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Evaluation of Key Factors for the Port Logistics Development in Countries Along the Belt and Road

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Abstract The port logistics capacity of countries along the Belt and Road is of great significance to promoting Chinese overseas comprehensive supporting system. The study combines quality data with numerical data to extract the key factors affecting the port logistics development for countries along the Belt and Road. Based on grey correlation analysis and factor analysis, 17 major ports of these countries are evaluated from 11 key factors. The results show that infrastructure, transportation, and entering and leaving costs are crucial for the development of port logistics. The research provides scientific decision-making basis for the construction of an overseas comprehensive supporting system under the context of the Belt and Road Initiative.

Keywords port logistics; grey relation analysis; factor analysis; Belt and Road Initiative

1 Introduction

Following the international trade development and competition, regional economic cooperation and logistics management has become important increasingly. In 2013, the Belt and Road Initiative (BRI) was raised under the background of global economic integration, which calls for strengthening regional cooperation among countries and has attracted wide attention since proposed[1]. It integrates various production factors, and enhances the relevant connectivity between railway, highway, inland shipping and other transportation modes. In the context of the BRI, the logistics networks need to develop towards integration and flexibility to meet the new trends and requirements of economic development[2].

For realistic reasons such as land bordering and transportation costs, shipping logistics is the common and economical way of cross-border logistics transportation, where port wharfs act as cargo collecting and distributing centers, and the function of various ports is to connect trade between different regions. 80% of cargoes involved in global trade are shifted through sea

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routes[3]. The BRI strategy promotes the development of foreign economic relations and trade, which affects the cargo throughput of ports, to further affect the development of port logistics. It has triggered a lots of international logistics activities, and the port capacity of countries along the Belt and Road is of great significance to improve the construction of China's overseas comprehensive support system. But research regarding BRI, particular from port logistics management perspective, is scarce[4].

With the globalization of industry chain and the integration of global and regional economy, it is worthy to improve the logistics capacity of entering and leaving port for countries along the Belt and Road. This paper aims to explore the key factors affecting the port logistics capacity of countries along the Belt and Road. Constructive solutions and suggestions are proposed to give a development orientation for the ports, and then promote the local economic development.

The main objectives of this paper are as follows:

1) Both quantitative data and qualitative data are considered, taking the berth depth, handling equipment, transportation mode, routes, port attributes, and security as the factors.

2) Two evaluation models of key factors affecting the port logistics capacity are established by grey relation analysis (GRA) and factor analysis.

3) A case study is provided and the key influencing factors are identified.

4) Port strategy suggestions for Chinese overseas comprehensive supporting system are provided.

The remainder of the paper is organized as follows: A systematic review of related research is provided in Section 2. Section 3 introduces the evaluation model of key factors by GRA and factor analysis. Section 4 displays a case study and analysis. Data specification and preprocessing are provided, and a result comparison analysis of two methods is given. Section 5 concludes the results and suggestions for future research direction.

2 Literature Review

Theoretical and applied scientific studies on port logistics capacity evidences the necessity for the identification of key indexes and factors for its development. Previous studies can be divided to three parts: Key factors of capacity, competitiveness evaluation and analytical methods.

The port logistics capacity consists of multiple aspects, including logistics competitiveness, logistics performance, and integration level. Many researchers have studied from one or more aspects. Jiao[5] concluded that the port logistics performance is affected by 3 factors including hardware, management level, and logistics service level. 21 evaluation sub-factors of the greatest importance are summarized by questionnaire, and an integrated evaluation method is built. Zheng[6] noted that the port logistics competitiveness and integration level are embodied in the economic foundation, transportation situation and infrastructures, and the regional logistics performance. Liu, et al.[7] considered the port logistics as a system with four characteristics, hierarchy, purpose, environmental adaptability and integrity, and 22 evaluation indexes are selected according to the characteristics. Sarkar, et al.[8] identified and analyze 18 key barriers associated with port logistics in Industry 4.0 era, considering the views of stakeholders. A hierarchical model is developed by TISM to reveal the inter-dependencies among the barrier,

and sever clusters are obtained by MICMAC analysis. Liu, et al.[9] studied the application of blockchain technology in the port supply chain.

