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중국 일대일로 항만의 효율성 평가*

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Evaluating the Efficiency of Chinese Ports from the Perspective of Maritime Silk Road

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Abstract

The 21st Century Maritime Silk Road (MSR) is an important part of Belt and Road Initiative(BRI). As an economic and trade corridor for dozens of countries in Asia, Europe and Africa, and the port as an important link node, the efficiency of port operation directly affects the implementation of BRI's strategy.

On the basis of combining BRI and related evaluation methods of port efficiency, this paper uses DEA-BCC model to select port production berth number and production berth length as input index container throughput and cargo throughput as output index to analyze the port efficiency of 14 ports in China. The results show that: (1) The overall efficiency level of the ports along the MSR is relatively low. Most of the ports have not reached the DEA efficiency and there are different degrees of problems in scale investment and technological improvement. However, this situation is accompanied by the implementation of China's maritime cooperation strategy and becoming better year by year. (2) The low operating efficiency of ports along China's MSR is mainly due to the lack of coordination between scale efficiency and technical efficiency, which is caused by insufficient scale investment in the port itself, weak economic linkage between the hinterland and the port, (3) Whether a port has a strong comprehensive strength does not entirely depend on the cargo throughput or scale but also includes the port's operating efficiency.

Key words: Belt and Road Initiative (BRI), 21st- Century Maritime Silk Road (MSR), Port Efficiency, Data Envelopment Analysis (DEA) BCC model

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Ⅰ. Introduction

For decades, numerous and complex changes are taking place in the world, the deep-seated impact of the international financial crisis is gradually emerging, and the recovery of the world economy is clearly divided due to the lack of dynamic support. the pattern of international trade and investment has obviously changed the rules of multilateral trade and investment.

In September and October 2013, Chinese President Xi Jinping visited ASEAN and put forward cooperative initiatives for the construction of the "New Silk Road Economic Belt" and "21st Century Maritime Silk Road" respectively, referred to as Belt and Road Initiative.

On March 28, 2015, the Vision Action for promoting the Joint Construction of the Silk Road Economic Belt and the 21st Century Maritime Silk Road jointly issued by the National Development and Reform Commission, the Ministry of Foreign Affairs and the Ministry of Commerce clearly pointed out that investment and trade cooperation is the key content of "Belt and Road Initiative" construction, and efforts should be made to solve the problem of trade liberalization and facilitation and eliminate trade barriers. Build a good business environment in the region, actively discuss the establishment of free trade zones with countries and regions along the route, and stimulate and unleash the potential for cooperation.

In 2017, the document "Belt and Road Initiative's tentative Plan for Maritime Cooperation" clearly pointed out that MSR will mainly build three blue economic channels, the first of which extends westward to the Mediterranean region. The second is to extend southward and eventually to the South Pacific Region; the third is also westward to reach the European developed economic circle and proposes to establish a friendly port alliance in terms of strengthening port cooperation.

As an important transportation facility, port is not only a platform for the development of export-oriented economy, but also provides support for the country's economic construction and the development of foreign trade. With the rapid development of economy and the improvement of traffic environment, the functions of ports continue to extend, the service requirements of customers are becoming more and more diverse, and the competition of various ports is becoming more and more fierce. The improvement of port efficiency and the continuous adjustment and improvement of port function have become an important factor in the comprehensive competitiveness of the port. Since the Chinese government put forward the strategy of the "Maritime Silk Road" in the 21st century, the initiative to build unobstructed, safe and efficient transport channels with key ports as nodes has received a positive response from more than 60 countries around the world. 58 countries have realized sea links with China, the Indo-China Peninsula Economic Cooperation Corridor has initially taken shape, and a number of ports and terminals invested by China have been put into use.

The research on the comprehensive efficiency of the port can improve the port connectivity, promote the integration of the supply chain between ports, and enhance the competitive posi-

Figure 1. Port distribution of MSR

tion of the port. It is of great practical significance to the sustainable development of the port.

This study will divide the 15 ports proposed in the 'Vision and Action' Document into 5 regions, and compare the logistics efficiency of each port in 2016 and 2018.

II. Literature Review

With the rapid development of international trade, port efficiency has become the focus of research. The research on port efficiency has developed from single index to multi-index at first, and then to measurement methods, which are divided into parametric method and non-parametric method.

