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Performance Evaluation of Port Logistics Informatization Construction: A Case Study from China

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Abstract: Global economic integration has accelerated frequency of trade between different countries and promoted logistics industry to quickly become another development highland. Facts have proved that logistics has been separated from production and circulation as an independent link, driven by existing technology and demand, and with its characteristics and needs of the times, logistics has formed a strong professional field. At the same time, it can also independently undertake corresponding brokerage business activities in trade exchanges. To better understand the role of port and logistics in trade, it is particularly necessary to study port logistics informatization. Considering efficiency of input and output, more attention should be paid to performance evaluation of port logistics informatization construction. Based on analysis of port logistics informatization development, evaluation index system and DEA evaluation model which can represent performance of port logistics informatization were constructed. 17 listed ports in China were taken as examples for empirical study, and suggestions for development of port logistics informatization are put forward. Results show that among 17 ports, only Tangshan port, Shenzhen port, Yantian port and Chongqing port have a technical efficiency value of 1, while the other 13 ports have a certain degree of redundancy in technical efficiency value of information input, indicating that development and construction of port logistics informatization has a very important impact on port logistics income. Efficiency value of average annual net profit indicates that the port has redundant investment in information construction, which means that construction of port logistics informatization can not only blindly pay attention to informatization input, and that shortage of informatization output will be affected by other factors to a certain extent. The more investment in informatization construction is not the better, and different ports are affected by different types of factors. Therefore, it is necessary to combine actual development status of ports and to apply right medicine to avoid insufficiency or redundancy of port input, to realize optimal investment strategy for informatization construction of port logistics. Through this study, it is expected to achieve the purpose of systematically sorting out, concluding and expanding relevant theories of port logistics informatization construction, clarifying management problems that need to be solved, indicating methods for promotion of informatization construction, and providing new ideas and reference basis for reform, transformation and upgrading of port enterprises.

Keywords: DEA evaluation; informatization construction; performance evaluation; port logistics

1 INTRODUCTION

With the development of global economic integration, modern logistics has become an increasingly prominent position in national economy and social development, and has become an important pillar industry, known as the third source of profit of social and enterprise management and development. It is the key driving force to achieve industrial upgrading and enterprise restructuring. One of the basic characteristics of modern logistics is that under the guidance of the idea of systems engineering, logistics business process and resources are restructured, optimized, to ensure informatization and globalization of logistics development. Extensive use of information technology makes the boundary between various business links in logistics business process more blurred, to better control business process of enterprise, to achieve purpose of improving service level, and to reduce production cost of the enterprise. In development and evolution of modern logistics industry, ports play an important role. They are at the key node of comprehensive transportation network and realize not only reloading function of land and water goods in traditional sense, but also are indispensable and important links in the whole cargo supply chain. Development of port logistics has a far-reaching impact on modern logistics system and plays an important strategic role for port enterprises. Although port logistics has solved many problems in past port operation, driven by the wave of new logistics technology, people have higher and higher requirements for port business. Relying solely on port logistics technology can no longer meet rowing production demand, so port logistics informatization comes into being. Port logistics informatization refers to use of modern information technology to integrate and manage port logistics information. Through effective processing of this logistics information to control logistics, information flow and other related business activities in the logistics process, it can help the port realize reasonable allocation of resources when dealing with logistics business. To reduce the cost, it should improve level of decision-making and enhance automation of logistics business, information and so on. In the era of vigorous development of logistics, transportation and information industry, level of port logistics informatization construction has become one of important symbols to measure modernization of logistics in a region or a city.

At present, port informatization construction has entered a new stage. Especially some coastal cities have put forward strategy of building the city by port according to business characteristics of their ports. For example, Shenzhen wants to build a world-class port. Shanghai wants to build an international shipping center. Dalian wants to build an important international shipping center in Northeast Asia. Chongqing wants to build a western logistics center and so on. Information technology plays a decisive role in realizing these grand goals. Therefore, the decision-making level of each major port has realized that promotion of port competitiveness is inseparable from high informatization construction.

Current port informatization construction in China is mainly reflected in application of networked computer system, which plays a leading role in daily operation and management of the port. However, information development status of most ports shows that increasingly prominent problems in ports have affected improvement of port business, and it is difficult to support further development of ports in fierce market competition. At present, overall level of port logistics informatization construction in China is still in the stage of data connectivity, while port logistics informatization in some developed countries has reached the stage of supply chain visualization and even supply chain management decision support system, and construction level is far higher than that in China. For example, Rotterdam port in the Netherlands, Los Angeles port and New York port in the United States, Antwerp port in Belgium, Hamburg port in Germany, Singapore port in Singapore, Yokohama port in Japan and Busan port in South Korea are all worthy of reference in various aspects of logistics informatization construction infrastructure, information technology and management methods.

