Evaluation of Port Logistics Competitiveness Based on DEA

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Abstract. The index system of port logistics competitiveness is established. The improved DEA algorithm model is constructed based on principal component analysis method and DEA algorithm. The efficiency value of Shenzhen port logistics competitiveness from 2012 to 2016 is obtained through the model solution. The calculation results show that the input and output of Shenzhen port in 2015 and 2016 are unreasonable, and there is a waste of resources. The results are consistent with the present situation, which provides a scientific basis for the relevant departments to formulate the port logistics and economic development strategies.

1. Introduction
Port is the important station of international resource circulation and the connection point between land and sea transportation. In the new era, port logistics has the characteristics of integrated service, large logistics and virtual chain. Modern ports need to constantly improve the functions of logistics to meet the requirements of port logistics globalization. Therefore, the scientific evaluation of port logistics competitiveness is of great significance to conform to the globalization of port logistics and enhance the core competitiveness of port logistics.

Scholars at home and abroad have done some researches on the evaluation of port logistics competitiveness. Gi-Tae Yeo[1] takes the coastal ports in Southeast Asia as an example to analyze the competitiveness of port logistics by AHP and fuzzy mathematics. Yang Yongyi[2] uses the three major ports in the Pearl River Delta as an example and uses SWOT model to analyze the advantages and disadvantages of the three ports qualitatively and quantitatively. And Bertrand game theory model is used to demonstrate the impact of port logistics business mode and strategy on port and city. Song Cuicui[3] uses DEA method to study port logistics competitiveness, the main models are CCR and CCGSS. Jiao Xinlong[4] uses Delphi method and AHP to establish the AHP model of port logistics, and uses fuzzy comprehensive evaluation method to evaluate the performance of comprehensive evaluation. Xiao Haihui[5] establishes the evaluation index system of port logistics competitiveness, and uses factor analysis and cluster analysis to evaluate the competitiveness of port logistics in the Yangtze River Delta and the Pearl River Delta. Zhu Rongzheng[6] selects evaluation indexes from three aspects of enterprise's social contribution, output benefit and sustainable development ability, and uses DEA method to evaluate and analyze Hebei port group. So far, there are few articles on the competitiveness of Shenzhen port logistics.

The main methods of research on the competitiveness of port logistics are summarized as follows: principal component analysis, factor analysis, analytic hierarchy process, data envelopment analysis and fuzzy comprehensive evaluation. The advantages and disadvantages of each method are more obvious. Factor analysis and AHP are difficult to be objective in application. Fuzzy comprehensive evaluation may lead to repeated analysis between indexes and neglect the key factors of analysis. At
present, how to build a scientific and rigorous index system and choose the right method of empowerment and evaluation is still an important research topic. Data envelopment analysis (DEA) is a nonparametric efficiency evaluation method based on the concept of relative efficiency and combining convexity tools with linear programming. This paper focuses on the data envelopment analysis (DEA) method to study the competitiveness of Shenzhen port logistics. This paper uses the method of principal analysis to improve the shortage of data envelopment analysis in the research of port logistics competitiveness, so as to evaluate the logistics competitiveness of Shenzhen port scientifically and further improve the core competitiveness of Shenzhen port logistics.

2. Establish improved DEA algorithm model
There are limitations in the traditional DEA algorithm model. For example, the number of input and output indicators should not be too large. If the index is too high, the number of effective decision making units will be increased, and the effectiveness of port logistics competitiveness evaluation can be reduced. However, the number of indicators limits the selection of indicators. Moreover, there may be strong linear correlation between evaluation indicators. This leads to redundancy of evaluation indicators, which makes the evaluation results inaccurate. Finally, the DEA algorithm requires that the input and output indexes must be non-negative. If negative numbers are present, the operation evaluation can not be carried out. In order to avoid these limitations, we adopts principal component analysis to deal with the original evaluation index. In this way, we can make up for the limitation of traditional DEA algorithm and establish an evaluation model of port logistics competitiveness based on improved DEA algorithm\(^7-8\).

The principal component analysis method is reorganized according to the linear correlation of the original index, so that the reorganized variable factor can reflect most of the information of the original variable and compress the number of the original index, then the total number of factor variables is far less than the number of the original indexes. Aiming at the requirement of non-negative input data in DEA, in the process of original data processing, the data is standardized and its rotation matrix is obtained. Then, we use orthogonal rotation and regression analysis to deal with the data without negativity, and finally ensure that the input data are nonnegative.

