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Importance rankings of nodes in the China Railway Express network under the Belt and Road Initiative

Xu Zhang\textsuperscript{a}, Wei Zhang\textsuperscript{b}, Paul Tae-Woo Lee\textsuperscript{c,*}

\textsuperscript{a}School of Traffic and Transportation Engineering, Dalian Jiaotong University, Dalian, China
\textsuperscript{b}Department of Maritime and Logistics Management, National Centre for Ports and Shipping, Australian Maritime College, University of Tasmania, Launceston, Australia
\textsuperscript{c}Ocean College, Zhejiang University, Zhoushan, China

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ABSTRACT

China Railway Express (CR express) refers to the regular container trains transporting between China and European countries under the Belt and Road Initiative (BRI). This paper aims to conduct the systematic and in-depth research on the importance ranking of logistics nodes across the complex CR express network from China’s national plan of the BRI perspective, with consideration of the connectivity between the 21st-Century Maritime Silk Road (MSR) and the Silk Road Economic Belt (SREB). In doing so, first, it sets up the complex network in the CR express transport. Second, based on the restraint coefficients in the theory of structural hole such as network scale, efficiency, grading and clustering co-efficiency, this paper applies the Multiple Attribute Decision Making (MADM) model in association with algorithm development in calculating the importance of the CR express nodes including both inland nodes and seaport nodes. The paper has three-fold contributions. In theory, it confirms the accuracy and practicability of the structural hole theory in the importance ranking of nodes in the complex network. In practice, it identifies important logistics nodes of CR express network across the BRI. Further, the findings in the paper contribute to optimising the structure of CR express transport and improving its network stability.

1. Introduction

China’s Belt and Road Initiative (BRI) jointly builds the Silk Road Economic Belt (SREB) and the 21st-Century Maritime Silk Road (MSR). The BRI is the strategic economic vision of the opening-up of and cooperation among the countries along the SREB and MSR. It has made significant influences in developing infrastructure development in tandem with the establishment of the Asian Infrastructure Investment Bank (AIIB) in 2015. The BRI creates a global infrastructure network. The China Railway Express (CR express) is the important transport framework of the SREB and facilitates the improvement of regional cooperation and the connectivity on a trans-continental scale. The CR express is a strategic link between the MSR and the SREB through the rail-sea intermodal transport in association with dry ports in China and Europe (Lee, 2018; Wei et al., 2018; Lee et al., 2018).

CR express has the ‘one-off’ feature for the entire transportation process, i.e. the one-off declaration, inspection and release. Comparing with other transport modes, the CR express with the capability of conducting the rail-sea intermodal transport has the significant advantage in the cost saving for a long-haul shipment, such as the distance is over 400 km as claimed by Tsamboulas.

* Corresponding author.
E-mail address: paultaewoo.lee@zju.edu.cn (P.T.-W. Lee).

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(2008). In addition, the rail-sea intermodal transport is characterised with the external effects such as lower pollution and noise. Therefore, rail-sea intermodal transport provides an effective way of connecting landlocked countries on the SREB with countries along the MSR, which is generally advocated by most countries in the world. Despite well-recognised significance of the rail-sea intermodal transport, most literature focused on the rail issue only without considering rail-sea intermodalism (e.g., note Álvarez-SanJaime et al., 2016; Chen et al., 2016; Jiao et al., 2014; Perl and Goetz, 2015; Shao et al., 2018; Shaw et al., 2014; Sheu and Kundu, 2018; Wang et al., 2018; Zhao et al., 2018). This is a research lacuna in the literature related to the issue of CR express, especially from the perspective of the rail-sea intermodal transport in the context of BRI. Therefore, this paper aims to fill up the research gap, by conducting a systematic and in-depth research on the importance ranking of various nodes across the complex CR express network from the infrastructure development of the BRI perspective. In doing so, first, it sets up the complex network of CR express transport. Second, based on the restraint coefficient in the theory of structural hole such as network scale, efficiency, network grade and clustering coefficient, this paper applies the Multiple Attribute Decision Making (MADM) model in association with the method of evaluating the importance of nodes on CR express network. The paper has three-fold contributions. First, from the theoretical viewpoint, it verifies that the structural hole theory can be applied accurately in the studies of node’s importance ranking in a complex network. Second, from the managerial and policy perspective, it explores the important nodes of CR express network. Finally, research results would help to optimize the structure of CR express network, improve the network stability and provide supports for implementing the strategic planning of the BRI in terms of the infrastructure development.

The remainder of the paper consists of the followings. Section 2 is concerned with a literature review on the complex theory in transport studies and evaluation of node’s importance for complex transport network. Section 3 deals with the theory and application of complex network. It sets up the topological graph of the CR express transport and discusses its characteristics of the complex network topology. In addition, it carries out the index selection and designs the algorithm on importance ranking of nodes. Section 4 conducts the empirical analysis on importance rankings for both the rail nodes and seaport nodes. The last section draws the conclusion and suggests future studies.

2. Literature review

Based on the research motivation and gap as described in Introduction, the paper reviews studies on the rail-sea container transport mainly from two aspects. They are complex theory in the transportation area and the importance of nodes in the complex theory.