2 STATE OF THE ART

2.1 Port Logistics

In initial stage of accelerated development of global information technology, ports in developed countries soon realized that they should introduce information technology to speed up development of port logistics. Therefore, in the 1980s, development of port logistics in developed countries took lead into a new stage of development. Introduction of new management methods and information technology not only effectively reduced business scope of port logistics and improved service quality, but also reduced cost of port logistics and intensive operation of the business. Among them, development of port logistics in the United States, Japan and some European countries was a typical example. For example, Atlanta port in the United States had realized mechanization of cargo handling, automation of storage, information management and standardization of packaging. Under the leadership of these advanced ports, development of port logistics had entered a new stage, which was stage of port logistics supply chain management. At this time, other countries also began to regard development of port logistics informatization as an important content of port construction in the new era, and most scholars also began to pay attention to research in the field of port logistics informatization construction.

Some scholars pointed out that port logistics should contain four major functions, namely, storage function, distribution and distribution function, manufacturing function, trade function. The United Nations Conference on Trade and Development (UNCTAD) had put forward the third-generation ports and the fourth-generation ports. Ellram et al. [1] took the fourth-generation port as research object and positioned it as waterfront green stronghold of logistics supply chain. Through analysis of supply chain logistics, study of port alliance and in-depth discussion of green ports, the fourth-generation port theory was enriched.

García-Tabuenca et al. [2] modified structural evolution model and took some Australian ports as examples for an empirical study after adding scheduled liner service parameters. Based on empirical results, relationship between port logistics and maritime traffic was analyzed. Notteboom [3] took the European continental port as an example and analyzed port logistics data from 1980 to 2004. He believed that although hub ports occupied a strong position in competition with whole port system, small ports had effectively developed rather than been eliminated in process of constantly challenging hub ports. At the same time, he pointed out that the government would introduce corresponding policies to protect development of small ports due to needs of regional economic development. In port logistics system, hub ports and small ports were developing in competition with each other. Development of port logistics in the middle and lower reaches of the Yangtze River was analyzed by introducing field strength theory, deeply discussing its spatial competition pattern, analyzing dynamic factors affecting evolution of port logistics pattern, and proposing future evolution trends. System dynamics model was applied to study development of port logistics system in the Yangtze River Delta, and a set of causality diagram of port logistics system was established by taking Ningbo and Shanghai, two major coastal cities as objects [4]. A further analysis was made from micro level and took port container operating system as an example to establish a set of cooperative optimization system for container loading and unloading based on multiple agents [5]. The use of this system played an important role in promoting optimization of container operations. The fuzzy comprehensive evaluation method was introduced to evaluate port logistics system, built evaluation index system according to business characteristics of port logistics, and then combined with analytic hierarchy process (AHP) to determine weight of each index. Finally, three ports in the Bohai Rim economic zone were taken as examples for empirical analysis, and correctness of index system and model was verified. Business development level of three ports was ranked, from high to low, which were Qingdao port, Tianjin port and Dalian port respectively [6].

Borko [7] believed that with the increasing port logistics business and convergence of various transportation modes, port traffic congestion would become a serious problem. Therefore, Barke took differentiation process of ports as the main idea, innovated and studied Taaffe model to a certain extent. It was proposed that port logistics activities in the city center area should be transferred to surrounding ports or ports in the suburbs of the city, which could effectively solve the problem of port traffic congestion. Centralized development of port logistics would be mainstream trend in the future, and discussed centralized development mode between feeder ports and container hub ports. Further discussed relationship between feeder ports and container hub ports, and pointed out that scale economy was a powerful driving force to promote centralized development between them. Based on this, three poles of port logistics development were proposed, namely hub port, feeder port and feeder port [8]. Multi-product cost function model was introduced and Spain was taken as an example to summarize and analyze operating data of 26 ports in that country from 1998 to 2008. Conclusion further confirmed existence of port logistics economies of scale. Meanwhile, it also found that with the introduction of information technology, scale economy of old big ports was declining.

2.2 Port Logistics Evaluation

Tongzon [9] believed that it was not convincing to study port logistics solely from the perspective of operating performance. He introduced the DEA method to evaluate port logistics performance from perspective of input and output, and his research conclusions comprehensively revealed important indicators and influencing factors leading to imbalance of port logistics development. Although there were many research achievements on port logistics, most of them were not representative and evaluation research on port logistics performance was lacking in methods and models, which only showed situation of port logistics at a certain level. The port played an important role as the hub between logistics warehousing and logistics transportation, and quality of port logistics service was directly related to cost of logistics warehousing and transportation. Therefore, Spain port was taken as an example to study and found that nearly 40-50% of the cost of cargo transportation was used for storage and loading and unloading at the port [10]. Hilling [11] believed that port logistics could be evaluated from two aspects, which were value-added logistics services and general logistics services. Port logistics enterprises were evaluated by using fuzzy hierarchical analysis method, analyzed port logistics enterprises in western India and several other port logistics enterprises according to key factors, and finally obtained performance ranking of these port logistics enterprises [12]. Coordinated development relationship between port logistics and regional economic development was studied by establishing correlation model. Taking Dalian port as an example, quantitative relationship between economic development of Dalian city and Dalian port was studied by introducing Pearson correlation coefficient method and unitary linear regression model. Taking Tianjin port as an example, relationship between throughput of Tianjin port and GDP of Tianjin city was analyzed by using vector autoregression (VAR) model and it was found that there was a dynamic correlation between logistics of Tianjin port and economic development. Backpropagation (BP) neural network model was introduced to measure development trend of urban economy and port logistics, and to evaluate degree of coordinated development between them by establishing corresponding efficacy function and coordination validity function model. The Delphi method was introduced to build a hierarchical model of port logistics, and then the AHP method was used to establish an index system and calculate index weights based on sub-model.

