single-mode network rankings, indicating that the cities that hold important positions in the single-mode networks continue to maintain their significant status in the integrated network as well, such as Wuhan, Chongqing, Tianjin, Shanghai, and Guangzhou. At the same time, the ranking results revealed that the competitiveness of a node city increases as it accommodates more transportation modes. Consequently, the city's cargo turnover capacity within the entire transportation network also strengthens.

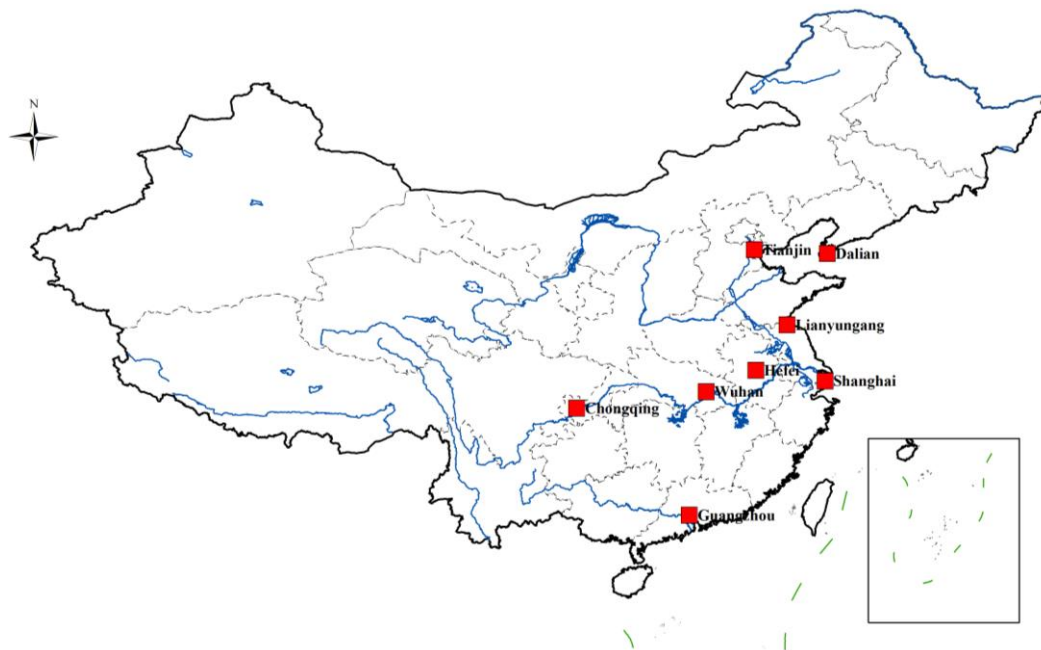


Figure 7. Topological map of location of consolidation centers.

7. Discussion

It is well known that the feasibility of results can be confirmed by the applied evaluation method. In this subsection, an evaluation was performed with the TOPSIS to validate the rationality and accuracy of the proposed GRA-TOPSIS method. Table 4 indicates the comparison results of the two different methods.

Table 4. Ranking results for different methods.

Number	City	GRA-TOPSIS		TOPSIS	
		Value	Ranking	Value	Ranking
1	Chongqing	0.537127	2	0.457012	3
2	Wuhan	0.545447	1	0.486452	1
3	Zhengzhou	0.401084	34	0.27509	37
4	Suzhou	0.450306	24	0.306019	29
5	Guangzhou	0.515681	5	0.453044	4
6	Xi'an	0.468879	19	0.428785	6
7	Hefei	0.495783	9	0.380365	11
8	Shenyang	0.395705	37	0.303452	30
9	Ningbo	0.47054	18	0.320886	24
10	Changsha	0.454045	23	0.306945	28
11	Lianyungang	0.497178	8	0.374032	13
12	Urumqi	0.37025	44	0.23912	42
13	Harbin	0.394531	38	0.32307	22
14	Lanzhou	0.42458	32	0.319028	25
15	Qingdao	0.473226	16	0.321006	23
16	Kunming	0.4357	28	0.343287	17
17	Xiamen	0.449684	25	0.284713	35
18	Changchun	0.38529	41	0.275626	36
19	Nanchang	0.478111	15	0.329265	20
20	Dalian	0.494194	10	0.40438	8
21	Dongguan	0.435441	29	0.350229	16
22	Nanjing	0.492293	11	0.356334	15
23	Xining	0.394515	39	0.319023	26
24	Tianjin	0.537	3	0.465946	2
25	Taiyuan	0.39277	40	0.252404	41
26	Shenzhen	0.465798	20	0.299306	31
27	Jinan	0.39833	36	0.290313	33
28	Shanghai	0.52019	4	0.437888	5
29	Tangshan	0.487521	12	0.386399	9
30	Shijiazhuang	0.374376	43	0.219985	44
31	Chengdu	0.434533	30	0.361857	14
32	Yinchuan	0.398694	35	0.271357	39
33	Nanning	0.484117	14	0.340074	18
34	Hohhot	0.378585	42	0.225792	43
35	Hangzhou	0.504626	7	0.381728	10
36	Fuzhou	0.463257	21	0.29892	32
37	Guiyang	0.429311	31	0.32843	21
38	Beijing	0.416231	33	0.314666	27
39	Xuzhou	0.458418	22	0.286317	34
40	Quanzhou	0.443887	27	0.274308	38
41	Jiujiang	0.485931	13	0.337719	19
42	Yantai	0.507155	6	0.419587	7
43	Liuzhou	0.473085	17	0.378515	12
44	Wuxi	0.445269	26	0.260848	40