2.1. Complex network theory in transportation studies

The mathematical basis of complex network research lies in the graph theory, as many complex systems can be abstracted into networks and described by networks (Farr et al., 2012). Complex networks have the significant topological features which do not occur in simple networks, such as random graphs, but in real systems in nature and society. The complex network theory is applied mostly in empirical studies for understanding various real systems and finding out the robust organising principles that governs the topology and evolution of real networks (Albert and Barabási, 2002). Studies on transport networks and their topological features can provide a good reference for planning, design and maintenance of transport networks (Chen et al., 2011; Derrible and Kennedy, 2011). With the application of complex network theory in the field of transportation, researchers apply the analytical methods for complex networks into the transport networks analysis. Existing literature confirms that complex networks exist in many transport networks, such as the rail network (Sen et al., 2003), the civil aviation network (Song and Yeo, 2017) and the urban transport network (Seaton and Hackett, 2004). Therefore, the complex network method is appropriate to be used in analysing transport networks. This research takes the multimodal transport network, precisely the rail-sea intermodal transport element in the CR express transport in this study, as the research object which does not consider the interconnection of different transport mode networks at the operational level. It extends the adaptability of the complex network analytical method in the study of the combined transport networks, considering the importance of both railway nodes and seaport nodes of the CR express network holistically. This can present the importance of seaports as important connecting nodes between inland rail transport and shipping. Based on the establishment of CR express network, this paper verifies the topological characteristics of the CR express complex network and analyses its topological structure by using the complex network analytical method.

2.2. Importance evaluation of complex transport network nodes

With the application of complex network analytical methods in transport networks, it is found that the recognition of important nodes in complex networks has the important impact on the prevention and control of attacks on transport networks, traffic congestion control, network optimisation (Lin and Ban, 2013). Based on different types of transport networks and demands, four evaluations on node importance have been studied based on: (1) centrality of nodes (Barthélémy, 2011), (2) the route-based evaluation (Stephenson and Zelen, 1989), (3) the eigenvector-based evaluation (Borgatti, 2005) and (4) location attributes of nodes (Kitsak et al., 2010; Garas et al., 2012). Among them, the evaluation method on centrality of nodes is widely used. For example, Newman (2001) takes the actual transportation network as the research object and adopts the method of node centrality to rank the importance of network nodes.

Most existing studies on importance evaluation of complex transport network nodes take one single index as the evaluation standard. However, topology characteristics are different in different types of complex transport networks. As such, evaluation with
one single index can result in large errors in evaluation results. This makes it impossible to identify accurately the importance of nodes. It also has the negative impact on further optimisation of the structure of transport networks. This paper ranks the importance of the main nodes of CR express transport network by selecting multiple indexes to fill the current research gap. In order to achieve this goal, this research set up the network topology of the CR express network and selects the indexes for evaluating the node importance based on the structural hole theory. Therefore, this paper provides a practical reference for the sound development of the CR express transport.

3. Complex network of CR express: Theory and application

3.1. Assumptions of complex network of CR express

Having recognized the research gaps in complex theory in transportation studies and importance evaluation of complex transport network nodes in the previous section, this paper has three assumptions for the model of the CR express transport network as follows.

- The CR express routes are a complex network in P-space. It assumes that a connection exists between two cities if the CR express goes across two cities (Li and Cai, 2004).
- If a city has a CR express station, the city is defined as a node.
- This paper considers the important nodes from the perspective of CR express transport in China.

3.2. Topological graph of CR express transport network

Fig. 1 shows the topological graph of the CR express transport network, covering hinterland nodes, inland nodes, seaport nodes and boundary nodes, which are planned ports stipulated in the BRI Initiative (National Development and Reform Commission (NDRC), 2015), as well as the stations adjacent to the seaports as inquired from the China Railway (12306) website (http://www.12306.cn). The graph was obtained by the software Pajek. This paper analyses the topological characteristics of the complex network of the CR express by examining the degree and its distribution, the distribution of cumulative degree, the average path length and the clustering coefficient of the network.

3.3. Topological characteristics of the CR express complex network

3.3.1. Degree, distribution of degree, distribution of cumulative degree

The degree refers to the number of a node’s adjacent nodes which connect to the node (Freeman, 1979). The degree of the CR express transport can be calculated by Eq. (1) in Section 3.4.1 (all indexes are presented in Section 3.4 to make a complete set of...
(Barabási and Albert, 1999). In practice, it means some nodes, i.e. hubs, in the CR express transport network are highly connected comparing to other nodes (Strogatz, 2001). With this property, the network is resistant to random failures due to a few hubs dominating the network’s topology. On the other side, the network is vulnerable to failures if these hubs are attacked (Albert et al., 2000). This property provides the insightful suggestions to policy makers which will be discussed in detail in Section 4.

### 3.3.2. Average path length

Table 1 shows characteristics comparison between the CR express transport network and the random network with same 124 nodes. The average path length of the CR express transport (L) is 1.88021. The value of L indicates that the separation degree between the two nodes is low. This means, on average, one transfer is needed only from one city to another in the CR express transport network.

![Fig. 2. Degree distribution of the CR express transport. Source: Drawn by the authors.](image)

![Fig. 3. Curve fitting of the CR express transport. Source: Drawn by the authors.](image)
3.3.3. Aggregation degree

The aggregation degree of the CR express transport (C) can be obtained as 0.33086. Average path length and aggregation coefficient of the CR express transport network are smaller and higher than those of the random network, respectively.

From the results and analysis shown in Table 1, it can be found that comparing the random network with the CR express network at the same 124 nodes, the average degree (K) of the CR express transport (36.60) is smaller than that of the random network (39.21). For the average path length (L) of the two networks, they are 1.88180 and 1.88021, respectively. It means that L values of two networks are almost the same. The aggregation coefficient (C) of the CR express transport network is 0.33086, which is much higher (about

| Network                          | Number of nodes | Average degree (K) | Average path length (L) | Aggregation coefficient (C) |
|----------------------------------|-----------------|--------------------|-------------------------|-----------------------------|
| Random network                  | 124             | 39.21              | 1.88180                 | 0.16001                     |
| CR express transport network     | 124             | 36.60              | 1.88021                 | 0.33086                     |

Source: Calculation by the authors.

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twice) than that of the random network (0.16001). This verifies further that the CR express transport network is a small-world network (Watts and Strogatz, 1998). In practice, it means that the CR express network possesses the attribute of clustering and transitivity with a higher C, i.e. if node A can link to node B and node B can link to node C, node A will highly likely link to node C on the condition of node A being not linked to node C directly (Strogatz, 2001). A smaller L value means that the node’s connectivity of the CR express transport network is better than it is in a random network. The former mainly covers large-and-medium-sized cities, with few connections to remote areas and feeder terminal areas.