2.3 Port Logistics Informatization

At present, scholars had made some achievements in study of port logistics informatization, which was mainly concentrated in fields of logistics information system, intelligent optimization, logistics information platform and so on. Main manifestations were port logistics information service platform, such as Singapore port logistics service system, and the largest information center in China's Qingdao port. Then, it included logistics information systems, such as electronic data interchange system at Antwerp port. In addition, it also included intelligent optimizations, such as Rotterdam port's electronic services Ship notification and EDI Cargo Notification, enabling paperless operations between enterprises and government agencies, especially customs [13]. Through implementation of the Digital Logistics Port project, Dalian port completed development and application research of logistics and business service, customs supervision and customer service and other applications of bulk and general cargo terminal. By integrating application of computer, communication, automatic control, global satellite navigation and positioning system, geographic information system and other technologies, Guangzhou port realized the seamless logistics service of Port to Door.

At present, theoretical research on port logistics informatization was relatively less than application research, mainly discussing necessity of port logistics informatization construction, development strategy and other aspects [14]. Borko advanced theory of port logistics informationization aspect research, their potential index of the P (Informatization Utilization Potential) model method was used to evaluate performance of port logistics information. An information ring estimation model was proposed to reflect level of information infrastructure construction and potential capacity of information utilization of a port enterprise. Liu et al. [15] believed that construction of port logistics informatization must be based on port information resource planning, with construction of an integrated logistics information service platform as main implementation means, and corresponding supply chain management system should be developed based on combination of logistics and information technology. Improving international competitiveness of open port cities was one of effective ways to enhance overall competitiveness of national economy, and development of port logistics, as an inevitable choice to improve competitiveness of port cities, must develop port logistics informatization. Based on radio frequency technology of Internet of Things, cost of logistics transportation could be effectively reduced and efficiency of logistics transportation could be improved. Construction of a diversified port logistics information external service platform could effectively improve port's external competitiveness, and it was also an effective means to promote integrated development of port business, information technology and management system when discussing idea of information construction to adapt to sustainable development of ports.

As an important node of logistics system, the port is in the position of hub, bridge and portal. Information construction of port logistics is of great strategic significance to enhance international competitiveness of the port, accelerate transformation and upgrading of industry, and improve efficiency of enterprises [16]. At present, academic research on informatization construction of port logistics mainly stays at the level of influence of information technology application on enterprises, and research on scientific management theory and method in informatization construction stage of port logistics is less involved, and the focus is scattered [17]. Basically, it still stays at preliminary discussion of related concepts and lack of further in-depth research. This study intends to discuss relevant contents of port logistics informatization construction from two aspects of management and application, to discuss key issues such as performance of port logistics informatization construction, and to conduct empirical analysis based on cases, hoping to provide beneficial theoretical reference and problem-solving ideas for decision-makers of port logistics informatization construction. At the same time, it can also be beneficial for smooth and efficient development of port informatization construction.

3 METHODOLOGY
3.1 Evaluation Method

Performance evaluation of port logistics informatization is a complex comprehensive evaluation process, including determination and establishment of multiple factors and indicators, and selection of evaluation methods determines the evaluation results. Therefore, it is necessary to choose performance evaluation method according to its background. Common informatization performance evaluation methods include AHP, principal component analysis, fuzzy comprehensive evaluation and data envelopment analysis (DEA) [18-20]. Through analysis of these methods, it is found that main role of AHP in performance evaluation is to set weight of indicators. However, once evaluated object is relatively complex, due to fuzzy relationship between indicators, it will make division of levels more difficult. At the same time, the method needs to determine corresponding judgment matrix according to indexes in implementation of evaluation, and formulation of judgment matrix comes from expert scoring, which increases subjectivity in evaluation process and reduces scientific and accurate evaluation conclusions. Evaluation of principal component analysis is mainly based on objective actual data of evaluated object. However, in evaluation of principal component analysis, a large number of index data need to be collected, calculation is large and complicated, and a lot of manpower and material resources need to be consumed. Subjectivity in evaluation process of fuzzy comprehensive evaluation method is a major problem in this method. There is a considerable degree of subjectivity in setting of indicators, weight calculation and other aspects, which leads to a large error between evaluation results and real results. DEA mainly studies evaluated object from perspective of input and output, with purpose of evaluating effectiveness of input and output. Main advantage of this method is that it does not need to explicitly guide specific function relationship between input and output variables. Meanwhile, it does not need to consider index weight and corresponding parameter values. After calculating input and output values, it can get technical efficiency value, scale economy and so on. DEA method has many advantages in calculation. Firstly, it can evaluate effectiveness of input and output of small sample objects. Secondly, it does not need to guide specific functional relationship between input and output indicators, but only needs corresponding data of input and output indicators, which is subject to relatively few constraints.

