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A DEA-Based Study on the Measurement of Regional Intermodal Transportation Efficiency in China

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Abstract: In order to explore the development of intermodal transportation in China, this paper analyzes the intermodal transportation efficiency from 2018 to 2020 in 10 provinces and cities of Liaoning, Tianjin, Shandong, Jiangsu, Sichuan, Shanghai, Zhejiang, Fujian, Guangdong, and Guangxi Provinces by using the DEA model. Based on the relevant data in 2018, 2019 and 2020, the pure technical efficiency, scale efficiency and total efficiency of the ports in these provinces and cities are calculated, and it is concluded that China's current intermodal transportation scale efficiency is low, e.g., China's average total efficiency value in 2020 will be 0.277. This paper analyzes the reasons for China's low intermodal transportation scale efficiency, and proposes relevant measures to solve the problem.

1. Introduction

Intermodal transportation is a transportation process that is jointly completed by two or more modes of transportation connecting and transferring to each other. The use of intermodal transport can reduce transportation costs, reduce intermediate links, and shorten the time of cargo transportation. The January 2022 document "Promoting the Development of intermodal Transportation and Optimizing the Adjustment of Transportation Structure (2021-2025)" was issued, which emphasizes the need for China to improve the capacity of intermodal transportation and the level of connectivity. This paper applies the DEA model to measure the efficiency of intermodal transportation in 10 provinces and cities in China, to find out the factors affecting the development of intermodal transportation, and to provide a theoretical basis for the continuous development of intermodal transportation in China.

2. Literature review

As scholars in related fields have gradually increased their attention to intermodal transportation, the number of related research results has been increasing in recent years. Intermodal transportation utilized in China includes: sea-railway intermodal transportation, sea-air intermodal transportation and sea-land intermodal transportation. The literature review in this paper starts from two aspects: DEA model and intermodal transportation efficiency.

Using a three-stage DEA-Malmquist model, Pei Longfei et al. studied the road transport efficiency of 30 provinces in China, showing that the level of economic development, the level of urbanization, and the size of the population have a significant effect on the road transport efficiency measures [1].

Wang Xuanshang et al. constructed a DEA three-stage analysis for the operational efficiency level of inland container ports in China, and compared the operational efficiency of inland container ports, proving the importance of the influence of environmental factors and stochastic variables on the efficiency of ports [2]. Zhan Bin et al. used the DEA model to evaluate the efficiency of major river ports along the Yangtze River, and concluded that scale inefficiency and the existence of large input redundancy and resource waste caused the overall comprehensive efficiency of major ports along the Yangtze River to fall short of the efficiency frontier [3]. The efficiency of the main ports along the Yangtze River is not at the frontier of efficiency as a whole.

Wang Ling used SBM model and DEA window analysis to evaluate the operational efficiency of the main intermodal logistics corridors in Liaoning Province, and concluded that there is an excess of two input factors, capital and technology, in Liaoning Province [4]. Wang Wei et al. constructed a DEA model based on the AHP constraint cone, and evaluated the efficiency of containerized sea-land intermodal transport mode in Taicang port through the DEA model with constraint cone (DEAHP), which indicated that ocean transportation, road transportation and port efficiency are the determinants of sea-land intermodal transport efficiency [5]. It shows that ocean transportation, road transportation and port efficiency are the determinants of sea-land intermodal transportation efficiency. Liu Mingwu et al. used covariance fuzzy to evaluate the efficiency of iron and water intermodal transportation of inland river container terminals, indicating that China's inland river terminals are more efficient and develop faster [6].

From the above studies, it is clear that intermodal transport plays an important role in the logistics and transportation industry. However, compared with the research on other modes of transportation, there is a lack of research on the efficiency measurement of intermodal transportation. Based on previous studies, this paper selects 10 provinces and cities in China from 2018 to 2020 as research objects, uses the DEA model to evaluate their intermodal transportation efficiency, studies the factors that affect the development of intermodal transportation, and puts forward relevant suggestions and countermeasures.