From the discussion from Section 3.3.1 to Section 3.3.3, it verifies that the CR express transport network is a scale-free and small-world network, to which structure hole theory and its evaluation index method can be applied (Barabási and Albert, 1999).

3.4. Selection of indexes

The structural hole theory is based on the scenario that in a network, there is no direct connection between two parties, but connectable via a third party. In this case, the third party occupies a structural hole in a relationship network (De Silva and Ghrist, 2007). The structural hole in the social network has the advantage of providing the information and resources to organisations or individuals at their respective positions. Nowadays, there are few studies on the application of the structural hole theory to complex networks. It is still necessary to further study the measurement of structural hole nodes. To quantify the structure hole in terms of evaluating important nodes, betweenness centrality was firstly proposed as the index (Freeman, 1979). Then the network constraint, network size, efficiency and network hierarchy are used (Burt, 1992; 2000; 2004). Further, indexes such as PageRank (Havelliwala, 2003) and local clustering coefficient (Newman et al., 2002), are used individually for evaluation.

For selecting indexes to evaluate the node importance of a complex network, a single index is hard to capture the comprehensive topological features of the whole network; while multiple indexes may possess the correlation, which exerts influence over results in the case of evaluating results are close to each other. Further, prior to the selection of the evaluation indexes, the wide scopes of defining an ‘importance’ (Borgatti, 2005) needs to be considered. This paper defines the importance of a node from the four perspectives. They are the influence over results in forming a cluster with its adjacent nodes. After defining the scopes of the importance of a node, six evaluation indexes are adopted finally for evaluating the node importance, i.e. degree, network constraint, network grade, network scale, efficiency and clustering coefficient. Thereinto, degree, network grade and network scale are used to evaluate the connectivity of a node; efficiency is to evaluate the impact of the node to the network efficiency; network constraint is to measure the reliance of other nodes to the target node; and the clustering coefficient is to evaluate the tendency of the target node in forming a cluster with its adjacent nodes. As such, it aggregates all indexes to one single indicator by assigning different weights to different indexes to achieve the goal of ranking the node importance.

3.4.1. Degree

The degree as defined in Section 3.3.1 is written as Equation (1).

\[
k_i = \sum_{j \in G} a_{ij}
\]

(1)

In which,

- \(k_i\) is the degree of the node i.
- \(j\) represents adjacent nodes of node i.
- \(G\) is set of adjacent nodes of node i.
- \(a_{ij}\) represents the connectable attribute between the node i and the node j, \(a_{ij} = 0\) or 1.

The degree can reflect the direct effect of one node on other nodes. In general, a higher numerical value of the degree means the node is more important and influential in the network.

3.4.2. Network constraint

Network constraint evaluates the reliance of one node on other nodes. If the network constraint is higher, the connecting effect reflecting the extend of such reliance is higher. Meanwhile, with a stronger reliance, the structural hole of the node is smaller, and the node has a higher probability to become the central node (Burt, 2001). The network constraint \(C_q\) is expressed as below.

\[
C_q = \left(P_j + \sum_{q \neq i, j} P_{iq}P_{qj}\right)^2
\]

(2)

In which,

- \(P_j\) represents the proportion of node i’s resources used directly in connecting j.
- \(\sum_{q \neq i, j} P_{iq}P_{qj}\) represents the proportion of node i’s resources used indirectly in connecting j. The node q is the shared adjacent node of nodes i and j, \(q \neq i, j\).

The total network constraint of node i is as Equation (3).
\[ C_i = \sum_j C_{ij} \]  

(3)

3.4.3. Network grade

Network grade denotes the concentration degree of a node’s restriction. If the grade is higher, a node’s restriction is more concentrating within the scope of the node (Zhang and Chen, 2017). The calculation of network grade is as below.

\[ H_i = \frac{\sum_j \left( \frac{C_{ij}}{n} \right) \ln \left( \frac{C_{ij}}{n} \right)}{n \ln n} \]  

(4)

In which,

- \( n \) represents the number of all nodes.

3.4.4. Network scale

Network scale indicates the overall influence of nodes. It measures the node importance of a structural hole (Zhang and Chen, 2017). The equation is given below.

\[ ES_i = \sum_j \left( 1 - \sum_q P_{iq} P_{qj} \right) \]  

(5)

In which,

- \( P_{iq} \) and \( P_{qj} \) represent the proportions of node q among adjacent nodes of nodes i and j respectively.

3.4.5. Efficiency

Efficiency reflects the connectivity of a network. Normally, a node locating in the structural hole has a higher efficiency normally (Zhang and Chen, 2017). The calculation is as below.

\[ EF_i = \frac{ES_i}{n} \]  

(6)

If the network is fully connected, the efficiency is 1. If it is not connected, the efficiency is 0.

3.4.6. Clustering coefficient

Clustering coefficient reflects the tendency of a node in forming a cluster with its adjacent nodes. When a node has a small clustering coefficient, it can be the node of a structural hole (Jiang and Claramunt, 2004). The calculation of clustering coefficient \( C(i) \) is expressed as below:

\[ C(i) = \frac{2E(i)}{k(i)[k(i) - 1]} \]  

(7)

In which,

- \( E(i) \) is the number of links between adjacent nodes of node i.

3.5. Evaluation model

As discussed above, six indicators, i.e. degree, network constraint, network grade, network scale, efficiency, and clustering coefficient, are selected to evaluate the importance of nodes for the CR express transport. They are not put into evaluation one by one but into calculation all together to evaluate importance ranking of nodes of the CR express transport network. In doing so, Multiple Attribute Decision Making (MADM) model is applied to this research because it solves the decision-making problems in the selection of the optimal alternative or the ranking of multiple-attribute alternatives (Kuo et al., 2008). Two methods are commonly used in the MADM model. One method is based on the value or utility function; the other is based on the ranking of advantages (Lahdelma et al., 2000). To evaluate importance ranking of nodes of the CR express transport network, this paper adopts the second method of decision-making model with referring to Zhang and Chen (2017)’s work, i.e. based on the ranking of advantages.