Therefore, after comparing and analyzing above evaluation methods, this study finally decides to use DEA as main method to evaluate port logistics informatization. Main reasons are as follows. It is impossible to consider all ports in the research, and some ports are mainly selected as research objects in form of sampling, which is easy to lead to phenomenon of overgeneralization, which is not conducive to the research. However, DEA method is more suitable for analysis of small samples, so it has become the first choice to evaluate performance of port logistics informatization construction.

3.2 Evaluation Index

Overall research idea of this study is to use DEA method to evaluate performance of port logistics informatization construction. Therefore, according to characteristics of the DEA model, it is necessary to determine the index, namely input index and output index in performance evaluation of port logistics informatization construction, referring to existing research results. After comprehensive comparison, indexes are processed as follows. Firstly, input indexes are screened. Combined with existing research results, this study finally selects informatization investment as input index, which covers all costs in construction process such as management costs and infrastructure construction costs. At the same time, average annual net profit and annual operating income are screened as output indexes. The final performance evaluation index system of port logistics informatization construction is shown in Tab. 1.

Table 1 Port logistics informatization index system

Input variables	Output variables	
Informatization investment	Annual operating income	Average annual net profit

The reason why this study chooses to extract the above input and output indexes is that they are relatively feasible in data acquisition, and authenticity and authority of the data can be guaranteed. For example, output data can be obtained by analyzing annual financial statements and statistical yearbooks of each port.

3.3 Construction of Evaluation Model

There are two DEA models, C^2R and BC^2. Among them, C^2R model is the main model to evaluate DEA effectiveness of decision making units, while BC^2 model is a model to evaluate technical efficiency. In BC^2 model, relative efficiency means that DEA effectiveness in DEA model is relatively effective, that is, it is effective relative to other similar *DMU* units, and it is not effective in technology and scale. Therefore, to better evaluate performance of port logistics informatization, this study mainly chooses C^2R model for analysis. Contents are as follows.

Supposing that there are n decision making units, (j = 1, 2, ..., n), each decision making unit has the same m inputs, and input vector is shown as Eq. (1).

$$x_j = (x_{1j}, x_{2j}, ..., x_{mj})^{\mathrm{T}} > 0,\ j = 1, 2, ..., n \tag{1}$$

Each *DMU* has the same s output, and output vector is shown as Eq. (2).

$$y_j = (y_{1j}, y_{2j}, ..., y_{mj})^{\mathrm{T}} > 0,\ j = 1, 2, ..., n \tag{2}$$

That is, each *DMU* has m types of inputs and s types of outputs.

x_{ij} represents input of the j^{th} decision-making unit to the i^{th} type of input.

y_{ij} represents output of the j^{th} decision-making unit to the i^{th} type of output.

To integrate all inputs and outputs, production process is a simple production process with only one input and one output. It needs to give weight to each input and output. And then, it lets weight vectors of input and output be respectively $v = (v_1, v_2, ..., v_m)^T$, $u = (u_1, u_2, ..., u_s)^T$. v_i is weight of the i^{th} type input, and u_r is the weight of the r^{th} type output.

At this time, comprehensive value of input of the j^{th} decision-making unit is $\sum_{i=1}^{m} v_i x_{ij}$, and comprehensive value of output is $\sum_{r=1}^{s} u_r y_{rj}$. It defines efficiency evaluation index of each decision-making unit DMU_j, shown as Eq. (3).

$$h_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \tag{3}$$

In Eq. (3), x_{ij} and y_{ij} are known numbers (which can be obtained from historical data or prediction data), so the problem is actually to determine a set of optimal weight vectors v and u to maximize efficiency value h_j of the j^{th} decision-making unit. This maximum efficiency evaluation value is the relative efficiency evaluation value that cannot be higher than other decision-making units. It limits all h_j values (j=1, 2, ..., n) to no more than 1, that is, max $h_j \le 1$. This means that if the k^{th} decision-making unit $h_k = 1$, the decision-making unit has the highest productivity compared with other decision-making units, or the system is relatively effective; If $h_k < 1$, productivity of the DMU is still to be improved compared with other DMUs, or production system is not effective. According to above analysis, relative efficiency optimization evaluation model of the j_0^{th} decision-making unit is shown as Eq. (4).

$$\max h_{j0} = \frac{\sum_{r=1}^{s} u_r y_{rj0}}{\sum_{i=1}^{m} v_i x_{ij0}}$$
$$\text{s.t.}\begin{cases} \dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \ j = 1, 2, ..., n \\ v = \left(v_1, v_2, ..., v_m\right)^T \ge 0 \\ u = \left(u_1, u_2, ..., u_s\right)^T \ge 0 \end{cases} \tag{4}$$