It can be seen that Wuhan, Chongqing, Guangzhou, Tianjin, Shanghai, and Yantai were always the best candidate cities for consolidation centers in the integrated transportation network. In contrast, Zhengzhou, Urumqi, Shijiazhuang, Yinchuan, Changchun, Taiyuan, and Hohhot were all the least suitable locations for consolidation centers as indicated by the comparison of the two methods. Moreover, some cities such as Xi'an, Harbin, Lanzhou, Kunming, Xiamen, Dongguan, Xining, Shenzhen, Chengdu, and others showed significant changes when their results were compared. The reasons for the above situation are the limited transportation modes or routes, and the results could be reflected by the core ideas of these two methods. Specifically, the GRA-TOPSIS approach focuses on the distance

between alternative solutions and the connection between standards. The TOPSIS mainly considers the distance between alternative reference schemes and the best reference scheme.

Additionally, to compare the result obtained using the two methods, Kendall's tau correlation coefficient (KTC) was applied to study the difference in accuracy between the two methods [39]. The value of the calculated KTC of the two methods was 0.661734. It can be concluded that the obtained rankings have a high correlation with each other. Meanwhile, the reliability of an evaluation method was also demonstrated based on the distinction degree of the evaluation methods [40]. Accordingly, the values of the GRA-TOPSIS and TOPSIS methods were 1.075746 and 1.075126, respectively. The value of the GRA-TOPSIS was greater than that of the TOPSIS and then the reliability of the GRA-TOPSIS is relatively better than that of the TOPSIS. Tables 5 and 6 show the values of KTC and distinction degree, respectively.

Table 5. KTC of GRA-TOPSIS and TOPSIS.

Method	GRA-TOPSIS	TOPSIS
KTC	1	0.661734

Table 6. Distinction degree of GRA-TOPSIS and TOPSIS.

Method	GRA-TOPSIS	TOPSIS
Distinction degree	1.075746	1.075126

8. Conclusions

The selection of the consolidation centers in the integrated transportation network under the BRI was evaluated in this paper, with the aim to reduce freight transportation costs and improve the efficiency of logistics operations. First of all, 44 node cities were selected based on the relevant national policies. Then, the transportation networks composed of railway, air, highway, and water routes were constructed. Based on the above work, the corresponding indicators were determined according to complex network theory, and the weights of these indicators were also determined based on the CRITIC approach. Then, the TOPSIS and GRA methods were combined to calculate data on the different transportation modes of each node city. Next, the proportion of the freight volume of the different transportation modes to the total freight volume in 2022 published by the Chinese government was used as the weight of each transportation mode to calculate the comprehensive score of each node city. The results showed that there are the top-ranked node cities in the integrated transportation network are all intersections of the four transportation modes, and most of them are located in inland rivers or coastal areas, indicating that inland river and coastal shipping play an important role in cargo transportation. Additionally, it also indicates that the absence of water transportation weakens the competitiveness of inland cities. Finally, based on the comprehensive consideration, Wuhan, Chongqing, Tianjin, Shanghai, Guangzhou, Lianyungang, Hefei, and Dalian were recommended as the consolidation centers of the integrated transportation network. Moreover, the GRA-TOPSIS method was found to be better than the TOPSIS through Kendall's tau correlation coefficient and the distinction degree based on the comparison between the GRA-TOPSIS and TOPSIS methods. Additionally, this study can also provide some reference for other countries with transportation networks similar to those of China.

This paper has covered transportation modes such as rail, water, air, and highway when evaluating the consolidation center of the integrated transportation network. However, there are still some limitations that require further study. For example, more factors could be considered when choosing the candidate consolidation centers, such as industrial output value, economic scale, export scale, and the distance between cities. On the other hand, more indicators could be considered for urban population, transportation cost, the impact on urban environments, the carrying capacity of the transportation mode, and

the traffic conditions of the node cities in future research. It is hoped that this result can provide some insights for the government to outline and build consolidation centers for an integrated transportation network composed of railway, air, highway, and water routes and for enterprises to choose transportation routes.