There is extensive focus on the port logistics competitiveness. Guo, et al.[10] summarized 11 sub-indexes included in 3 main indexes, operation scale, infrastructure, and economics, and calculate the competitiveness of Qinzhou port and other major ports in China. A strategy is further proposed to improve the competitiveness. Wu, et al.[11] considered the difficulties in acquiring the data of evaluation indexes, and introduce classical port logistics statistical indexes such as industry production, entering and leaving port volume, social consumption and investment cost, and transportation network density. Chan, et al.[12] selected 9 factors to analyze the factors affecting the development of port logistics, including infrastructure, collecting and distributing facilities, port management mechanism, near-port industry, informatization, macro economy, hinderland economy, hinderland industry structure, and policy. Chen, et al.[13] combined qualitative and quantitative methods and find that the key factors affecting port logistics competitiveness are capacity, cost and efficiency. Specific indexes are berth quantity of 10,000 tons and above, average leaving port time, information centrality, proportion of transshipment containers, cargo throughput, and direct hinterland railway density. Xu[14] believed that the competitiveness is not only influenced by internal port factors economic strength and infrastructure, but also affected by competitive potentials which refers to external factors such as trade potentials and informatization levels. Wu[15] built a two-level index system for principal component analysis, where fist-level indexes are operational conditions and capabilities, and second-level indexes include maximum water depth, berth quantity, annual cargo throughput, and berthing capacity. Seven ports including Chongjin port and Busan port are selected for competitiveness analysis.

Various factors have different effects on the port logistics development, and analytical methods are applied for the construction of index system. Zhao[16] reviewed the evaluation methods of urban logistics competitiveness system, including Delphi method, analytic hierarchy process (AHP), multi-level fuzzy judgment, and so on. Yang[17] analyzed the influencing factors of regional logistics competitiveness by the diamond model, and an evaluation method is established based on fuzzy comprehensive estimation. Chung[18] put forward assessment criteria of logistics cluster competitiveness by Porter's diamond model, where the weight of each criterion is obtained by AHP. A case study is provided to evaluate the logistics cluster competitiveness of Asia main countries. Yang, et al.[19] proposed a multi-criteria decision-making approach combining AHP and GRA, to analyze the competitiveness of three hub ports in Northeast Asia. 20 evaluation factors are summarized from political-economic situation, operation environment, cost situation, infrastructure facilities, and incentive environment. Liu, et al.[20] considered the vagueness in the process of evaluating the judgements in AHP and propose a new concept of fuzzy consistency of comparison matrices. Zong, et al.[21] constructed a logistics competitiveness system of cities in western China by AHP model, and modify the weight of indicators based on entropy weight method. Yazdani, et al.[22] presented a multi-attribute decision support system in the supply chain, which integrates the quality function deployment and GRA in consideration of the fuzziness among factors. Liu, et al.[23] established a triangle model of regional logistics competitiveness based on the diamond model, whose evaluation index system

is constructed based on resource supply, logistics service, and market demand. Wang, et al.[24] reviewed the port dominance evaluation methods and point out the importance of information technology development in shipping activities. Many studies employ single-faceted evaluation methods without enough factors, but they cannot evaluate real advantages of ports effectively.

At present, current research has made exploration with regard to correlation analysis and cluster analysis. Studies on ports mainly focus on transport efficiency and competitiveness, and the influencing factors considered mainly are cargo throughput, berth quantity of 10,000 tons and above, berth depth, hinterland economic level and density of transportation mode. However, the influence of security and routes of ports cannot be ignored. Since there are few studies on comprehensive evaluation for major ports in countries along the Belt and Road, the paper considers the available data and characteristics of ports, taking the berth depth, handling equipment, transportation mode, routes, port attributes, and security as factors affecting the port development. Different to extant studies, the paper combines quantitative data with qualitative data, to obtain scientific results based on plentiful real data. To avoid subjectivity of expert evaluation, GRA and factor analysis are applied to evaluate key factors about port logistics development. An in-depth analysis is provided for the affecting mechanism of different results, with a view to providing suggestions for the construction of Chinese overseas comprehensive supporting system.