This is a fractional programming model, and it must turn it into a linear programming model to solve it.

$$t = \frac{1}{\sum_{i=1}^{m} v_i x_{ij0}}, \ \mu_r = t u_r, \ w_i = t v_i \tag{5}$$

Then the model is converted to the following Eq. (6).

$$\max h_{j0} = \sum_{r=1}^{s} \mu_r y_{rj0}$$
$$\text{s.t.}\begin{cases} \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} w_i x_{ij} \le 0, \quad j = 1, 2, ..., n \\ \sum_{i=1}^{m} w_i x_{ij0} \\ \mu_r, w_i \ge 0, \ i = 1, 2, ..., m; \ r = 1, 2, ..., s \end{cases} \tag{6}$$

Vector form is shown as Eq. (7).

$$\max h_{j0} = \mu^T Y_0$$
$$\text{s.t.}\begin{cases} \mu^T Y_j - w^T X_j \le 0 \\ w^T X_0 = 1 \qquad j = 1, 2, ..., n \\ w \ge 0, \ \mu \ge 0 \end{cases} \tag{7}$$

A very important and effective theory in linear programming is the dual theory. It is easier to make in-depth analysis in theoretical and economic sense by establishing a dual model. The dual problem is shown as Eq. (8).

$$\min \theta$$
$$\text{s.t.}\begin{cases} \sum_{j=1}^{n} \lambda_j x_j \le \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j \ge y_0 \\ \lambda_j \ge 0, \ j = 1, 2, ..., n \\ \text{No constraints of } \theta \end{cases} \tag{8}$$

It further introduces relaxation variable s^+ and residual variable s^-, and turns above inequality constraints into equality constraints.

$$\min \theta$$
$$\text{s.t.}\begin{cases} \sum_{j=1}^{n} \lambda_j x_j + s^+ = \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^- = y_0 \\ \lambda_j \ge 0, \ j = 1, 2, ..., n \\ \text{No constraints of } \theta \ s^+ \ge 0, \ s^- \ge 0 \end{cases} \tag{9}$$

Assuming that the optimal solution of above problem is λ^*, s^{*-}, θ^*, following conclusions and economic implications are reached.

If $\theta^* < 1$, and $s^{*+} = 0$, $s^{*-} = 0$, then decision-making unit DMU_{j0} is DEA effective, that is, there is $w^* > 0$, $\mu^* > 0$ in solution of original linear programming, and its optimal value is $h_{j0}^* = 1$. At this time, production activities of decision-making unit DMU_{j0} are both technically effective and scale effective.

But at least one input or output relaxation variable is greater than zero. Then optimal value of original linear programming is $h_{j0}^* = 1$. DMU_{j0} is called weak DEA effective, which is not both technically effective and scale effective.

If $\theta^* < 1$, decision-making unit DMU_{j0} is not DEA valid. Its production activities are neither the best in technical efficiency, nor the best in scale efficiency.

In addition, it uses optimal value of λ_j in the C^2R model to judge the return to scale of *DMU*.

If there is $\lambda_j^* \left(j = 1, 2, ..., n \right)$, which makes $\sum \lambda_j^* = 1$ tenable, DMU_{j0} means that scale benefit remains unchanged. If there is no $\lambda_j^* \left(j = 1, 2, ..., n \right)$, which makes $\sum \lambda_j^* = 1$ tenable, and if $\sum \lambda_j^* < 1$, DMU_{j0} is increasing in scale benefit. If there is no $\lambda_j^* \left(j = 1, 2, ..., n \right)$, which makes $\sum \lambda_j^* = 1$ possible, then if $\sum \lambda_j^* > 1$, DMU_{j0} is decreasing in scale benefit.

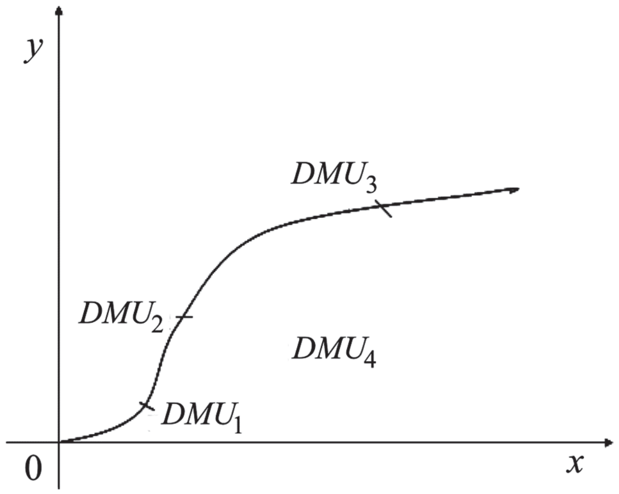

Figure 1 Effective diagram of DEA scale

Effective technology means the output has reached the maximum relative to the input, that is, the decision-making unit is located on curve of production function. Effective scale refers to the input being neither too large nor too small, which is between increasing and decreasing returns to scale, that is, return to scale is unchanged.