2.1. Construct comprehensive evaluation efficiency model
Assume \( H_j \) is comprehensive evaluation efficiency of port logistics competitiveness, \( j \) represent the year number, \( u \) and \( v \) are the weight vectors of input and output items respectively, then:

\[
H_j = \frac{\sum_{i=1}^{n} u_i y_j}{\sum_{i=1}^{n} v_i x_i} \tag{1}
\]

2.2. Evaluation model matrix expression

\[
\begin{align*}
\text{max} & \quad u^T y_0 \\
\text{st.} & \quad u^T y_j \leq 1 \\
& \quad v^T x_j \leq 1 \\
& \quad u \geq 0, v \geq 0 \\
& \quad j = 1, 2, \ldots, 5
\end{align*}
\tag{2}
\]

2.3. Charnes-Cooper transform

\[
t = 1/v^T x_0 \quad w = tv \quad \mu = tu \tag{3}
\]
2.4. **Equivalent linear programming model**

\[
\begin{align*}
\max & \quad \mu^T y_0 \\
\text{s.t.} & \quad \omega^T x_j - \mu^T y_j \geq 0 \\
& \quad \omega^T x_0 = 1 \\
& \quad \omega \geq 0, \mu \geq 0 \\
& \quad j = 1, 2, \ldots, 5
\end{align*}
\]

(4)

2.5. **Dual model**

\[
\begin{align*}
\min & \quad \theta \\
\text{s.t.} & \quad \sum_{j=1}^5 x_j \varepsilon_j \leq \theta x_0 \\
& \quad \sum_{j=1}^5 y_j \varepsilon_j \leq y_0 \\
& \quad \varepsilon_j \geq 0 \\
& \quad j = 1, 2, \ldots, 5
\end{align*}
\]

(5)

3. **Preparation of the index system**

3.1. **Research objects and data**

After nearly 40 years of reform and opening up, the development of port logistics in Shenzhen has become the vane of domestic port development. Objective evaluation of the present situation of Shenzhen port logistics is conducive to summing up the development experience of Shenzhen port logistics. It is more conducive to the lack of Shenzhen port logistics development, so as to rationally allocate resources and comprehensive management, to further improve the core competitiveness of Shenzhen port logistics. The direct economic hinterland of Shenzhen Port is Shenzhen, Huizhou and Dongguan. After consulting *Chinese Port Yearbook*, *China Statistical Yearbook*, *Guangdong Statistical Yearbook*, *Shenzhen Statistical Yearbook*, and other authoritative statistical yearbooks and websites, the basic data of Shenzhen port logistics are collected and listed in Appendix.

3.2. **Initial index system**

This paper uses the method of literature analysis \cite{1-6,9} to build a first level index system from five aspects to analyze the competitiveness of Shenzhen port logistics. They are port logistics operating conditions, port logistics development environment, port logistics infrastructure conditions, port logistics service level and the potential of port logistics development period. And we determine the second level indicators as shown in Table 1.

| First level index | Second level index |
|-------------------|--------------------|
| Port logistics operating conditions | Container throughput | Port cargo throughput |
| | Port foreign trade cargo throughput |
| Port logistics development environment | The economic level of the hinterland | Port city GDP |
| | Hinterland economic ranking |
| Port logistics infrastructure conditions | Port production wharf length | Port berth |
| | Equipment loading capacity | Reservoir capacity |
| Port logistics service level | Port operation rate |
4. Construct index system

4.1. Data standardization

The 0-1 matrix is obtained by dimensionless processing of the original data. The methods are as follows:

\[ y_{ik} = \frac{x_{ik} - \min x_{ik}}{\max x_{ik} - \min x_{ik}} \]  

(6)

Among them: \( i \) represents \( i \) port, \( k \) represents index, \( x_{ik} \) represents initial data of \( k \) index in \( i \) port, \( y_{ik} \) represents standardized data of \( k \) index in \( i \) port, \( \max x_{ik} \) represents the maximum of \( k \) index in \( i \) port from all ports, \( \min x_{ik} \) represents the minimum of \( k \) index in \( i \) port from all ports.