From the perspective of spatial autocorrelation theory, if two objects are close to each other, the reliance between them is strong. Therefore, adjacent nodes contribute greater to the current node on the importance of nodes. Since many complex systems correlate positively with the node’s degree, the importance of the adjacency index matrix correlates positively with the value of degree in the process of the node importance evaluation. When considering the influence of a single characteristic, such as the value of degree, to the importance of the node, the node importance evaluation function for any node i is as Equation (8).

\[ I_i = a \delta_i + b^1 \sum_{j \in S^1_i} \delta_j + b^2 \sum_{j \in S^2_i} \delta_j + \cdots + b^m \sum_{j \in S^m_i} \delta_j \]  

(8)

In which,
I_i represents the importance evaluation of the node i.

a and b are two adjustable parameters, which adjust the dependency of node importance on the node attributes and adjacent nodes from the first order to the mth order respectively. 

\( \delta \) represents the attribute value of the investigated node. It can be one of the indexes mentioned in Section 3.4, such as the degree of the node or the network constraint.

Assume a total of n evaluation indexes are selected for each node and \( \delta_{ij} \) represents the jth index value of node i. Thus the importance evaluation function of node i can be written as below.

\[
I_i = AE_i
\]  

(9)

In which, A denotes the evaluation coefficient matrix, or the importance contribution matrix, of node i and its adjacent nodes of various orders to the node i. In this equation, it assumes the same contribution to the node i exists among all adjacent nodes with the same order, i.e. the evaluation coefficient is the same.

\( E_i \) represents the evaluation index matrix of the node i. It includes index values of the node i and its adjacent nodes of various orders. \( E_i \) is expressed as below.

\[
E_i = \begin{bmatrix}
\delta_{i1}^{0} & \delta_{i1}^{1} & \ldots & \delta_{i1}^{n} \\
\delta_{i2}^{0} & \delta_{i2}^{1} & \ldots & \delta_{i2}^{n} \\
\vdots & \vdots & \ddots & \vdots \\
\delta_{in}^{0} & \delta_{in}^{1} & \ldots & \delta_{in}^{n}
\end{bmatrix}
\]

(10)

\( \delta_{mk}^{n} \) represents the contribution amount of the set of adjacent nodes of the mth order belonging to node i to the importance of node i under the restriction of the n-th order index.

Suppose the weights of n evaluation indexes are written as \( W = [w_1, w_2, \ldots, w_n]^T \). In order to work out the normalised evaluation index matrix based on the normalised index value, it is assumed that the importance of any node i in the network can be expressed as \( A = [a, b, c, \ldots, b]^T \). Then \( I_i = AE_iW \), which is as Equation (11).

\[
I_i = [a, b, c, \ldots, b]^T \times \begin{bmatrix}
\delta_{i1}^{0} & \delta_{i1}^{1} & \ldots & \delta_{i1}^{n} \\
\delta_{i2}^{0} & \delta_{i2}^{1} & \ldots & \delta_{i2}^{n} \\
\vdots & \vdots & \ddots & \vdots \\
\delta_{in}^{0} & \delta_{in}^{1} & \ldots & \delta_{in}^{n}
\end{bmatrix} \times \begin{bmatrix}
w_1 \\
w_2 \\
\vdots \\
w_n
\end{bmatrix}
\]

(11)

3.6. Evaluation process of the node importance

It is crucial to investigate the degree of a node as it can reflect the node importance. This is because the degree value of a node considers the information of adjacent nodes of the mth order. This facilitates the contribution analysis of a node to a network and the importance attribute of the node location. The following part discusses the algorithm for evaluating nodes, given the network topology, the evaluation index set and the index weight matrix W.

1. Extract the node set of the node i’s adjacent nodes with various orders based on the network topological structure;
2. Calculate index values of adjacent nodes with various orders as \( \delta_{ik} = \sum_{j \in E_i} \delta_{ij} \), \( k = 1, 2, \ldots, m \). This is to work out the evaluation index matrix of node i;
3. Achieve evaluation index matrix \( E_i \) after normalising every index value in the \( E_i \);
4. Work out the ideal value and weighted coefficient of each index, i.e. \( b_j (j = 1, 2, \ldots, n) \) and \( w_j (j = 1, 2, \ldots, n) \);
5. Calculate the target value of each index by Eq. (11) and rank these values.

4. Empirical results and discussions

This part analyses the importance ranking of nodes for the CR express transport with 124 nodes in total. To some extent, degree values of nodes can reflect the importance of nodes. Considering the research scope, since the CR express is the important transport framework of SREB and the strategic link between SREB and MSR, more top inland rail nodes are presented than the top seaport nodes. Consequently, the top 10 of degree values for all inland rail nodes and top 5 of degree values for all seaport nodes in the CR express transport are selected. Then the importance of these nodes is calculated and analysed as follows.

4.1. Ranking of CR express nodes

In order to evaluate the node importance in the whole network, the degree and location information of the node is employed. As such, the mth order of adjacent node is taken as the research objective when evaluating the node importance. It also considers the contribution of the mth order of adjacent node on the node importance. m is equal to 1 in the calculation. The top 10 rail nodes are listed with detailed index calculation results shown in Table 2.
for each index value in the case of top 10 rail nodes. The importance of the target is also ranked as v1, v4, v2, v3, v5, v6, v9, v7, v10 and v8, based on the calculation results. It can be observed that the rank of the node importance correlates closely to the rank of the degree value. However, although the degree value of Minsk (v2), i.e. 88, is higher than Warsaw (v4), i.e. 86, Warsaw (v4) is more significant in the network due to the higher degree of connecting nodes of Warsaw (v4).