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Appendix A

Table A1. List of national or regional logistics node cities.

No.	City	Node City	No.	City	Node City
1	Chongqing	National logistics node city	23	Xining	National logistics node city
2	Wuhan	National logistics node city	24	Tianjin	National logistics node city
3	Zhengzhou	National logistics node city	25	Taiyuan	National logistics node city
4	Suzhou	National logistics node city	26	Shenzhen	National logistics node city
5	Guangzhou	National logistics node city	27	Jinan	National logistics node city
6	Xi'an	National logistics node city	28	Shanghai	National logistics node city
7	Hefei	National logistics node city	29	Tangshan	Regional logistics node city
8	Shenyang	National logistics node city	30	Shijiazhuang	National logistics node city
9	Ningbo	National logistics node city	31	Chengdu	National logistics node city
10	Changsha	National logistics node city	32	Yinchuan	National logistics node city
11	Lianyungang	Regional logistics node city	33	Nanning	National logistics node city
12	Urumqi	National logistics node city	34	Hohhot	National logistics node city
13	Harbin	National logistics node city	35	Hangzhou	National logistics node city
14	Lanzhou	National logistics node city	36	Fuzhou	National logistics node city
15	Qingdao	National logistics node city	37	Guiyang	National logistics node city
16	Kunming	National logistics node city	38	Beijing	National logistics node city
17	Xiamen	National logistics node city	39	Xuzhou	Regional logistics node city
18	Changchun	National logistics node city	40	Quanzhou	Regional logistics node city
19	Nanchang	National logistics node city	41	Jiujiang	Regional logistics node city
20	Dalian	National logistics node city	42	Yantai	Regional logistics node city
21	Dongguan	Regional logistics node city	43	Liuzhou	Regional logistics node city
22	Nanjing	National logistics node city	44	Wuxi	Regional logistics node city

Source: China Association for Engineering Construction Standardization (<http://www.cecs.org.cn/zhxw/7729.html>, accessed on 11 February 2023).

Table A2. List of node cities of CR Express.

No.	City	Node City	No.	City	Node City
1	Chongqing	Node city of CR Express	23	Xining	Node city of CR Express
2	Wuhan	Node city of CR Express	24	Tianjin	Node city of CR Express
3	Zhengzhou	Node city of CR Express	25	Taiyuan	Node city of CR Express
4	Suzhou	Node city of CR Express	26	Shenzhen	Node city of CR Express
5	Guangzhou	Node city of CR Express	27	Jinan	Node city of CR Express
6	Xi'an	Node city of CR Express	28	Shanghai	Node city of CR Express
7	Hefei	Node city of CR Express	29	Tangshan	Node city of CR Express
8	Shenyang	Node city of CR Express	30	Shijiazhuang	Node city of CR Express
9	Ningbo	Node city of CR Express	31	Chengdu	Node city of CR Express
10	Changsha	Node city of CR Express	32	Yinchuan	Node city of CR Express
11	Lianyungang	Node city of CR Express	33	Nanning	Node city of CR Express
12	Urumqi	Node city of CR Express	34	Hohhot	Node city of CR Express
13	Harbin	Node city of CR Express	35	Hangzhou	Node city of CR Express
14	Suzhou	Node city of CR Express	36	Fuzhou	Node city of CR Express
15	Qingdao	Node city of CR Express	37	Guiyang	Node city of CR Express
16	Kunming	Node city of CR Express	38	Beijing	Node city of CR Express
17	Xiamen	Node city of CR Express	39	Xuzhou	Node city of CR Express
18	Changchun	Node city of CR Express	40	Quanzhou	Node city of CR Express
19	Nanchang	Node city of CR Express	41	Jiujiang	Node city of CR Express
20	Dalian	Node city of CR Express	42	Yantai	Node city of CR Express
21	Dongguan	Node city of CR Express	43	Liuzhou	Node city of CR Express
22	Nanjing	Node city of CR Express	44	Wuxi	Node city of CR Express

Source: 95306 China Railway (<https://ec.95306.cn/hycp/?active=0>, accessed on 7 February 2023).

Table A3. List of node cities of water transportation.