DeMonie(1987) used only one index to evaluate the efficiency of the port and then measured its productivity. Stent and Bendall(1987) evaluated port performance by measuring the efficiency of terminal operations. Sachish(1996) compared the ideal optimal throughput with the actual throughput of the port to analyze the efficiency of the port.

The above literatures only analyzed through an index of the port. Actually the port operation is not a simple system. So if only a single index be selected, the port efficiency can only be reflected from one aspect. Then, some scholars evaluated the port performance by constructing multiple indicators such as port throughput, port infrastructure and port operating profits.

The empirical research methods on port efficiency can be divided into two categories as parametric method and non-parametric method. Parametric method can be divided into linear regression method and SFA method. Tongzon(2001) built a linear regression model based on 23 international ports around the world to analyze the impact of selected variables on port efficiency. Clark(2004) also used the method of constructing linear regression model to study the port efficiency of the United States. Liu(2010) used SFA method to construct a new evaluation index to evaluate the cost efficiency of port enterprises. Coto-Millan et al.(2016) collected the cross-sectional data of 27 ports in Spain and used the stochastic frontier cost function to evaluate the efficiency of the port. Through the researches, it can be concluded that the port management model has a significant impact on the efficiency while the port scale has no effect on the port economic efficiency. Notteboom et al.(2000) used SFA model to evaluate the efficiency of 40 container ports, different with Coto-Millan's research results, they believed that the size of the port has a positive impact on the efficiency of the port. Cullinane et al.(2002) collected mixed data and cross-sectional data of major ports in Asia, and used stochastic frontier analysis to evaluate the comprehensive efficiency of some container ports in Asia, which is consistent with the results obtained by Notteboom, The efficiency of ports with larger scale is higher than that of ports with smaller scale.

The above researches were based on the parametric analysis method which enriches the method system of port efficiency measurement to a certain extent. However, there was subjective in function setting and data selection. Therefore, more and more studies tended to use non-parametric analysis method, mainly using DEA model to measure port efficiency. Roll et al.(1993) used DEA-CCR model to evaluate port efficiency for the first time. Al-Eraqi et al.(2010) used standard DEA and DEA window analysis methods to measure port efficiency. Chudasama et al.(2008) selected the number of berths and ships by one-stage DEA model to measure the operational efficiency of the main coastal ports in India. And compared the dynamic changes of efficiency horizontally. Zhang, et al.(2018) Use the three-stage DEA model to measure the technical efficiency of the regional construction industry affected by environmental regulations. Sun, J., et al.(2017) proposes a non-radial DEA preference model, based on the assumption of variable returns to scale (VRS) and the Directional Distance Function (DDF) model to evaluate and analyze the efficiency of Chinese-listed port enterprises. Chen, C et al.(2018) using a two-stage data envelopment analysis (DEA) proposes a new method for measuring the sustainable development of different port city systems. While the previous empirical studies often separate the port system and the urban system, this paper assesses the two systems in an integrated way. Wang, Z. et al.(2020) construct three data envelopment analysis (DEA) models to evaluate the environmental efficiency of ports under the circumstances of environmental control, non-environmental control and PM emission through inter-ports cooperation. Lu, W. (2019) uses data envelopment analysis (DEA) to analyze the logistics efficiency of four major ports in Liaoning Province. Then based on the results of data envelopment analysis (DEA) analysis, the relationship between logistics efficiency and its influencing factors is studied.

Through the collation and research of the existing literatures, it is found that the research perspectives of China's port efficiency mainly focus on large cities and coastal ports.The distinction of this paper is that it compares the efficiency of the 14 ports delineated in the MSR policy of the BRI as a benchmark, which provides not only the specific implementation measures for practical applications, but also reliable data and theoretical basis for following research in this area.

Ⅲ. Methodology

Data Envelopment Analysis (DEA) has been a classic performance evaluation methodology in situations where multiple inputs (e.g., the number of employees) and outputs (e.g., the number of products) need be converted into a combined efficiency score. The DEA - BCC model was created by Charnes et al. to analyze the efficiency of 20 virtual ports. Subsequently, a number of studies have been done measuring the efficiency of container ports using DEA models. One of them is the CCR-DEA model, which was proposed by A. Charnes, W.W. Cooper, and E. Rhodes in their paper on measuring the efficiency of decision-making units.