3 Evaluation Model of Key Factors

3.1 Grey Relation Analysis

GRA derives from grey system theory, focusing on uncertain systems with partially available information. It explores the realistic rules by the movement of things through sequence operators according to information coverage, with competitive computing time. There are many factors about the competitiveness of port logistics, but lacking available data of some factors or their numerical relationship. The steps of GRA of the key factors for port logistics development are as follows:

1) Determine the comparison sequence and reference sequence. For each port, the sequence of key factors for port logistics is constructed based on its characteristics. In this paper, the port availability is used as the reference sequence, and other attributes are used as the comparison sequence. The reference sequence $x_0(k)$ and comparison sequence $x_i(k)$ are selected from the sequences of key factors of port logistics respectively as follows:

$$x_0(k), \quad k = 1, 2, \cdots, n, \tag{1}$$

$$x_i(k), \quad i = 1, 2, \cdots, m, \ k = 1, 2, \cdots, n. \tag{2}$$

2) Data pre-processing. The key factors involve such multi-dimensional characteristics as physical, geographical, cost, and economic attributes. There is much difference in dimension, numerical magnitude and diversity degree between them, so the original data cannot be analyzed directly by weighted calculation. The method of data pre-processing includes initial value processing and average value processing, suitable for data with stable growth trend or not

respectively. In this study, each sequence is initialized as:

$$x_i(k) = \frac{x_j(k)}{\max_j x_j(k)}, \quad j = 0, 1, \cdots, m. \tag{3}$$

3) Calculate the correlation coefficient.

$$\epsilon_i(k) = \frac{\min_i \min_k [x_0(k) - x_i(k)] + \rho \max_i \max_k [x_0(k) - x_i(k)]}{[x_0(k) - x_i(k)] + \rho \max_i \max_k [x_0(k) - x_i(k)]}, \tag{4}$$

where ρ is a constant coefficient located in $[0, 1]$. $\epsilon_i(k)$ is the correlation coefficient that indicates the correlation intensity of element k between sequence x_i and sequence x_0.

4) Calculate the correlation between sequences x_i and x_0.

$$\gamma_i = \frac{1}{N} \sum_{k=1}^{N} \epsilon_i(k). \tag{5}$$

According to the sorting of γ_i, further analysis can be conducted about the influence intensity of key factors for port logistics.

3.2 Factor Analysis

To judge the feasibility of factor analysis, a correlation analysis on the original data is conducted first to identify if there are overlaps of information among variables. Matrix method is an easy correlation analysis method to carry out, but with high subjectivity. To conduct a more objective result, Bartlett's Test of Sphericity and Kaiser-Meyer-Olkin (KMO) Test are conducted for analysis, where a test statistic is calculated and the feasibility is judged by its significance level. The statistics calculated by KMO Test are as follows:

$$\text{KMO} = \frac{\sum \sum_{i \neq j} r_{ij}^2}{\sum \sum_{i \neq j} r_{ij}^2 + \sum \sum_{i \neq j} p_{ij}^2}, \tag{6}$$

where r_{ij} represents the correlation coefficient between variables of port logistics i and j. p_{ij} represents the partial correlation coefficient with other variables. KMO represents the correlation intensity between variables, and the closer its value approaches 1, the stronger its correlation. When KMO is greater than 0.5, original variables can be selected as characteristic variables for factor analysis.

For the evaluation of the key factors for port logistics development, the steps of factor analysis are adopted as follows: 1) Extract the characteristic variables and conduct a feasibility analysis. 2) Determine the number of key factors based on the principal component analysis, where the factor loading matrix is calculated and then the number of factors is obtained according to the characteristic root or the cumulative variance contribution rate of factors. Generally, the number of factors is no more than three. 3) Since the key factors in port logistics development involve multi-dimensional characteristics, the absolute load value of a factor may be prominent in the factor loading matrix. To solve the problem, the factor loading matrix is rotated so that the absolute load values approach as close to 0 or 1 as possible. 4) The factors are named by Varimax, to describe the revealing degree of factors to the original factor variables. 5) Key factors are described based on the scores calculated by the least squares regression.

Table 1 Variable description and data source

Variables	Definition	Type	Unit	Data source
berth depth	the maximum water depth for ship berthing	character	m	National Survey Report
berth length	the overall length for ship berthing	character	km	
handling equipment condition	all equipment for handling operation	character	-	
collecting and distributing condition	transport modes for collecting and distributing	character		
route	route of port transportation line	character	-	
port attribute	personnel attribute of port	character	-	
security	comprehensive assessment of port ownership, diplomatic relations between the country with China, and piracy situation	character	-	
availability	port activity index, calculated by the number and size of vessels anchored	integer	-	
entering port time	the time of shipping standardized cargo entering port in 2015	integer	day	World Bank
leaving port time	the time of shipping standardized cargo leaving port in 2015	integer	day	
entering port cost	fees levied on cargo entering port in 20-foot containers in 2015	integer	US Dollar	
leaving port cost	fees levied on cargo leaving port in 20-foot containers in 2015	integer	US Dollar	
port traffic	20-foot equivalent units	integer	TEU	UNCTAD

4 Case Study and Analysis

In order to verify the effectiveness of the analysis method, the information of major ports in countries along the Belt and Road is collected, as well as important technical parameters, such as the port berth attributes, handling equipment attributes, geographical location and route attributes. Key influential factors of ports are extracted by GRA and factor analysis, and the evaluation results of ports are provided.