Based on the empirical results, nodes v1–v5 are the most important inland nodes of the whole network. As such, large and comprehensive logistics hubs and rail container hubs are suggested to locate in and around these node cities. Alashankou (v6) is an essential port for the Sino-Europe inland customs clearance. Therefore, multiple-access passages are recommended for Alashankou (v6) in order to accelerate passing speed and improve the efficiency. For nodes v7–v10, medium-sized logistics centres and container transfer rail centres are recommended based on their own freight flows.

From a bird’s eye view, the top 10 nodes locate in Russia (v1 and v10), Belarus (v2 and v3), Poland (v4), Kazakhstan (v5, v7, v8 and v9) and China (v6). They are the important nodes of CR express which are expected to bring more developmental opportunities for both China and the countries across the SREB.

Take Russia (v1 and v10) for an example. Russia locates in the interactions of many CR express lines and an important transhipment node of CR express transport. It has become the key hub of CR express entry into Europe (Wang et al., 2018). To utilise the transhipment advantage, it is suggested that Russia expands the infrastructure construction and improve the framework conditions, such as the constructions of Trans-Siberia Railway and Baikal-Amur Mainline and logistics hubs adjacent to the railways. Further, considering the low freight rate for backhaul of CR express, Russia can promote its exporting to China by developing the icefield railway and connecting to costal and offshore industrial facilities of the Arctic. This suggestion aligns with the Russia’s strategy of being the important logistics hub between Europe and Asia and being investing in the expansion of the rail infrastructure (GTAI, 2019).

Kazakhstan (v5, v7, v8 and v9) can also takes the advantage in its significant location in the CR express network. It is encouraged to continue its ambition as the logistics hub of Central Asia. To achieve this goal, it is recommended that Kazakhstan accelerates the construction of the Zhezkazgan-Beyneu railway to reduce the transit time within the country. It is also suggested to facilitate the international logistics park construction, simplify the customs clearance process and reduce the clearance time. These suggestions align with the economic policy “Bright Road” proposed by President Nazarbayev of Kazakhstan in 2014 which is complementary and mutually reinforcing with the BRI (China Keywords, 2017).

Alashankou (v6) is the largest land border portal in the Northwest of China. Its unique geographic location enables Alashankou (v6) to change from the important freight gateway to the international logistics hub. Although the logistics infrastructure has been developing recent years, the increasing freight demand via CR express requires more efficient customs clearance process and improved mechanism. This research suggests constructing the international railway between Alashankou (v6) and Aktogay (v5) till the Comprehensive Bonded Zone of Alashankou and the high-speed highway between Druzhba and Usharal. This is to facilitate the highly efficient operations of CR express. In the meanwhile, it is also necessary to set up the ‘Greenlane’ for promoting the quick customs clearance and the mechanism of the ‘7x24-hour’ customs clearance appointment. Further, the empirical result confirms the necessity of boosting the collaborative mechanism of Three Ones, i.e. one declaration, one inspection and one releasing for both the Customs and the Inspection and Quarantine. In addition, the result urges the international cooperation between two border countries in terms of the custody being mutually recognised, the mutual aid for enforcing law and information exchange. Ultimately, the CR express achieves to provide the highly-frequent-and-scheduled international freight transport service in Central Europe and Central Asia (China Development, 2015; SCI, 2017).

### 4.2. Ranking of seaport nodes

The BRI brings new development opportunities for China’s seaports, especially for ports in provinces of Guangdong, Fujian and Guangxi (NDRC, 2015). However, challenges and opportunities coexist. It has the tendency of bringing over-sized construction and overcapacity problems in the seaport construction. If the seaport development along the MSR neglects the priority issue, which may
exert negative impacts on the sustainable and competitive development of China’s maritime transport and hinder the CR express transport business. Prior to the construction planning for seaports involved in the BRI, it is necessary to evaluate the importance ranking of seaports and specify the functional orientation for each one. To achieve this goal, it primarily evaluates the importance of five seaports in China along the MSR and connecting with CR express transport based on degree values. The top 5 seaport nodes with detailed index calculation results are shown in Table 3.

The evaluation matrix $E^I$ for each index value for top 5 seaport nodes can be shown in Appendix C. The importance of the target is calculated as $I^S = [0.8417 \ 0.8786 \ 0.2440 \ 0.3328 \ 0.2848]$. The empirical results show that Beihai and Guangzhou ports (v11 and v12) with higher degree values possess the high importance. It indicates that Beihai port (v11) and Guangzhou port (v12) are the most important seaport nodes from the perspective of the rail-sea intermodal transport network. This result confirms with the BRI strategy, in which the Beihai port (v11) will be built as an important seaport to connect MSR and SREB, and Guangzhou Port (v12) will become as the strategic supporting port. Although the importance values of ports of Fuzhou (v14), Xiamen (v15) and Quanzhou (v13) are smaller, these three ports are important land-sea connection nodes for the CR express transport across the BRI.