3. Research methodology and modeling

Data Envelopment Analysis (DEA) modeling is an evaluation method that combines convex analysis and linear programming to study inputs and outputs. The DEA methodology consists of a number of models, the most widely used of which are the CCR model and the BBC model. In this paper, the BBC model with variable returns to scale is used in the analysis process. The BBC model is shown below:

$$\begin{gathered}
\min[\theta-\varepsilon(e^{T\wedge}S^{+}+e^{T}S^{-})] \\
\sum_{j=1}^{n}\lambda_{j}x_{j}+S_{m}^{+}\leq\theta x_{0} \\
\sum_{j=1}^{n}\lambda_{j}x_{j}-S_{n}^{\prime-}\geq\theta y_{0} \\
\sum_{j=1}^{n}\lambda_{j}=\frac{\|S_{m}^{+}-S_{n}^{\prime-}\|}{\theta_{j}} \\
\varepsilon_{j}\in\frac{1}{n}\left(\sqrt{S_{m}^{+}+S_{n}^{\prime-}}\right) \\
\lambda_{j}\geq 0,j=1,2,\cdots,n \\
S^{+}\geq 0,S^{-}\leq 0;m\textcircled{x}n^{-}\subset 1
\end{gathered} \tag{1}$$

Formula $S^{-}(S_1^{-},S_2^{-}\cdots S_n^{-})^{T}$ and $S^{+}(S_1^{+},S_2^{+}\cdots S_n^{+})^{T}$ are input and output slack variables,

respectively, which are planning decision variables, and θ is the efficiency value of x_j and y_j are the input and output variables, respectively.

4. Selection of indicators and data sources

Based on the principle of DEA model, this paper uses the ratio of intermodal transportation volume to intermodal transportation resource input to measure the efficiency of intermodal transportation, and establishes the indicator system from the perspectives of inputs and outputs, which are set as input indicators and output indicators. The selection of indicators in this paper follows the principles of scientificity, practicality, comprehensiveness, rationality and accessibility, and combines with the actual situation of China's intermodal transportation to establish a reasonable indicator system, as shown in Table 1.

Table 1: Selection of indicators

Indicator category	Indicator name	Unit (of measure)
Output variables	intermodal throughput	million TEUs
input variable	Investment in fixed assets for roads and waterways	Ten thousand dollars
	Employment in transportation, storage and postal services	man
	Number of persons employed in intermodal transport and transport agency industry	man

This paper combines the characteristics of intermodal transportation itself, comprehensively adopts the DEA model, analyzes the relevant literature on intermodal transportation efficiency, and selects the investment in fixed assets in highways and waterways and the number of people employed in transportation, warehousing and postal industry, as well as the number of people employed in intermodal transportation and transport agency industry as input indicators. The input indicators are selected from the specific real data of each province and city in 2018-2020.

Intermodal transportation throughput can directly reflect the development level of China's intermodal transportation, and at the same time, this data is open and transparent. For this reason, this paper selects intermodal throughput as an output indicator to measure the efficiency of China's intermodal transportation. The indicator adopts specific real data of each province and city from 2018 to 2020.

Data sources

The research period of this paper was selected as 2018-2020, and 10 provinces and cities in China were selected as the initial sample of intermodal transportation. The data were obtained from China Statistical Yearbook [7], China Port Statistical Yearbook, and the official website of China's ports.

5. Empirical findings

From the results of DEAP software operation, it can be concluded that in the time dimension, the overall intermodal transportation efficiency of each province and city in 2018-2019 has an improvement. The support for intermodal transportation in the Three-Year Plan for Promoting Transportation Restructuring and other relevant policies accelerated the development of intermodal transportation. In 2020, the total efficiency of intermodal transportation in some provinces and cities showed a downward trend. Under the influence of the new crown epidemic, regional transportation of commodity goods was hindered in many places. However, intermodal transportation in all provinces and cities in 2018-2020 is in the state of incremental scale compensation.