It can be seen from Fig. 1 that DMU_1, DMU_2 and DMU_3 are all in technical effective state. DMU_1 is not effective for scale it is in state of increasing returns to scale. DMU_3 is not effective for scale, and it is in a state of diminishing returns to scale. DMU_2 is scale effective. If DEA model is used to judge the effectiveness of DEA, there is only the optimal value corresponding to DMU_2 is that. It can be seen that DEA is effective under the C^2R model, and its economic meaning is that it is effective in technology and effective in scale.

4 CASE STUDY

4.1 Data Source and Processing

From above analysis, it can be seen that decision-making unit is the port to be selected. First of all, according to requirements of DEA model for indexes and *DMU*s during evaluation, the number of *DMU*s should be twice or more than the sum of input indexes and output indexes, that is, there should be at least 6 *DMU*s in this study. In actual selection process, to make calculation results universal, this study selects 17 ports in Chinese Mainland as the most decision-making units, which far exceed required value of DEA model, and collects index data of each port for evaluation and analysis of information construction performance. What needs to be pointed out is that input index data mainly comes from the data published in relevant websites, management departments and newspapers of various port cities, such as Ningbo Daily, Wenzhou Daily, Lianyungang Daily, etc., and corresponding port and shipping management departments, such as Tianjin port Authority. Secondly, it is necessary to define data source of input indexes. The year-end financial statements of each port are main source of index data of average annual net profit and annual operating income. For example, the 2020 Annual Report of Shanghai International Port (Group) Co., Ltd. and the 2020 Annual Report of Jiangsu Lianyungang Port Co., Ltd. At the same time, it refers to other operating statements given by each port. Finally, the data of input indexes and output indexes after preliminary sorting are shown in Tab. 2.

Table 2 Performance evaluation index data of port logistics informatization

DMU	Port name	Input variable (100 million CNY)	Output variable (100 million CNY)	
		Informatization investment	Annual operating income	Average annual net profit
DMU_1	Shanghai port	0.518	295.108	78.653
DMU_2	Ningbo port	0.461	165.206	27.792
DMU_3	Tianjin port	0. 412	154.024	16.867
DMU_4	Tangshan port	0.041	51.574	12.938
DMU_5	Shenzhen port	0.016	18.726	6.527
DMU_6	Dalian port	0.159	88.862	5.691
DMU_7	Yingkou port	0.052	37.878	5.245
DMU_8	Yantian port	0.012	2.489	5.227
DMU_9	Beibu Gulf port	0.028	30.547	4.081
DMU_{10}	Rizhao port	0.092	43.779	3.717
DMU_{11}	Xiamen port	0.064	72.612	2.878
DMU_{12}	Wuhan port	0.073	36.589	1.926
DMU_{13}	Jinzhou port	0.028	18.055	1.295
DMU_{14}	Chongqing port	0.014	20.661	1.254
DMU_{15}	Zhuhai port	0.037	20.227	0.806
DMU_{16}	Lianyungang port	0.017	12.418	0.512
DMU_{17}	Nanjing port	0.004	1.5820	0.233

Source: statistical yearbooks, financial statements and annual reports of ports in 2021.

It can be seen from Tab. 3 that correlation coefficients among three indexes of informatization investment, annual operating income and average annual net profit are all above 0.8, indicating that correlation is significant. However, before DEA evaluation, it is necessary to check linear relationship between indicators. Here, SPSS software is still used for data inspection. Inspection results are shown in Tab. 4.

It can be seen from Tab. 4 that the model adjustment $R^2 = 0.811$, indicating that the model has a good fit. *Sig* = 0.000 indicates that regression equation is significant within the 95% confidence interval. The value of Durbin-Watson is 2.807, between 2 and 4, indicating that variables are independent of each other. Therefore, the above data can be used for DEA analysis.

Table 3 Correlation analysis results

		Informatization investment	Annual operating income	Average annual net profit
Informatization investment	Correlation	1.000	0.848**	0.847*
	Significance (bilateral)	.	0.000	0.000
	df	0	15	15
Annual operating income	Correlation	0.848**	1.000	0.923**
	Significance (bilateral)	0.000	.	0.000
	df	15	0	15
Average annual net profit	Correlation	0.847	0.923**	1.000
	Significance (bilateral)	0.000	0.000	.
	df	15	15	0

Note: **Indicates significant correlation at 0.01 level. * Indicates significant correlation at 0.05 level.

Table 4 Model correlation coefficients

R	R^2	Adjusted R^2	Error of standard estimate	Changed Statistics			Durbin-Watson
				Changed R^2	Changed F	Changed Sig. F	
0.864	0.847	0.811	0.08274	0.747	20.650	0.000	2.807

4.2 Evaluation Result

According to the linear correlation analysis results of indicator data given above, DEAP software is used to calculate efficiency value. According to calculation results of DEAP, DMU_{14} is decision-making unit that has been referred to for the most time, which has been referred to for 13 times in total. According to basic criterion of DEA model, it is explained that the data in decision-making unit is taken as the constant when calculating technical efficiency value during DEA evaluation.