No.	City	Node Type	No.	City	Node Type
1	Chongqing	Inland river node city	15	Tianjin	Coastal node city
2	Wuhan	Inland river node city	16	Shenzhen	Coastal node city
3	Suzhou	Inland river node city	17	Shanghai	Coastal node city
4	Guangzhou	Coastal node city	18	Tangshan	Inland river node city
5	Hefei	Inland river node city	19	Nanning	Inland river node city
6	Ningbo	Coastal node city	20	Hangzhou	Coastal node city
7	Changsha	Inland river node city	21	Fuzhou	Coastal node city
8	Lianyungang	Coastal node city	22	Xuzhou	Inland river node city
9	Qingdao	Coastal node city	23	Quanzhou	Coastal node city
10	Xiamen	Coastal node city	24	Jiujiang	Inland river node city
11	Nanchang	Inland river node city	25	Yantai	Coastal node city
12	Dalian	Coastal node city	26	Liuzhou	Inland river node city
13	Dongguan	Inland river node city	27	Wuxi	Inland river node city
14	Nanjing	Inland river node city	28		

Source: Ministry of Transport of the People's Republic of China (https://xxgk.mot.gov.cn/2020/jigou/zhghs/202308/t20230825_3899151.html, accessed on 13 February 2023).

Table A4. List of node cities of air transportation.

No.	City	Node Type	No.	City	Node Type
1	Chongqing	Air node city	21	Xining	Air node city
2	Wuhan	Air node city	22	Tianjin	Air node city
3	Zhengzhou	Air node city	23	Taiyuan	Air node city
4	Guangzhou	Air node city	24	Shenzhen	Air node city
5	Xi'an	Air node city	25	Jinan	Air node city
6	Hefei	Air node city	26	Shanghai	Air node city
7	Shenyang	Air node city	27	Shijiazhuang	Air node city
8	Ningbo	Air node city	28	Chengdu	Air node city

Table A4. *Cont.*

No.	City	Node Type	No.	City	Node Type
9	Changsha	Air node city	29	Yinchuan	Air node city
10	Lianyungang	Air node city	30	Nanning	Air node city
11	Urumqi	Air node city	31	Hohhot	Air node city
12	Harbin	Air node city	32	Hangzhou	Air node city
13	Lanzhou	Air node city	33	Fuzhou	Air node city
14	Qingdao	Air node city	34	Guiyang	Air node city
15	Kunming	Air node city	35	Beijing	Air node city
16	Xiamen	Air node city	36	Xuzhou	Air node city
17	Changchun	Air node city	37	Jiujiang	Air node city
18	Nanchang	Air node city	38	Yantai	Air node city
19	Dalian	Air node city	39	Liuzhou	Air node city
20	Nanjing	Air node city	40	Wuxi	Air node city

Source: Civil Aviation Administration of China [41].

Table A5. List of provincial capitals.

No.	City	Node Type	No.	City	Node Type
1	Chongqing	Municipality	16	Xining	Provincial capital
2	Wuhan	Provincial capital	17	Tianjin	Municipality
3	Zhengzhou	Provincial capital	18	Taiyuan	Provincial capital
4	Guangzhou	Provincial capital	19	Jinan	Provincial capital
5	Xi'an	Provincial capital	20	Shanghai	Municipality
6	Hefei	Provincial capital	21	Shijiazhuang	Provincial capital
7	Shenyang	Provincial capital	22	Chengdu	Provincial capital
8	Changsha	Provincial capital	23	Yinchuan	Provincial capital
9	Urumqi	Provincial capital	24	Nanning	Provincial capital
10	Harbin	Provincial capital	25	Hohhot	Provincial capital
11	Lanzhou	Provincial capital	26	Hangzhou	Provincial capital
12	Kunming	Provincial capital	27	Fuzhou	Provincial capital
13	Changchun	Provincial capital	28	Guiyang	Provincial capital
14	Nanchang	Provincial capital	29	Beijing	Municipality
15	Nanjing	Provincial capital	30		

Source: Ministry of National Resources of the People’s Republic of China (https://www.mnr.gov.cn/zt/hd/chfxc/gcdgtl_29657/gjbtzs/201608/t20160811_2130097.html, accessed on 14 February 2023).

Appendix B

Table A6. Values of indicators of railway transportation network.