Since 1980, port efficiency has received great attention, and scholars have adopted different methods to study it. The port efficiency studied in this paper includes comprehensive technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE). Port TE is a manifestation of the level of port competitiveness which is reflected in all aspects of port development, including technical factors and scale factors of port development. It reflects the ratio of actual output to the ideal maximum output when the amount of input is constant. Port PTE refers to the efficiency of various production factors which is reflected in port production and operation. It is an indicator to measure the rationality of port input and output. It is an intuitive reflection of port production efficiency and is of great significance to the study of port efficiency. Port SE refers to the gap between the existing scale and the optimal scale under certain other conditions. The port industry is a very large-scale industry, and economies of scale are very important for its development. Reasonable planning of port scale can promote the improvement of production efficiency and at the same time achieve the effect of resource allocation optimization which is very important for improving the efficiency of the entire port.

The traditional DEA model further decomposes TE into SE and PTE. TE refers to the maximum output when the input is constant, or the minimization of input when the output is constant, and PTE refers to the efficiency affected by technology, management and other reasons. The traditional BCC pattern is as follows:

$$\min[\theta - \epsilon(\sum_{i=1}^{m} s_i^- + \sum_{j=1}^{t} s_j^+)]$$

$$s.t: \sum_{r=1}^{n} \lambda_r x_{ir} + s_i^- - \theta x_{ir0} = 0$$

$$\sum_{r=1}^{n} \lambda_r x_{jr} + s_j^+ = y_{jr0}$$

$$\lambda_r \geq 0, r = 1,2,......, n$$

$$s_i^-, s_j^+ \geq 0$$

Where n represents the number of DMU, m is the number of inputs, t is the number of outputs, and s_i^- is the number of inputs. s_j^+ is the value of the output relaxation variable, x_{ir} is the input index, y_{jr} is the output index, and TE is the value of output. If θ = 1, it is said that the decision-making unit is effective, otherwise it is invalid.

Ⅳ. Empirical Analysis and Result

4.1 Selection of input/output variables and data source

According to the input-output theory of production, the input variables include port production berth number and production berth length . The output variables include port container throughput and cargo throughput. As the logistics to get from input to output takes time, DEA analyses used data from a sample of the 14 major port for 2016 and 2018 to get the best picture of the logistical efficiencies of these areas.

All input and output variables selected have been frequently used in previous literature studies on logistics efficiency. Based on the literature review and data availability, this research uses two input variables and two output variables. (see Table 1)

4.2 DEA results

This paper uses Deap2.1 software to conduct an input-oriented BCC model measurement analysis of 14 major ports in China in 2016 and 2018. The overall average efficiency of the 14 ports along the MSR shown in Figure 1. In 2016 and 2018, the average efficiency index fluctuated

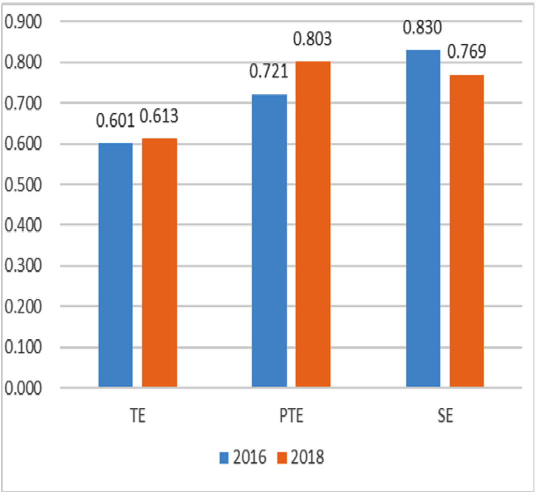

Figure 2. Comparison of average efficiency in 2016 and 2018

around 0.6, with a small gap between the two years. That indicates the overall efficiency of the port logistics industry is low and there is still much room for improvement. The scale efficiency index (SE) was 0.830 in 2016 and decreased to 0.769 in 2018, indicating that China's logistics scale has expanded in recent years, but the efficiency has not improved significantly. The PTE efficiency index has increased from 0.721 to 0.803 from 2016 to 2018, indicating that it is necessary to expand the scale and make better use of existing resources.(see Figure 2)

According to the TE index, the efficiency value of Shenzhen Port and Qingdao Port is 1 in 2016 and the efficiency value of Guangzhou Port has also reached 1 from 0.539 in 2016 to 2018. The three ports are at the forefront of technology. Among them, Zhanjiang Port has been greatly improved from 0.782 in 2016 to 0.908 in 2018 and is in a period of growth, indicating the need to increase scale and technol