4.1 Data Specification and Pre-Processing

The data includes two parts mainly: One is the statistical data of logistics resources about transportation of major ports in countries along the Belt and Road; the other is about the time and cost of import and export in different countries provided by the World Bank. The basic information of variables in the evaluation of key factors is provided in Table 1.

Some of the above data are quality data that need to be converted into numerical data. With reference to relevant studies, the original variables are quantified and processed as shown in Table 2.

Table 2 Processing methods of original data

Variables	Processing methods
berth depth	the maximum value among port regions
berth length	the cumulative value of port regions
handling equipment condition	the total capacity of equipment (single equipment: the maximum value; equipment with unknown number: 2/3 of the maximum value)
collecting and distributing condition	the total number of transport modes
route	the total number of ports in the route
port attribute	1 for civil port, 0.5 for civilian-military port
security	the original value, or 0.5 with plus sign
availability	the original value, without processing
entering/leaving port time	the original value, without processing
entering/leaving port cost	the original value, without processing
port traffic	the original value, without processing

4.2 Evaluation Results Based on Grey Relation Analysis

The results of the correlation analysis between variables are: $\gamma_1 = 0.74$, $\gamma_2 = 0.86$, $\gamma_3 = 0.73$, $\gamma_4 = 0.76$, $\gamma_5 = 0.78$, $\gamma_6 = 0.75$, $\gamma_7 = 0.72$, $\gamma_8 = 0.73$, $\gamma_9 = 0.80$, $\gamma_{10} = 0.78$, $\gamma_{11} = 0.81$. The specific correlation is shown as Figure 1. By GRA, the influence of different factors on port availability ranks as follows: Handling equipment condition > port transportation > entering port cost > port attributes > leaving port cost > route > security > berth depth > collecting and distributing condition > leaving port time > entering port time. Among them, handling equipment condition is the main influencing factor. The capacity of the handling equipment has a direct effect on the availability of ports. For example, for COSCO-PSA Terminal (CPT) and Piraeus port, the number of shore gears and cranes is more than 45, and the availability is

more than 80. With less value of handling equipment condition, the availability of Doha port and Massawa port is less than 60. Therefore, the better handling equipment condition enables the improvement of port availability.

The handling capacity of a port is closely related to the operation time of the shipping, which determines the performance and efficiency of a port directly, and further affects the comprehensive logistics cost. With less berthing time and higher working efficiency, the total cost is reduced. Therefore, the handling capacity of ports is also an important factor for port availability. Port traffic is also vital since it reflects the efficiency of port cargo transportation, and the lower efficiency means longer ships with higher cost, which decreases the port availability.