No.	City	Degree	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient	Comprehensive Score of Railway Network	Ranking
1	Chongqing	13	0.302326	0.007049	0.573333	0.138340	0.147733	0.589744	0.468878	26
2	Wuhan	17	0.395349	0.023898	0.623188	0.171448	0.128758	0.514706	0.483948	13
3	Zhengzhou	26	0.604651	0.045035	0.716667	0.247857	0.111981	0.455385	0.495845	8
4	Suzhou	16	0.372093	0.013435	0.614286	0.166533	0.131415	0.541667	0.481240	17
5	Guangzhou	24	0.558140	0.055312	0.693548	0.226815	0.112617	0.445652	0.500474	6
6	Xi'an	23	0.534884	0.018487	0.682540	0.241499	0.124304	0.561265	0.506751	3
7	Hefei	14	0.325581	0.006573	0.573333	0.152294	0.145876	0.615385	0.477620	20
8	Shenyang	15	0.348837	0.014351	0.581081	0.135663	0.151742	0.514286	0.480288	18
9	Ningbo	15	0.348837	0.013626	0.597222	0.156819	0.141121	0.590476	0.483715	14
10	Changsha	22	0.511628	0.028515	0.671875	0.220099	0.126504	0.523810	0.504486	4
11	Lianyungang	9	0.209302	0.003035	0.551282	0.099512	0.175169	0.638889	0.454819	38
12	Urumqi	26	0.604651	0.097795	0.716667	0.237736	0.108931	0.421538	0.507032	2
13	Harbin	9	0.209302	0.009000	0.537500	0.074581	0.171475	0.444444	0.454941	37
14	Lanzhou	16	0.372093	0.029593	0.614286	0.150493	0.135311	0.458333	0.475377	22
15	Qingdao	23	0.534884	0.031140	0.682540	0.224187	0.119908	0.486166	0.499621	7
16	Kunming	15	0.348837	0.011352	0.597222	0.149395	0.145318	0.571429	0.478006	19
17	Xiamen	15	0.348837	0.016713	0.605634	0.146181	0.125621	0.447619	0.466563	29
18	Changchun	10	0.232558	0.004698	0.544304	0.085074	0.199911	0.622222	0.457503	35
19	Nanchang	23	0.534884	0.031356	0.682540	0.227865	0.123532	0.513834	0.503000	5
20	Dalian	8	0.186047	0.003583	0.511905	0.065188	0.220170	0.607143	0.458258	33

Table A6. Cont.

No.	City	Degree	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient	Comprehensive Score of Railway Network	Ranking
21	Dongguan	3	0.069767	0.000000	0.472527	0.036872	0.397977	1.000000	0.450085	40
22	Nanjing	20	0.465116	0.040724	0.651515	0.184936	0.118198	0.436842	0.492756	11
23	Xining	2	0.046512	0.000000	0.430000	0.022584	0.551827	1.000000	0.457530	34
24	Tianjin	25	0.581395	0.065271	0.704918	0.215978	0.113469	0.403333	0.495618	9
25	Taiyuan	14	0.325581	0.004659	0.573333	0.150739	0.150503	0.637363	0.476714	21
26	Shenzhen	17	0.395349	0.021504	0.623188	0.169303	0.133101	0.514706	0.484054	12
27	Jinan	19	0.441860	0.032107	0.641791	0.168003	0.122759	0.438596	0.483260	15
28	Shanghai	20	0.465116	0.032380	0.651515	0.194503	0.115797	0.457895	0.493701	10
29	Tangshan	6	0.139535	0.000929	0.472527	0.045667	0.269930	0.733333	0.455568	36
30	Shijiazhuang	10	0.232558	0.001965	0.551282	0.105552	0.175782	0.666667	0.458857	31
31	Chengdu	22	0.511628	0.016248	0.671875	0.232521	0.129773	0.588745	0.509849	1
32	Yinchuan	3	0.069767	0.000143	0.462366	0.030719	0.384650	0.666667	0.432786	42
33	Nanning	15	0.348837	0.006503	0.605634	0.163758	0.154230	0.666667	0.481669	16
34	Hohhot	17	0.395349	0.044308	0.614286	0.139838	0.114371	0.345588	0.470704	25
35	Hangzhou	12	0.279070	0.011596	0.544304	0.103557	0.155106	0.439394	0.466891	28
36	Fuzhou	7	0.162791	0.005679	0.511905	0.054375	0.174249	0.238095	0.428890	43
37	Guiyang	10	0.232558	0.001753	0.524390	0.105467	0.196212	0.755556	0.472797	23
38	Beijing	15	0.348837	0.014928	0.597222	0.143288	0.133323	0.485714	0.471305	24
39	Xuzhou	8	0.186047	0.003215	0.524390	0.072299	0.194695	0.535714	0.452254	39
40	Quanzhou	5	0.116279	0.002304	0.518072	0.046195	0.260505	0.600000	0.427987	44
41	Jiujiang	5	0.116279	0.000123	0.483146	0.052814	0.289660	0.900000	0.458679	32
42	Yantai	6	0.139535	0.000154	0.500000	0.070883	0.242848	0.866667	0.467560	27
43	Liuzhou	8	0.186047	0.001409	0.524390	0.090434	0.203046	0.714286	0.461740	30
44	Wuxi	6	0.139535	0.001638	0.505882	0.049560	0.242902	0.600000	0.440172	41

Table A7. Value of indicators of air transportation network.