For the Guangzhou port (v12), it has already been the node on many CR express transport routes as in Fig. 1. The empirical results suggest that Guangzhou Port (v12) should continue its development as the logistic hub in terms of connecting the MSR and SREB effectively and efficiently, since it ranks the first place regarding the importance of seaport nodes. In 2019, additional eight liner routes were put into operation in Guangzhou port (v12). Within the eight new routes, six of them are on the MSR. Of all the 217 shipping routes connecting the Guangzhou port (v12), 92 routes are on the MSR. Guangzhou port (v12) has been the hub in the Great Bay Area that connects Africa, Mediterranean and Asia. All these facts confirm the findings of Guangzhou port (v12) being the important seaport node on the CR express network from empirical demonstration (Xinhua, 2019). However, Guangzhou Port (v12) is lacking a specialised managing system for the rail-sea intermodal transport network. The current situation is that each section within the port works independently without cooperation, which makes the whole system inefficient. As such, it is necessary to comply with the BRI strategy in improving customs clearance facilities, establishing the ‘single-window’ and increasing customs clearance capability. It also needs to expand information exchanges and strengthen cooperation, such as the national transport and logistics public information platform (Lam and Yap, 2011; Lee and Lam, 2016; Gekara and Nguyen, 2020), declaration of the logistics information interconnection cooperation, and exchange of port and shipping information. This aims to form a convenient and efficient logistics information hub. Ultimately, as the top one seaport ranking in this research, Guangzhou Port (v12) can establish a comprehensive cross-boundary e-logistics business platform, integrate the basic information resources of commerce and trade, standardise e-commerce data standards and establish data centres to realise data sharing. In addition, it can provide the E-commerce customs clearance, logistics, data exchange, foreign trade coordination, business information, business credit and other integrated services and thus forming the ‘Network Silk Road’ (Lam, 2011; NDRC, 2015).

The Beihai port (v11) locates in Guangxi Province which is a strategic point that connects with the ASEAN countries in the BRI strategy. However, the rail-sea intermodal transport cannot access Beihai Port (v11) directly but transfer through Kunming. This makes the node Beihai (v11) less important than Guangzhou (v12), though its degree value is higher than Guangzhou (v12). The highest degree (61) means the total number and frequency of the CR express of Beihai Port (v11) are higher than Guangzhou port (v12). The strong rail transport supply indicates the high demand for maritime cargo. This suggests that Beihai Port (v11) shall put more efforts for promoting the maritime transport, expanding its land connection and improving the rail-sea network efficiency to possess the smooth land-water transportation channels (NDRC, 2015; Wang and Chen, 2019). The year 2019 observed Beihai launched several infrastructure projects, including the first port on Maritime Silk Road project which promoted the seaward economy and the highway construction for connecting with the Lianzhou Bay. The strategic planning for Beihai Port (2019–2035) states that Beihai port will conduct the channel expansion in Tieshan (part of Beihai port), and the expansion of the crude oil berth and the bulk cargo berth (The People’s Government of Beihai, 2019.). All these facts and strategy confirm the empirical results in terms of the Beihai port (v11) being the top seaport node on the CR express network.

Ports of Fuzhou (v14), Xiamen (v15) and Quanzhou (v13) locate in Fujian Province. They are close to each other from the geographic perspective. However, land transport routes which are connected by three seaports respectively, are quite independent of each other. These routes are characterised as small and scattered. This makes importance values of the three ports relatively lower in the empirical results. As such, these three ports are suggested not to operate independently but to participate co-ordinately in the rail-sea intermodal transport business. The possible ways for the latter include formation of the port alliance and then cooperation in the form of holding or equity on the areas of port infrastructure investment, operation management, the ‘single-window’ system and the hinterland development with countries such as Thailand, Indonesia and other ASEAN countries. In addition, it is necessary to increase

| Ports   | Node | Degree | Network constraint | Network grade | Network scale | Efficiency | Clustering coefficient |
|---------|------|--------|--------------------|---------------|---------------|------------|------------------------|
| Beihai  | v11  | 61     | 0.0269             | 0.0421        | 60.1059       | 0.9853     | 0.95                    |
| Guangzhou | v12  | 56     | 0.0201             | 0.0395        | 55.2011       | 0.9857     | 0.9636                  |
| Quanzhou| v13  | 40     | 0.0004             | 0.0075        | 39.1158       | 0.9779     | 0.9615                  |
| Fuzhou  | v14  | 40     | 0.0176             | 0.0299        | 39.1558       | 0.9789     | 0.9487                  |
| Xiamen  | v15  | 36     | 0.0159             | 0.0269        | 35.0929       | 0.9748     | 0.9571                  |

Source: Calculation by the authors.
the number of shipping routes, developing new ones to ASEAN countries, such as Indonesia and Malaysia, so that it enables Ports of Fuzhou (v14), Xiamen (v15) and Quanzhou (v13) to achieve the goal of establishing freight ‘shuttle bus’ on the MSR. In doing so, the ports can promote the mutual trade (Chhetri et al., 2020), complement each other with advantages and ultimately, improve their node importance in the network (Wang and Cullinane, 2014). These recommendations confirm that investment and trade co-operation is a major task in building the BRI (NDRC, 2015).

In conclusion, this research investigates and confirms the attributes of small-world and scale-free network of the CR express transport network in Section 3.3. This indicates that the network is vulnerable to deliberate attacks, such as natural disasters (e.g. typhoon and landslide) or human factors (e.g. war and COVID-19), on important nodes as identified in this section. This will draw the attention of policy makers for infrastructural planning in terms of optimising and improving the stability of the CR express transport network. Firstly, based on the empirical results, it is vital to strengthen the resilience and resistance of the important nodes to attacks from the perspective of infrastructure planning and construction. The network needs to be resistant to the deliberate attacks on important nodes. Secondly, the empirical results pave the way for allocating resources effectively and efficiently to the nodes in CR express transport network, such as land and capital resources. It can avoid allocating resources equally or inappropriately to each node. Thirdly, the empirical results provide the guidance and reference for improving the weak aspects of each node, such as the policy suggestions for some top land nodes and seaport nodes in this section according to the evaluation results in Tables 2 and 3.