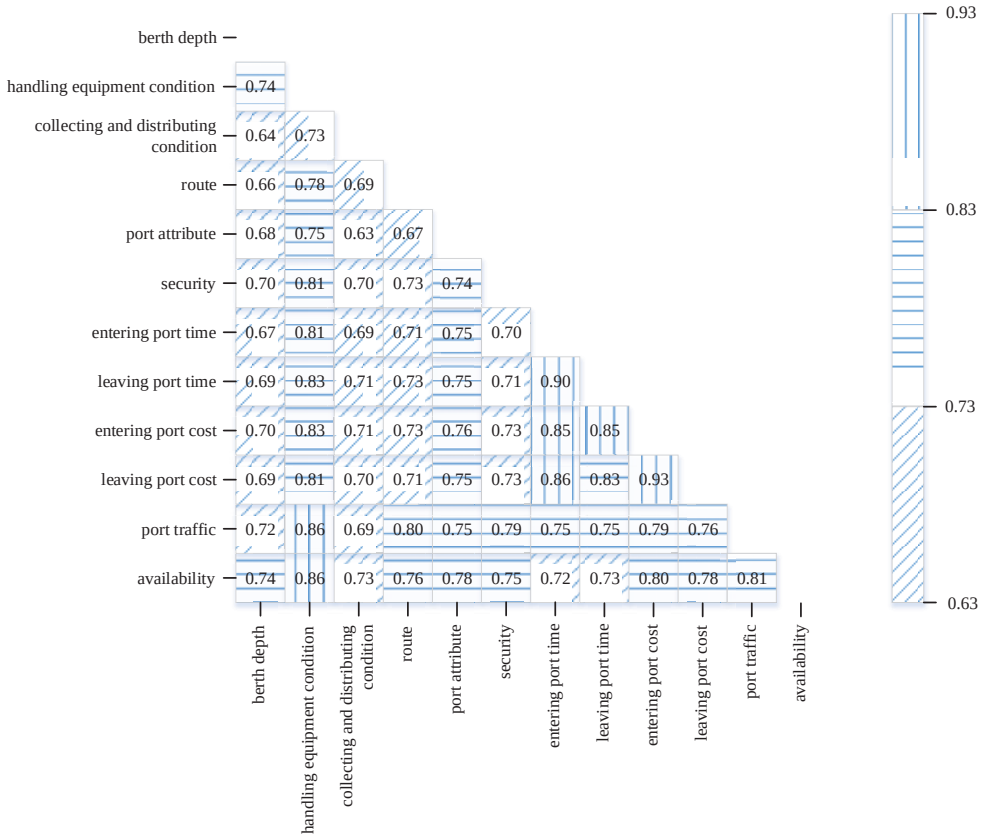

Figure 1 Correlation analysis of port availability

4.3 Evaluation Analysis Based on Factor Analysis

According to the characteristics of factor analysis, the basic data should satisfy two requirements: The variable can be expressed as a fixed value directly or indirectly, but not an interval; there is not missing data of a variable. Therefore, 17 major ports in the world constitute the research sample, and 11 factor variables are selected other than "berth depth" and "availability".

First, a feasibility analysis is executed based on the standardized data. The value of KMO is 0.611. In Bartlett's sphericity test, approximate chi-square is 0.611, degree of freedom (df) is 55, and significance (Sig.) is 0.000. In conclusion, the characteristic data of key factors obtained are

highly correlated, and can be further analyzed by factor analysis. Then, a principal component analysis is conducted to extract factors, with results shown in Table 3. It can be seen that the characteristic values of the first three components are larger than 1, and the cumulative contribution rate of variance is 75.53%, close to 80%. Therefore, the first three factors are selected as the principal component factors.

Table 3 Eigenvalue and variance contribution rate

Component variable sequence	Initial characteristic value		
	Total	Variance (%)	Cumulative (%)
1	4.581	41.645	41.645
2	2.587	23.514	65.159
3	1.141	10.369	75.527
4	0.755	6.864	82.391
5	0.751	6.828	89.219
6	0.465	4.225	93.444
7	0.408	3.705	97.149
8	0.172	1.565	98.714
9	0.092	0.838	99.552
10	0.038	0.342	99.894
11	0.012	0.106	100

After determining the number of factors, an orthogonal rotation is performed on the original factor loading matrix, with results shown in Table 4. It can be seen that the three components have large loads on different indexes. Combined with the specific meaning of each variable, the three factors are named as: generalized entering and leaving port cost (Factor 1), port internal attributes (Factor 2) and port external attributes (Factor 3).

Table 4 Component matrix after rotation

Variable	Component		
	1	2	3
Entering port cost	0.992	−0.151	−0.093
Entering port time	0.913	−0.153	−0.058
Leaving port cost	0.903	−0.162	−0.132
Leaving port time	0.89	0.1	−0.019
Port traffic	−0.626	−0.085	0.538
Overall berth length	−0.139	0.881	0.107
Handling equipment	−0.209	0.843	−0.056
Port attributes	−0.186	−0.775	−0.071
Security degree	−0.132	0.637	0.378
Collection and distribution	0.111	0.325	0.771
Route	−0.507	−0.019	0.69

Taking the variance contribution rate in Table 4 as the weight, comprehensive scores and rankings of each port are calculated by linear regression method, as shown in Table 5. According to the results, the top-three ports are Sudan port, Karachi port and Durban port, and their scores have at least one higher score in Factor 1 or Factor 2, and both positive and negative scores exist in Factor 3.