Table 2: DEA model results for 2018

city	efficiency value			Return on scale
	total efficiency	Pure technical efficiency	Scale efficiency	
Liaoning	1.000	1.000	1.000	-
Tianjin	0.001	1.000	0.001	irs
Shandong	0.032	0.420	0.076	irs
Jiangsu	0.007	0.457	0.016	irs
Sichuan	0.204	0.630	0.324	irs
Shanghai	0.004	0.262	0.016	irs
Zhejiang	0.744	0.892	0.834	irs
Fujian	0.077	0.693	0.111	irs
Guangdong	0.088	0.206	0.428	irs
Guangxi	0.217	1.000	0.217	irs
average value	0.237	0.656	0.302	

Table 3: DEA model results for 2019

city	efficiency value			Return on scale
	total efficiency	Pure technical efficiency	Scale efficiency	
Liaoning	1.000	1.000	1.000	-
Tianjin	0.033	1.000	0.033	irs
Shandong	0.048	0.421	0.114	irs
Jiangsu	0.010	0.442	0.024	irs
Sichuan	0.121	0.573	0.211	irs
Shanghai	0.008	0.1000	0.008	irs
Zhejiang	0.782	0.916	0.854	irs
Fujian	0.062	0.740	0.084	irs
Guangdong	0.106	0.232	0.456	irs
Guangxi	0.893	1.000	0.893	irs
average value	0.306	0.732	0.368	

Table 4: DEA model results for 2020

city	efficiency value			Return on scale
	total efficiency	Pure technical efficiency	Scale efficiency	
Liaoning	1.000	1.000	1.000	-
Tianjin	0.053	1.000	0.053	irs
Shandong	0.041	0.384	0.107	irs
Jiangsu	0.003	0.323	0.008	irs
Sichuan	0.042	0.878	0.048	irs
Shanghai	0.001	0.601	0.002	irs
Zhejiang	0.767	0.965	0.794	irs
Fujian	0.041	0.626	0.065	irs
Guangdong	0.118	0.335	0.351	irs
Guangxi	0.333	0.986	0.338	irs
average value	0.240	0.710	0.277	

Note: irs is incremental returns to scale.

In the spatial dimension, Liaoning, Tianjin and Guangdong provinces show increasing total efficiency during 2018-2020. While Jiangsu Province, Shanghai Municipality, Zhejiang Province,

Guangxi Province and Shandong Province present an increasing state of total efficiency in 2018-2019, while all of them are decreasing in 2020. Sichuan and Fujian provinces show a continuous decreasing total efficiency between 2018-2020. The results of the DEA model for 2018, 2019 and 2020 are shown in Table 2, Table 3 and Table 4, respectively.

According to the results, the scale efficiency of China's intermodal transportation is generally small and the total efficiency value is low. The future development of intermodal transportation in China should continue to improve the pure technical efficiency and scale efficiency, increase the investment in road and waterway fixed assets, the number of people employed in the transportation, warehousing and postal industry, and the number of people working in intermodal transportation and transport agency industries.

6. Conclusions and recommendations

Based on the results of the above analysis, China needs to further improve the efficiency of intermodal transportation, which can be done in the following aspects:

Enhancement of intermodal transportation capacity. We should increase investment in intermodal transportation, build and utilize a unified and efficient information platform for intermodal transportation, and promote the coordination of intermodal transportation in terms of facilities and equipment as well as management modes. Upgrade relevant facilities and equipment, and accelerate the research and development of new types of carriers and transshipment tools.

Improve the level of intermodal transportation connection. We should promote the use by railroads and ports of uniform standards for containers, pallets and other loading tools, as well as the cross-industry use of containers, pallets and other facilities and equipment. The differences between road, rail and waterway modes of transportation in terms of waybills should be narrowed, and uniform common documents and standards should be established to avoid forcing containerized goods to be disassembled or reassembled at the conversion nodes.

Promoting the restructuring of transportation in key regions. We should encourage the provinces and cities in China that currently contain inland ports as well as coastal areas to promote the use of intermodal transportation, and promote the development of intermodal transportation in each region in accordance with local conditions, and strengthen the integration of related ports, railroads and other resources.

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