5. Conclusion

The efficient CR express transport networks contribute to promoting and implementing the BRI, by connecting China to the countries on the SREB in association with sea transport along the MSR. This paper aims to conduct the systematic and in-depth research on the importance ranking of logistics nodes across the complex CR express network from China’s national plan of BRI perspective, with the consideration of the connectivity between the MSR and the SREB. This paper has devised the evaluation algorithm of node importance in the complex CR express transport network, which is also featured with rail-sea intermodal transport. It is carried out through adopting the analytical method of complex network and using theory of the structural hole. Six indicators are used in the evaluation index of node importance, i.e. degree, network constraint, network grade, network scale, efficiency, and clustering coefficient. From the empirical results, Moscow ranks the first in the overall node’s importance, which emphasises the significant role of Moscow in the CR express transport network. For the seaport nodes, the ports of Guangzhou and Beihai rank the top two places. This conforms with the strategic planning in the BRI strategy (NDRC, 2015). From the perspective of connecting the rail transport mode with the sea transport, it demonstrates the importance of the two ports in the CR express intermodal transport network.

This paper confirms that the coverage of the MSR can expand from coastal regions to the whole SREB through the rail-sea intermodal transport as proposed in the BRI strategy. The research employs related nodes in the provinces of China, such as Guangdong and Guangxi. The nodes behave both as the seaports of the rail-sea intermodal transport and as connecting points which link the sea transport with the inland transport for CR express trains (Cullinane and Wang, 2012). As such, the CR express intermodal transport can create more demand for the maritime transport and enhance the shipping connectivity (Pan et al., 2019). It also accumulates high-end industrial elements in the maritime domain. In addition, it promotes the transformation of the modes in both the industrial structure and the economic development in the MSR economic regions. Ultimately, it brings great opportunities to related seaports and dry ports by connecting the MSR economic region and the SREB region. China COSCO Shipping could be an enabler to augment the benefits of the intermodalism because the company is a leading liner to support the Chinese economy, having established world-wide shipping lines over the last four decades (Lee et al., 2003; Lee, 2015; Huo et al., 2018, 2019).

Types of goods and throughput of each rail-sea intermodal transport port, such as in Guangdong and Guangxi, can vary and be influenced greatly due to differences on the scheduling of trains and the stations for departure and arrivals, since these seaports are also important nodes of the CR express trains. However, it is still vague for the functional position of seaports on the rail-sea intermodal transport. The redundant planning, construction and expansion of seaports has the negative impact on the MSR economic regions. Therefore, it is necessary to conduct the importance rankings of nodes, particularly of the seaports of the MSR, in the CR express transport. By using the traffic network analysis, this research sets up the complex network and works out the significance of each node, especially the important seaports which connect the rail and sea, across the CR express transport. It also contributes to providing rationale references for the planning and development of the BRI economic regions.

In conclusion, the paper with the test results has not only confirmed the applicability of the analytical method of complex network in the transport area from a theoretical and literature viewpoint, but also provided a practical reference to develop efficient nodes in the CR express intermodal transport, referring to their importance ranking.

This paper has a limitation in evaluating the importance of sea-rail nodes, although it has followed a way to develop an algorithm. The study of the CR express transport is closely related to the corridors elaborated in the BRI strategy and continues to expand and extend in the two regions of the sea and land. Therefore, future study needs to consider the above to cope with nodal factors being changed over time and to determine important nodes instantly and accurately in complex networks.

CRediT authorship contribution statement

X. Zhang: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing - original draft. W. Zhang: Formal analysis, Methodology, Project administration, Resources, Supervision, Writing - review & editing. P.T.-W. Lee: Conceptualization, Investigation, Resources, Supervision, Writing - review &
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Appendix A. The schedule of CR express at inland ports

| No. | From (to) domestic city | Boundary crossings | To (from) overseas city | No. | From (to) domestic city | Boundary crossings | To (from) overseas city |
|-----|-------------------------|--------------------|------------------------|-----|-------------------------|--------------------|------------------------|
| 1   | Chongqing (Huоerguosi)  | Duisburg (Germany) | Hamburg (Germany)      | 16  | Changsha (Huoerguosi)   | Hamburg (Germany) | Hamburg (Germany)      |
| 2   | Manzhouli               | Cherkess (Russia)  | Lanzhou (Huoerguosi)   | 17  | Lanzhou (Huoerguosi)    | Erlianhaote (Mongolia) | Hamburg (Germany) |
| 3   | Alashankou (Huoerguosi)| Hamburg (Germany) | Beijing-Tianjin        | 18  | Changsha (Huoerguosi)   | Zhengzhou (Huoerguosi) | Hamburg (Germany) |
| 4   | Erlianhaote             | Hamburg (Germany) | 19 Lianyungang (Huoerguosi) | 19  | Alashankou (Huoerguosi) | Hamburg (Germany) | Hamburg (Germany) |
| 5   | Changsha (Huoerguosi)  | Lodz (Poland)     | Yingkou (Huoerguosi)   | 20  | Alashankou (Huoerguosi) | Zabaikalsky (Russia) | Hamburg (Germany) |
| 6   | Wuhan (Huoerguosi)     | Pardubice (Czech Republic) | 21 Kuming (Huoerguosi), Erlianhaote | 21  | Alashankou (Huoerguosi), Hamburg (Germany) | Rotterdam (Netherlands) |
| 7   | Wuhan (Huoerguosi)     | Hamburg (Germany) | 22 Wulumuqi (Huoerguosi) | 22  | Alashankou (Huoerguosi) | Almaty (Kazakhstan) | Almaty (Kazakhstan) |
| 8   | Manzhouli               | Tomsk (Russia)     | Xian (Huoerguosi)      | 23  | Xian (Huoerguosi)       | Alashankou (Huoerguosi), | Almaty (Kazakhstan) |
| 9   | Suzhou (Huoerguosi)    | Warsaw (Poland)   | Hefei (Huoerguosi)     | 24  | Hefei (Huoerguosi)      | Alashankou (Huoerguosi), | Almaty (Kazakhstan) |
| 10  | Manzhouli               | Brest (Belarus)    | 25 Xiamen (Huoerguosi), Manzhouli | 25  | Alashankou (Huoerguosi), Erlianhaote | Lodz (Poland) |
| 11  | Yiwu (Huoerguosi)      | Madrid (Spain)     | 26 Changchun (Huoerguosi) | 26  | Changchun (Huoerguosi)  | Warsaw (Poland) | Warsaw (Poland) |
| 12  | Shijiazhuang (Huoerguosi), | Minsk (Belarus)    | Nanning (Huoerguosi), Erlianhaote | 27  | Nanning (Huoerguosi), Manzhouli | Warsaw (Poland) | Warsaw (Poland) |
| 13  | Yinchuan (Huoerguosi)  | Tehran (Iran)      | 28 Boatsu (Huoerguosi), Erlianhaote | 28  | Boatsu (Huoerguosi), | Alashankou (Huoerguosi), | Almaty (Kazakhstan) |
| 14  | Yiwu (Huoerguosi)      | Tehran (Iran)      | 29 Wuwei (Huoerguosi)  | 29  | Wuwei (Huoerguosi)      | Alashankou (Huoerguosi), | Almaty (Kazakhstan) |
| 15  | Lianyungang (Huoerguosi)| Istanbul (Turkey)  | 30 Wuwei (Huoerguosi)  | 30  | Wuwei (Huoerguosi)      | Alashankou (Huoerguosi), | Almaty (Kazakhstan) |