Table 5 Factor scores and rankings of major ports in countries along the Belt and Road

Port name	Score of Factor 1	Score of Factor 2	Score of Factor 3	Comprehensive score	Rank
COSCO-PSA	−1.628	−0.76	1.248	−0.727	17
Bitung	−0.4	−0.429	0.604	−0.205	13
Haiphong	−0.079	0.82	1.2	0.284	5
Manila	−0.261	−0.309	1.229	−0.054	8
Bangkok	−0.437	−0.232	1.587	−0.072	9
Moresby	0.642	−1.017	−0.775	−0.052	7
Karachi	0.048	3.174	−0.612	0.703	2
Colombo	−0.368	−0.072	0.489	−0.119	11
Khalifa	−1.279	0.039	−0.825	−0.609	15
Djibouti	0.349	1.137	−0.1	0.402	4
Piraeus	−0.371	0.254	−0.318	−0.128	12
Doha	−0.407	−0.346	−1.41	−0.397	14
Bahrain	−0.706	−0.675	−1.671	−0.626	16
Sudan	2.884	−0.524	0.646	1.145	1
Dar es Salaam	0.509	−0.459	−0.12	0.092	6
Durban	0.985	0.291	0.007	0.479	3
Freetown	0.518	−0.893	−1.179	−0.116	10

From the results of factor analysis, the scale of entering and leaving port and the construction of internal facilities are main influencing factors on its logistics development. Sufficient internal facilities ensure that the port meets its expected maximum transportation capacity. The scale of entering and leaving port has an impact on the economic benefits directly, and further affects the port logistics development. On this basis, the improvement of external attributes such as collection and distribution, and routes can promote handling operations and improve the efficiency of port logistics.

However, the entering and leaving port cost has little relationship with its internal conditions, but the entering and leaving benefits are based on complete infrastructures. For most ports, it is necessary to expand the scale of internal infrastructures firstly, considering both quantity and quality, and then to improve transportation conditions outside. Extensive types of collection and distribution are needed and the port traffic should satisfy the maximum capacity of infrastructures as much as possible.

4.4 Results Comparison Analysis

Based on GRA, the top-three influencing factors identified for port logistics development are handling equipment, transportation, entering and leaving port cost, related to capacity, efficiency, and cost factors respectively. This is because the development of ports needs to attract the supply of cargoes and the capacity needs to meet the total requirements first. The attraction of ports also decreases with low transportation efficiency or high cost. Based on factor analysis, the development of port logistics is mainly affected by entering and leaving port scale, internal attributes and external attributes. By comparing the conclusions of two methods, three major factors obtained are similar, but with different order in importance. From GRA, the port handling equipment is the most influential factor, followed by port traffic and entering and leaving cost. According to factor analysis, the entering and leaving cost is the most important, followed by handling equipment and port traffic.

There are two reasons for the different results. The first one is embodied in the principles of two methods. The GRA needs to find a reference sequence and a comparison sequence. In this paper, the port availability is used as the reference sequence, and other attributes are used as the comparison sequence. Among them, the port availability refers to the port activity index calculated by the number and size of berthed ships. The port availability is related to the cost indirectly by high cost, low supply attraction, or low infrastructure availability. The factor analysis directly analyzes the factor load from all attributes to find the important one, so the cost factor occupies a prominent proportion. Another reason is that the specific meanings of three factors are different in the two methods. For example, the entering and leaving port cost in GRA only includes the money cost generated in the entering and leaving process. But in the factor analysis, it does not only include the money cost, but also the corresponding time cost. Therefore, the scope of latter concept is wider, with greater influencing weight.

In conclusion, the development of port logistics is closely related to the capacity, efficiency, and cost. Since the cost factor is easily affected by national policies, international environment and other reasons, with less controllability compared with the capacity or efficiency. Therefore, a port should give priority to improving the infrastructure capacity and logistics transportation efficiency itself.

5 Conclusion

Based on the data of major ports in countries along the Belt and Road, the results of GRA and factor analysis show that the infrastructure, transportation, entering and leaving cost have a great influence on the development of port logistics, and the feasibility of promoting port development is higher in infrastructure and transportation. The results have theoretical and practical significance in guiding port development strategies, to help countries along the Belt and Road to improve the level of port logistics development and international cooperation. Most of the data used in this paper are related to logistics cost or port infrastructure, but considering little policies of countries along the Belt and Road. Further studies will consider some social data such as policies.

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