No.	City	Degree	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient	Comprehensive Score of Air Network	Ranking
1	Chongqing	34	0.790698	0.022157	0.808898	0.207518	0.107610	0.691622	0.504407	12
2	Wuhan	27	0.627907	0.013749	0.702062	0.167107	0.111167	0.706553	0.507661	8
3	Zhengzhou	29	0.674419	0.011407	0.729594	0.178043	0.106081	0.677340	0.501550	14
4	Suzhou	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	42
5	Guangzhou	26	0.604651	0.005700	0.689061	0.166030	0.113788	0.756923	0.498788	19
6	Xi'an	33	0.767442	0.014321	0.791687	0.201866	0.106578	0.687500	0.494832	23
7	Hefei	22	0.511628	0.003839	0.641540	0.143496	0.114765	0.761905	0.484910	32
8	Shenyang	26	0.604651	0.012175	0.689061	0.163483	0.107634	0.707692	0.500712	15
9	Ningbo	18	0.418605	0.003174	0.600150	0.118785	0.122546	0.797386	0.482786	34
10	Changsha	32	0.744186	0.025009	0.775194	0.191227	0.102516	0.645161	0.513417	4
11	Lianyungang	9	0.209302	0.001655	0.516796	0.053307	0.159907	0.555556	0.457044	38
12	Urumqi	22	0.511628	0.004388	0.641540	0.141381	0.117314	0.761905	0.489342	28
13	Harbin	28	0.651163	0.005532	0.715564	0.181860	0.112862	0.777778	0.504578	11
14	Lanzhou	26	0.604651	0.004896	0.689061	0.169007	0.111967	0.766154	0.497409	21
15	Qingdao	30	0.697674	0.023128	0.744186	0.184530	0.106520	0.694253	0.525641	1
16	Kunming	34	0.790698	0.024978	0.808898	0.207101	0.106987	0.689840	0.508767	7
17	Xiamen	24	0.558140	0.003118	0.664452	0.160177	0.116026	0.811594	0.490206	26
18	Changchun	20	0.465116	0.006532	0.620155	0.129466	0.115638	0.747368	0.489678	27
19	Nanchang	28	0.651163	0.016774	0.715564	0.171219	0.107440	0.687831	0.511331	6
20	Dalian	31	0.720930	0.024997	0.759374	0.186932	0.104769	0.666667	0.520965	2
21	Dongguan	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	42
22	Nanjing	30	0.697674	0.014936	0.744186	0.182812	0.104540	0.668966	0.505921	9
23	Xining	10	0.232558	0.000190	0.524075	0.068746	0.165443	0.911111	0.482772	35
24	Tianjin	27	0.627907	0.008963	0.702062	0.170361	0.109642	0.726496	0.499631	16
25	Taiyuan	26	0.604651	0.004522	0.689061	0.169759	0.113734	0.781538	0.497693	20
26	Shenzhen	32	0.744186	0.020495	0.775194	0.195552	0.108230	0.693548	0.512061	5
27	Jinan	21	0.488372	0.002576	0.630666	0.140005	0.118750	0.809524	0.482850	33
28	Shanghai	33	0.767442	0.014887	0.791687	0.202652	0.107103	0.696970	0.496730	22
29	Tangshan	5	0.116279	0.000215	0.471004	0.030302	0.240696	0.600000	0.453250	41
30	Shijiazhuang	21	0.488372	0.007760	0.630666	0.128840	0.113221	0.685714	0.485398	30
31	Chengdu	32	0.744186	0.011791	0.775194	0.199600	0.109484	0.721774	0.499575	17
32	Yinchuan	20	0.465116	0.002538	0.620155	0.132878	0.123724	0.826316	0.485644	29
33	Nanning	25	0.581395	0.003217	0.676533	0.166405	0.117022	0.820000	0.494052	24
34	Hohhot	21	0.488372	0.001475	0.630666	0.144287	0.122168	0.871429	0.485132	31
35	Hangzhou	30	0.697674	0.014640	0.744186	0.182050	0.105157	0.668966	0.505550	10
36	Fuzhou	19	0.441860	0.004997	0.600150	0.123659	0.124252	0.795322	0.499014	18
37	Guiyang	27	0.627907	0.004663	0.702062	0.176297	0.116645	0.800570	0.504032	13
38	Beijing	32	0.744186	0.029049	0.775194	0.188191	0.103704	0.637097	0.520587	3
39	Xuzhou	7	0.162791	0.000610	0.509716	0.042801	0.199387	0.714286	0.456481	39
40	Quanzhou	13	0.302326	0.000670	0.547196	0.089531	0.137968	0.820513	0.476879	36
41	Jiujiang	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	42
42	Yantai	21	0.488372	0.007319	0.630666	0.133342	0.117115	0.747619	0.492713	25
43	Liuzhou	4	0.093023	0.000000	0.471004	0.029524	0.299941	1.000000	0.473039	37
44	Wuxi	5	0.116279	0.000123	0.489596	0.032621	0.249509	0.800000	0.455676	40

Table A8. Values of indicators of highway transportation network.