Table 1. Summary statistics for the sample

DUM(ports)	2016				2018			
	INPUT		OUTPUT		INPUT		OUTPUT	
	Number of berths (pc)	Length of pro-duction-wharf(m)	Container through-put (10,000TEU)	Cargo through-put (10,000ton)	Number of berths (pc)	Length of pro-duction-wharf(m)	Container through-put (10,000TEU)	Cargo throughput (10,000ton)
Shanghai	592	74066	3713	64482	573	75410	4201	73048
Tianjin	160	37133	1452	55056	167	40252	1600	50774
Ningbo-zhoushan	606	86089	2157	92209	723	90089	2510	57652
Guangzhou	485	49686	1885	52254	198	25515	1903	48033
Shenzhen	141	30521	2398	21410	156	32932	2574	25127
Zhanjiang	144	16793	72	25612	132	17388	101	30185
Shantou	87	9627	124	4985	89	10150	131	3963
Qingdao	94	25641	1805	50036	97	28378	1932	54250
Yantai	94	19494	260	26537	109	22658	300	31608
Dalian	222	40765	958	43660	100	25335	965	37807
Fuzhou	179	25207	268	14516	193	26007	334	17876
Xiamen	164	29236	961	20911	165	30654	1070	21700
Quanzhou	104	15971	209	12560	94	15464	240	12832
Haikou	60	8217	141	9952	60	8217	185	11883

ogy investment. On the other hand, the TE value of other ports has an increasing trend in 2018, indicating that the overall efficiency of 14 ports is improving in three years.

According to the PTE index, the pure technical efficiency of Shanghai Port, Ningbo Zhoushan Port, Shenzhen Port, Qingdao Port and Haikou Port in 2016 is 1. In 2018, the pure technical efficiency of Tianjin Port has decreased significantly, while the pure technical efficiency of Guangzhou Port and Dalian Port has been significantly improved. Shenzhen Port, Qingdao Port and Haikou Port still maintain a PTE efficiency of 1. The overall PTE average index is about 0.8, so it is necessary to continue to strengthen the management and operation of each port. From the SE indicators, Shenzhen Port and Qingdao Port have maintained the SE scale efficiency of 1 in the two years, Ningbo Port has increased from 0.899 to 1, and other ports have increased slightly, indicating that the port scale efficiency is slowly improving in the past three years and the port infrastructure construction is also gradually improving.(see Table 2)

At present, the ports in the IRS stage are Zhanjiang Port, Shantou Port, Yantai Port, Dalian Port, Fuzhou Port, Xiamen Port, Quanzhou Port and Haikou Port, which means that economies

Table 2. Efficiency of different ports 2016 & 2018.

DUM(ports)	2016				2018			
	TE	PTE	SE	RTS	TE	PTE	SE	RTS
Shanghai	0.671	1.000	0.671	drs	0.730	1.000	0.730	drs
Tianjin	0.760	0.968	0.785	drs	0.660	0.664	0.994	irs
Ningbo-zhoushan	0.549	1.000	0.549	drs	0.371	0.442	0.839	drs
Guangzhou	0.539	0.599	0.899	drs	1.000	1.000	1.000	-
Shenzhen	1.000	1.000	1.000	-	1.000	1.000	1.000	-
Zhanjiang	0.782	0.895	0.874	irs	0.908	0.973	0.933	irs
Shantou	0.265	0.854	0.311	irs	0.204	0.810	0.252	irs
Qingdao	1.000	1.000	1.000	-	1.000	1.000	1.000	-
Yantai	0.698	0.791	0.882	irs	0.730	0.777	0.939	irs
Dalian	0.549	0.561	0.978	irs	0.781	0.826	0.945	irs
Fuzhou	0.295	0.405	0.729	irs	0.360	0.426	0.845	irs
Xiamen	0.452	0.565	0.799	irs	0.473	0.574	0.823	irs
Quanzhou	0.403	0.598	0.674	irs	0.434	0.651	0.667	irs
Haikou	0.621	1.000	0.621	irs	0.756	1.000	0.756	irs
Averange	0.613	0.803	0.769		0.672	0.796	0.837	

of scale have not been fully demonstrated in the context of the Maritime Silk Road, and each port needs to be scaled according to its own conditions. In particular, the SE efficiency of Shantou Port is 0.3 in 2016 and 0.25 in 2018, which is due to the mismatch between more input and less output. In the future, more efforts are needed in terms of the scale and structure of investment in the port.