Sources: Compiled by the authors, by referring to NDRC China (2016); China Railway (2016).

Appendix B. Evaluation matrix $E^R_i$ for each index value of top 10 CR express nodes

The evaluation matrix $E^R_i$ for each index value can be obtained as below.

$$E^R_i = \begin{bmatrix} 98 & 0.0432 & 0.0734 & 97.0722 & 0.9905 & 0.4382 \\ 88 & 0.0388 & 0.0659 & 87.1217 & 0.99 & 0.5098 \\ 86 & 0.0379 & 0.0644 & 85.1879 & 0.9906 & 0.5271 \\ 86 & 0.0398 & 0.0654 & 85.3022 & 0.9919 & 0.5271 \\ 65 & 0.0287 & 0.0487 & 64.3992 & 0.9908 & 0.7228 \\ 65 & 0.0275 & 0.0501 & 64.2506 & 0.9885 & 0.6942 \\ 65 & 0.0263 & 0.0498 & 64.1156 & 0.9864 & 0.7103 \\ 65 & 0.0289 & 0.0488 & 63.8997 & 0.9831 & 0.7103 \\ 65 & 0.0273 & 0.0499 & 64.0887 & 0.986 & 0.7103 \\ 65 & 0.0255 & 0.0485 & 64.1229 & 0.9865 & 0.7103 \end{bmatrix}$$

After the normalisation for each index, the evaluation matrix $E^R_i$ is shown as below.

$$E^R_i = \begin{bmatrix} 1 & 1 & 1 & 1 & \frac{0.8409}{0.0734} \\ 0.6970 & 0.7514 & 0.6988 & 0.7000 & 0.7841 & 0.2516 \\ 0.6364 & 0.7066 & 0.6386 & 0.6417 & 0.8523 & 0.3124 \\ 0.6364 & 0.8079 & 0.6787 & 0.6452 & 0.1 & 0.3124 \\ 0 & 0.1808 & 0.0080 & 0.0151 & 0.8750 & 1 \\ 0 & 0.1130 & 0.0643 & 0.0106 & 0.6136 & 0.8995 \\ 0 & 0.0452 & 0.0522 & 0.0065 & 0.3750 & 0.9561 \\ 0 & 0.1921 & 0.0120 & 0 & 0 & 0.9561 \\ 0 & 0.1017 & 0.0562 & 0.0057 & 0.3295 & 0.9561 \\ 0 & 0 & 0 & 0.0067 & 0.3864 & 0.9561 \end{bmatrix}$$

For the matrix $E^R_iW$, the ideal point is $W^* = (1, 1, 1, 1, 1, 1, 1)$. The weight vector of the matrix indicator is equal to the weight proportion, namely $\omega_1 = \omega_2 = \omega_3 = \omega_4 = \omega_5 = \omega_6$. The importance of the target is calculated as below.

$$I^R = \begin{bmatrix} 0.8068 & 0.6471 & 0.6303 & 0.6801 & 0.3465 & 0.2835 & 0.2392 & 0.1934 & 0.2415 & 0.2249 \end{bmatrix}$$
Appendix C. Evaluation matrix $E^F_i$ for each index value of top 5 seaport nodes

The Evaluation Matrix $E^F_i$ for each index value can be obtained as below.

$E^F_i = \begin{bmatrix}
40 & 0.0176 & 0.0299 & 39.1558 & 0.9789 & 0.9487 \\
56 & 0.0201 & 0.0395 & 55.2011 & 0.9857 & 0.9636 \\
61 & 0.0269 & 0.0421 & 60.1059 & 0.9853 & 0.9500 \\
40 & 0.0004 & 0.0075 & 39.1158 & 0.9779 & 0.9615 \\
36 & 0.0159 & 0.0269 & 35.0929 & 0.9748 & 0.9571
\end{bmatrix}$

After the normalisation for each index, the evaluation matrix $E^*_i$ is shown as below.

$E^*_i = \begin{bmatrix}
0.1600 & 0.6491 & 0.6474 & 0.1624 & 0.3761 & 0 \\
0.8000 & 0.7434 & 0.9249 & 0.8039 & 1 & 1 \\
0.1600 & 0.1608 & 0.2844 & 0.5891 & 0 & 0.5638 \\
0.5849 & 0.5607 & 0 & 0 & 0.5638 \\
1 & 1 & 1 & 0.9633 & 0.0872 \\
0.1600 & 0.6491 & 0.6474 & 0.1624 & 0.3761
\end{bmatrix}$

The importance of the target is calculated as below.

$I^F = [0.8417 \quad 0.8786 \quad 0.2440 \quad 0.3328 \quad 0.2848]$

Appendix D. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2020.07.003.

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