Thus, publicized values are 0.014, 20.661, and 1.254, respectively. Thus, linear programming equations are constructed. Here, it sets $V_D = 1$, and specific formula of equation set is as Eq. (10). Among them, DMU_1 is λ_1. DMU_2 is $\lambda_2,\ldots$, DMU_{17} is λ_{17}. To facilitate the calculation, the corresponding relaxation variables are introduced.

$$\min \theta = V_D$$
$$\text{s.t.}\begin{cases} 0.518\lambda_1 + 0.461\lambda_2 + 0.412\lambda_3 + 0.041\lambda_4 + 0.016\lambda_5 + 0.159\lambda_6 \\ +0.052\lambda_7 + 0.012\lambda_8 + 0.028\lambda_9 + 0.092\lambda_{10} + 0.064\lambda_{11} + 0.073\lambda_{12} \\ +0.028\lambda_{13} + 0.014\lambda_{14} + 0.037\lambda_{15} + 0.017\lambda_{16} + 0.004\lambda_{17} + S_1 = 0.014\theta \\ 295.108\lambda_1 + 165.206\lambda_2 + 154.024\lambda_3 + 51.754\lambda_4 + 18.726\lambda_5 + 88.862\lambda_6 \\ +37.878\lambda_7 + 2.489\lambda_8 + 30.547\lambda_9 + 43.779\lambda_{10} + 72.612\lambda_{11} + 36.589\lambda_{12} \\ +18.055\lambda_{13} + 20.661\lambda_{14} + 20.227\lambda_{15} + 12.418\lambda_{16} + 1.582\lambda_{17} - S_2 = 20.661 \\ 78.653\lambda_1 + 27.792\lambda_2 + 16.867\lambda_3 + 12.938\lambda_4 + 6.527\lambda_5 + 5.691\lambda_6 \\ +5.245\lambda_7 + 5.227\lambda_8 + 4.081\lambda_9 + 3.717\lambda_{10} + 2.878\lambda_{11} + 1.926\lambda_{12} \\ +1.295\lambda_{13} + 1.254\lambda_{14} + 0.806\lambda_{15} + 0.512\lambda_{16} + 0.223\lambda_{17} - S_3 = 1.254 \end{cases} \tag{10}$$

In above Eq. (10), θ is regulating variable. Since the DEA model mainly evaluates efficiency values of input and output, when technical efficiency value of a decision-making unit is not equal to 1, that is, efficiency of input and output is not balanced. In other words, there may be input redundancy or input insufficiency. In this case, input value can be adjusted by adjusting variables, so that technical efficiency value of input and output is equal to 1. In this study, 17 decision units are selected. After calculation, technical efficiency of each decision-making unit is shown in Tab. 5.

The calculation results in Tab. 5 show that there are four effective decision-making units in DEA, namely DMU_4, DMU_5, DMU_8 and DMU_{14}. Technical efficiency value, redundancy value and insufficient value of each DMU are shown in Tab. 6. According to analysis of the data in Tab. 5, only Tangshan port, Shenzhen port, Yantian port and Chongqing port have a technical efficiency value of 1 among the above 17 ports.

That is to say, technical efficiency value of other 13 ports' informatization investment has a certain degree of redundancy. At the same time, the data also shows that there is no shortage of port revenue, that is, development and construction of port logistics informatization has a very important impact on port logistics revenue. However, efficiency value of average annual net profit shows that there are redundant information construction investments, such as Zhuhai port, Xiamen port, Wuhu port and Lianyungang port, and their net output is still insufficient. This phenomenon shows that construction of port logistics informatization cannot only focus on informatization input blindly, and the lack of informatization output will be affected by other factors to a certain extent. In this process, different ports are affected by different types of factors, that is, each port should combine its actual development status to solve the problem. Finally, through research on performance of logistics informatization construction of above 17 ports, it can be seen that the more investment in informatization construction is not the better. On the contrary, ports should analyze according to their conditions to avoid insufficient or redundant port input. Then, it may realize optimal investment strategy of port logistics informatization construction and reasonably allocate resources.

Table 5 Technical efficiency values of each DMU

DMU	Technical efficiency value
DMU_1	0.460
DMU_2	0.267
DMU_3	0.265
DMU_4	1.000
DMU_5	1.000
DMU_6	0.380
DMU_7	0.529
DMU_8	1.000
DMU_9	0.788
DMU_{10}	0.330
DMU_{11}	0.769
DMU_{12}	0.340
DMU_{13}	0.441
DMU_{14}	1.000
DMU_{15}	0.370
DMU_{16}	0.495
DMU_{17}	0.289
Average technical efficiency value	0.572

Table 6 Technical efficiency value, redundancy value and insufficient value of DMU