In addition, the ports in the DRS stage are Shanghai Port, Tianjin Port, Ningbo Port and Guangzhou Port. They are all high-throughput and large-scale ports but they are not effective. The problem of these ports is not caused by input redundancy and insufficient output, the root cause is that the input-output of the port is not coordinated with the scale. Thus it can be seen that the size of the port is not the bigger the better. It is necessary to optimize the scale of these ports to make them in line with the current situation of the development of each port.

V. Conclusion

This paper analyzes the efficiency of 14 main ports along the Maritime Silk Road in the 21st century. The main conclusions are as follows:

(1) The overall efficiency level of the ports along the MSR is relatively low. Most of the ports have not reached the DEA efficiency, and there are different degrees of problems in scale investment and technological improvement. However, this situation is accompanied by the implementation of China's maritime cooperation strategy It is improving year by year.

(2) The low operating efficiency of ports along China's MSR is mainly due to the lack of coordination between scale efficiency and technical efficiency. This is due to insufficient scale investment in the port itself, weak economic linkage between the hinterland and the port, or low resource allocation efficiency.

(3) Whether a port has a strong comprehensive strength does not entirely depend on the cargo throughput or scale, but also includes the port's operating efficiency.

Therefore, the economic development of ports not only depends on infrastructure and trade carrying capacity, but is also affected by the degree of coordination with the hinterland economy and input-output efficiency. China's port development should change the development concept from extensive to intensive, and productive to ecological Type change. To fundamentally improve port resource utilization and operational efficiency, it is necessary to establish scientific development ideas to guide port facility construction and integrated management.

First, through the adjustment of the development ideas and industrial distribution of each port, the optimization and upgrading of the port industry layout and resource allocation is realized, and the allocation of production factors is optimized on the basis of maintaining the current investment level, so as to achieve the improvement of port scale efficiency.

Second, the port should strive to seek the advancement of production technology, establish and improve the port management model based on local characteristics, improve the comprehensive management level, and achieve the improvement of the technological progress change index.

Third, coastal provinces and cities should strengthen the coordinated development of ports and hinterland economies, improve the construction of logistics and transportation systems, strengthen the linkage of regional economies, improve the port's risk aversion capability and logistics carrying capacity, and adapt to the new economic normal.

Fourth, port development should avoid blindly expanding its scale. It should comprehensively consider local realities, policy opportunities and the international environment, rationally determine the port development positioning, and accelerate integration into the construction wave of the Maritime Silk Road.

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중국 일대일로 항만의 효율성 연구

왕관* · 안승범**

국문요약

21 세기 해양 실크로드 (MSR)는 일대일로 이니셔티브 (BRI)의 핵심적인 부분이다. 아시아, 유럽, 아프리카 등 수십 개 국가의 경제 및 무역 통로이자 중요한 연결 노드인 항만과 항만 운영의 효율성은 BRI의 전략 실행에 직접적인 영향을 미친다.

본 논문에서는 BRI 및 관련 항만 효율 평가 방법을 결합한 DEA-BCC 모델을 사용하여 항만 생산 선석 수와 생산 선석 길이를 입력 지표 컨테이너 처리량으로,화물 처리량을 출력 지표로 선택하여 14 개 항만의 항만 효율성을 분석하였다. 결과는 다음으로 요약된다 : (1) MSR을 따라 항만의 전반적인 효율성 수준이 낮게 나타난다. 대부분의 항만은 DEA 효율성에 도달하지 못하였고 투자규모 및 기술 개선에 있어 상이한 문제를 보여준다. 하지만 이러한 상황은 중국의 해양 협력 전략의 실행과 함께 해마다 개선되고 있다. (2) MSR 항만의 낮은 운영 효율성은 주로 규모 효율성과 기술 효율성 간의 조정 부족 때문으로 볼 수 있다. 이는 항만 자체에 대한 투자규모가 불충분하고 배후지와 항만 간의 유기적인 연계가 취약하기 때문이다. (3) 항만이 종합적인 경쟁력 확보 여부는 화물 처리량이나 규모에 전적으로 의존하지 않고 항만 운영 효율성도 포함되어 역할을 하는 것으로 파악된다

주제어: 일대일로 이니셔티브(BRI), 해상 실크로드, 항만효율성, DEA-BCC 모델