No.	City	Degree	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient	Comprehensive Score of Highway Network	Ranking	
1	Chongqing	6	0.139535	0.058190	0.320494	0.334837	0.321927	0.466667	0.551215	3	
2	Wuhan	8	0.186047	0.130688	0.369579	0.364111	0.191493	0.178571	0.563992	2	
3	Zhengzhou	4	0.093023	0.031241	0.323018	0.186243	0.283203	0.166667	0.480866	22	
4	Suzhou	2	0.046512	0.002178	0.284884	0.044002	0.500000	0.000000	0.427225	43	
5	Guangzhou	6	0.139535	0.162912	0.366279	0.116712	0.166667	0.000000	0.510489	11	
6	Xi'an	8	0.186047	0.107286	0.341860	0.369397	0.242148	0.285714	0.571843	1	
7	Hefei	5	0.116279	0.074074	0.347655	0.212818	0.221250	0.100000	0.496015	15	
8	Shenyang	2	0.046512	0.088594	0.181519	0.000994	0.500000	0.000000	0.475598	27	
9	Ningbo	3	0.069767	0.008576	0.293023	0.082429	0.413580	0.333333	0.455729	31	
10	Changsha	2	0.046512	0.006943	0.318010	0.094605	0.500000	0.000000	0.434066	40	
11	Lianyungang	5	0.116279	0.104133	0.330833	0.106715	0.232044	0.100000	0.500935	14	
12	Urumqi	2	0.046512	0.011350	0.262970	0.046462	0.500000	0.000000	0.437345	38	
13	Harbin	1	0.023256	0.000000	0.134063	0.000040	1.000000	0.000000	0.477364	25	
14	Lanzhou	5	0.116279	0.074518	0.293023	0.074518	0.183821	0.261528	0.200000	0.515617	9
15	Qingdao	3	0.069767	0.062685	0.299440	0.042882	0.333333	0.000000	0.45468	32	
16	Kunming	6	0.139535	0.060330	0.303876	0.241649	0.267230	0.266667	0.530426	5	
17	Xiamen	3	0.069767	0.008712	0.282919	0.071386	0.333333	0.000000	0.430196	42	
18	Changchun	2	0.046512	0.045404	0.154805	0.000203	0.500000	0.000000	0.464427	30	
19	Nanchang	4	0.093023	0.015110	0.295131	0.129352	0.307726	0.166667	0.464533	29	
20	Dalian	2	0.046512	0.129568	0.217054	0.004848	0.500000	0.000000	0.493271	16	
21	Dongguan	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	44	
22	Nanjing	5	0.116279	0.055260	0.339035	0.136403	0.263600	0.200000	0.483643	21	
23	Xining	1	0.023256	0.000000	0.226648	0.036168	1.000000	0.000000	0.477001	26	
24	Tianjin	6	0.139535	0.186401	0.333522	0.072444	0.213611	0.066667	0.542425	4	
25	Taiyuan	4	0.093023	0.029904	0.323018	0.143596	0.301758	0.166667	0.472072	28	
26	Shenzhen	3	0.069767	0.040947	0.318010	0.066540	0.333333	0.000000	0.449829	36	
27	Jinan	5	0.116279	0.099076	0.339035	0.087577	0.200000	0.000000	0.478785	24	
28	Shanghai	6	0.139535	0.114235	0.356724	0.173884	0.250556	0.200000	0.51856	8	
29	Tangshan	2	0.046512	0.000000	0.282919	0.028432	0.700278	1.000000	0.48791	18	
30	Shijiazhuang	4	0.093023	0.028380	0.310782	0.096308	0.250000	0.000000	0.449369	37	
31	Chengdu	5	0.116279	0.018644	0.313155	0.304616	0.375972	0.600000	0.524607	6	
32	Yinchuan	4	0.093023	0.030564	0.308446	0.147397	0.352109	0.333333	0.485985	19	
33	Nanning	4	0.093023	0.073643	0.315564	0.128803	0.295139	0.166667	0.493179	17	
34	Hohhot	3	0.069767	0.048209	0.290945	0.052321	0.333333	0.000000	0.453534	34	
35	Hangzhou	6	0.139535	0.067050	0.320494	0.150083	0.255509	0.200000	0.50741	12	
36	Fuzhou	4	0.093023	0.030408	0.297270	0.094970	0.250000	0.000000	0.453631	33	
37	Guiyang	6	0.139535	0.041596	0.308446	0.238201	0.267230	0.266667	0.522408	7	
38	Beijing	5	0.116279	0.121983	0.341860	0.072057	0.264444	0.100000	0.504772	13	
39	Xuzhou	4	0.093023	0.034448	0.323018	0.116747	0.250000	0.000000	0.452537	35	
40	Quanzhou	3	0.069767	0.011185	0.277184	0.058074	0.333333	0.000000	0.430582	41	
41	Jiujiang	4	0.093023	0.029674	0.308446	0.174168	0.307726	0.166667	0.484654	20	
42	Yantai	3	0.069767	0.170007	0.266385	0.023646	0.333333	0.000000	0.511687	10	
43	Liuzhou	1	0.023256	0.000000	0.233087	0.047546	1.000000	0.000000	0.480385	23	
44	Wuxi	3	0.069767	0.025539	0.303876	0.049751	0.333333	0.000000	0.437343	39	