DMU	Technical efficiency value	Redundancy or insufficiency of informatization investment	Redundancy or insufficiency of output	Redundancy or insufficiency of average annual net profit
DMU_1	0.460	0.280	0.000	0.000
DMU_2	0.267	0.338	0.000	0.000
DMU_3	0.265	0.303	0.000	0.000
DMU_6	0.380	0.099	0.000	0.000
DMU_7	0.529	0.025	0.000	0.000
DMU_9	0.788	0.006	0.000	0.000
DMU_{10}	0.330	0.062	0.000	0.000
DMU_{11}	0.769	0.015	0.000	1.529
DMU_{12}	0.340	0.048	0.000	0.295
DMU_{13}	0.441	0.016	0.000	0.000
DMU_{15}	0.370	0.023	0.000	0.422
DMU_{16}	0.495	0.009	0.000	0.242
DMU_{17}	0.289	0.003	0.000	0.000

5 CONCLUSIONS AND IMPLICATIONS

5.1 Conclusions

This study first analyzes main research contents of port logistics informatization, summarizes existing research achievements in the field of performance evaluation of port logistics informatization, and proposes and constructs DEA evaluation model of port logistics informatization construction based on comparative analysis of different evaluation method and models. Secondly, combined with main characteristics of port logistics informatization construction, and based on the use of evaluation model, a set of scientific and effective performance evaluation index system of port logistics informatization is established, and practical evaluation ideas are put forward. Finally, 17 major ports in Chinese mainland are selected as examples for empirical analysis, and DEA evaluation is conducted by collecting index data and processing the data. It can be seen from evaluation results that there are still many problems and difficulties in port logistics management, and some deep-seated contradictions that affect improvement of port logistics performance still exist. Port production management is not in place, and overall service level of the port is not high. In general, research in this study can supplement and improve the research in the field of port logistics development, and also play a corresponding reference value in solving performance evaluation problem of actual project construction.

5.2 Managerial Implications

In view of the deficiencies in port development, this study proposes the following development strategies.

It should strengthen port infrastructure construction. Lack of infrastructure is a bottleneck problem that restricts development of port logistics of Ningbo port. To improve core competitiveness of the port and vigorously develop port logistics, an urgent task is to integrate existing resources of the port area, upgrade relevant supporting facilities, improve loading and unloading process and other methods to optimize operation process, improve utilization rate of equipment, and to maximize the port's throughput. Then, it should let each ship pass in a short time to reduce its stay in the port. In addition, it may accelerate construction of large-scale and orderly container terminals to ensure adequate deep-water reserves, provide large-scale modern warehousing services for port logistics service providers, strive to create conditions for customers, achieve zero warehousing, improve port logistics efficiency, and ensure sustainable development of port logistics.

It should accelerate construction of port informatization. An important index to measure level of port logistics service is port informatization. The lag of port information construction is one of the bottlenecks of port logistics development. Application of information platform and logistics technology plays an immeasurable role in promoting rapid development of port logistics.

Therefore, to vigorously develop port logistics, it is necessary to fully recognize position and role of science and technology. It is necessary to speed up construction of port informatization, and to use electronic ordering system, effective customer feedback, resource management system, MIS, database technology, Internet and other information technologies to provide relevant units with information such as freight market conditions, shipping schedule forecast, warehousing and storage, cargo handover documents, berth use, etc. By building a set of port logistics information service platform that can cover the whole port area and all business contents, and effectively connect all organizational structures, customers, cargo owners, suppliers, etc., it may have business dealings with the port, and realize smooth development of port logistics business in an open environment platform. Another is that informatization management level of many old port areas is still low, and it is difficult to achieve good data exchange and sharing. Therefore, it must increase investment in logistics science and technology, accelerate construction progress of port logistics information project, so that the port can have basic function of logistics informatization at the business level, to further expand the scope of business cooperation on this basis. All personnel and departments not involved in port logistics business provide more comprehensive, efficient and high-quality logistics services. Through promotion of port information construction, the port has function of logistics information port.

It should strengthen personnel education and training. Results show that with development of science and technology, simple port professionals can no longer meet current competitive demand, and more needs cross-sectional talents with both port expertise and information technology knowledge as well as management knowledge. However, most ports lag in introduction and training of cross-sectional talents, which makes it difficult to sustain sustainable development of port logistics. Meanwhile, it is not conducive to improving comprehensive competitiveness of port logistics. Therefore, in new situation, the port must take training and introduction of cross-sectional professionals as an important work of future talent training.

5.3 Research Limitations and Future Directions

Performance evaluation system of port logistics involves a wide range of research, which is a complex system problem involving port, logistics and regional economic development and so on. It is also a proposition with strong theory and practice. Therefore, research in this field still needs to be explored. However, due to limitations of basic knowledge, the study takes perspective of comprehensive evaluation on macro level of port logistics informatization construction. In future work and study, it is still necessary to strengthen research in the following aspects. Due to specific work experience in port logistics, this study only carries out short-term field research, and other information is from the literature of related fields. Therefore, with rapid development of information technology, index system proposed in this study may need to be adjusted in the middle and later stages of research. According to different research objectives, index system with dynamic functions should be built. This study conducts an empirical study on logistics performance of some ports in China, and evaluation has certain universality. Each port has its characteristics. Future research can also be refined for logistics performance evaluation of different ship types in specific ports.

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