Table A9. Values of indicators of water transportation network.

No.	City	Degree	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient	Comprehensive Score of Water Network	Ranking
1	Chongqing	6	0.230769	0.001055	0.509804	0.121452	0.335575	0.866667	0.515338	13
2	Wuhan	8	0.307692	0.008615	0.530612	0.133928	0.354590	0.607143	0.500424	23
3	Zhengzhou	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
4	Suzhou	20	0.769231	0.218469	0.787879	0.320946	0.180992	0.326316	0.532996	5
5	Guangzhou	17	0.653846	0.252188	0.742857	0.297861	0.185935	0.404412	0.547004	1
6	Xi'an	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
7	Hefei	8	0.307692	0.012659	0.577778	0.179610	0.258644	0.714286	0.505258	21
8	Shenyang	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
9	Ningbo	13	0.500000	0.024375	0.650000	0.288151	0.198567	0.666667	0.527235	7
10	Changsha	2	0.076923	0.000000	0.472727	0.059531	0.548331	1.000000	0.511659	15
11	Lianyungang	9	0.346154	0.014349	0.590909	0.206743	0.227639	0.694444	0.505318	20
12	Urumqi	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
13	Harbin	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
14	Lanzhou	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
15	Qingdao	11	0.423077	0.033293	0.619048	0.232660	0.353492	0.636364	0.538485	3
16	Kunming	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
17	Xiamen	11	0.423077	0.013371	0.619048	0.247289	0.263967	0.709091	0.524528	10
18	Changchun	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
19	Nanchang	4	0.153846	0.000000	0.490566	0.074821	0.440707	1.000000	0.522685	11
20	Dalian	11	0.423077	0.011388	0.619048	0.245856	0.235484	0.727273	0.518903	12
21	Dongguan	2	0.076923	0.000000	0.448276	0.048422	0.564354	1.000000	0.509409	18
22	Nanjing	12	0.461538	0.038400	0.604651	0.226923	0.288540	0.515152	0.529569	6
23	Xining	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
24	Tianjin	15	0.576923	0.054679	0.684211	0.302066	0.213960	0.542857	0.537336	4
25	Taiyuan	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
26	Shenzhen	9	0.346154	0.001166	0.590909	0.225655	0.252924	0.916667	0.524569	9

Table A9. Cont.

No.	City	Degree	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Constraint Coefficient	Clustering Coefficient	Comprehensive Score of Water Network	Ranking
27	Jinan	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
28	Shanghai	18	0.692308	0.116558	0.742857	0.331277	0.227944	0.424837	0.542556	2
29	Tangshan	5	0.192308	0.002897	0.541667	0.126045	0.298255	0.800000	0.504278	22
30	Shijiazhuang	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
31	Chengdu	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
32	Yinchuan	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
33	Nanning	2	0.076923	0.076923	0.448276	0.027415	0.719672	0.000000	0.446181	27
34	Hohhot	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
35	Hangzhou	3	0.115385	0.000000	0.490566	0.087101	0.397655	1.000000	0.514296	14
36	Fuzhou	8	0.307692	0.000342	0.577778	0.206196	0.261719	0.964286	0.524839	8
37	Guiyang	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
38	Beijing	0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0	28
39	Xuzhou	6	0.230769	0.007238	0.520000	0.117471	0.339870	0.533333	0.487505	24
40	Quanzhou	3	0.115385	0.000000	0.520000	0.079051	0.397919	1.000000	0.510794	16
41	Jiujiang	7	0.269231	0.005593	0.530612	0.137952	0.382926	0.714286	0.507533	19
42	Yantai	6	0.230769	0.002154	0.509804	0.128808	0.305361	0.800000	0.510318	17
43	Liuzhou	1	0.038462	0.000000	0.313253	0.002502	1.000000	0.000000	0.447931	26
44	Wuxi	3	0.115385	0.002747	0.520000	0.067202	0.420811	0.666667	0.482609	25

Note: 0 means that there was no participation in the ranking.

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