4.2. Determine the input index of the DEA model

The index is analyzed by the method of principal component analysis. Combined with the characteristics of input and output indexes of DEA model, the index that best reflects the competitiveness of Shenzhen port logistics is selected as shown in Table 2.

| Input index | Output index |
|-------------|--------------|
| Hinterland economy GDP \( x_4 \) | Port cargo throughput \( y_1 \) |
| Port city GDP \( x_5 \) | Container throughput \( y_2 \) |
| More than ten thousand ton berths \( x_6 \) | Foreign trade throughput \( y_3 \) |
| Container berth \( x_7 \) | GDP growth rate in the hinterland economy \( y_4 \) |
| Berth length of productive wharf \( x_8 \) | Growth rate of cargo throughput \( y_5 \) |
| Container terminal deep water berth \( x_9 \) | Logistics added value \( y_6 \) |
| Berth shoreline of container terminal \( x_{10} \) | Container throughput growth rate \( y_7 \) |
| Port berth \( x_{11} \) |

4.3. Extract input-output factor

The eigenvalue, variance contribution rate and cumulative variance contribution rate of correlation matrix are obtained through SPSS calculation. The cumulative contribution rate of the first three indicators in the input index reached 98.343%. This shows that these three indicators can reflect the information provided by the original eight input indicators. We can use these three indicators as the main influencing factors and bring them into the DEA model for analysis. From the analysis variance and variance contribution rate of output index correlation matrix, we can see that the cumulative variance of the first two indexes is 84.849%. This shows that the information of the original output index can be reflected by these two indicators.
4.4. Principal component analysis
Through the above principal component analysis, the common factors of three input common factors and two output indicators are found. These three input factors and two output factors are introduced into DEA model to study and analyze. This makes the DEA model more obvious. In the use of SPSS rotation, this paper uses the most commonly used orthogonal rotation method of Kaiser standardization in various orthogonal rotation methods to rotate the initial factor load matrix. In this way, the effects of each factor on the observed variables are differentiated into 0-1. The interpretability of the factor is enhanced. In this paper, regression analysis is used to calculate the scores of each index. As mentioned earlier, DEA input data is required to be non-negative, so it is necessary to standardize the factor scores to get the model coefficients.

5. Model solution
According to the formula (1) ~ (5) and the coefficients previously obtained, the CCR efficiency value model of 2012~2016 is established. Lingo is used to solve the model, and the results are 1, 1, 1.059, 0.37 and 0.701 respectively, that is, the CCR efficiency of 2012~2016.

According to the data processing results, the port benefit in 2012~2014 is basically equal to 1. This shows that the input-output ratio of ports in these years is reasonable. The scale is appropriate and the management level is high. The CCR efficiency of 2015 and 2016 was less than 1. This shows that input-output is unreasonable in the past two years, and there is a waste of resources.

6. Conclusions
Taking the competitiveness of port logistics as the research object, this paper combines principal component analysis and DEA algorithm to establish an improved DEA algorithm model. The research takes Shenzhen port logistics competitiveness as an example to analyze. The research constructs the analysis index system of Shenzhen port logistics competitiveness, including five first level indicators and seventeen second level indicators, including port logistics operating conditions, port logistics development environment, port logistics infrastructure conditions, port logistics service level and the potential of port logistics development period. Based on the improved DEA algorithm model, the competitiveness of port logistics in Shenzhen is quantitatively analyzed. The calculation results show that the input and output of Shenzhen port in 2015 and 2016 are unreasonable, and there is a waste of resources. At the same time, the results validate the adaptability of the improved DEA algorithm in port logistics competitiveness analysis.

Appendices

| Table 3. Shenzhen port logistics data. |
|---------------------------------------|
| **Index** | 2012 | 2013 | 2014 | 2015 | 2016 | Unit |
| Hinterland economy GDP | 127457 | 140438 | 153602 | 164960 | 179664 | hundred million |
| Port city GDP | 12971 | 14573 | 16002 | 17503 | 19493 | hundred million |
| More than ten thousand ton berths | 69 | 69 | 67 | 74 | 69 | individual |
| Container berth | 44 | 44 | 44 | 47 | 44 | individual |
| Berth length of productive wharf | 31.38 | 31.38 | 29.1 | 32.45 | 31.38 | kilometer |
| Container terminal deep water berth | 39 | 39 | 39 | 43 | 49 | individual |
| Berth shoreline of container terminal | 16943 | 16943 | 16943 | 15969 | 16943 | mi |
| Port berth | 160 | 147 | 144 | 172 | 172 | individual |
| Port cargo throughput | 2.2087 | 2.3398 | 2.2324 | 2.1703 | 2.14 | million tons |
| Container throughput | 2294 | 2328 | 2404 | 2420 | 2398 | ten thousand TEU |
| Foreign trade throughput | 1.82 | 1.82 | 1.84 | 1.84 | 1.80 | million tons |
| GDP growth rate in the hinterland economy | 9.94 | 10.18 | 9.37 | 7.39 | 8.91 | % |
| Annual growth rate of cargo throughput | -1.07 | 5.94 | -4.59 | -2.77 | -1.37 | % |
| Logistics added value | 470.955 | 463.291 | 500.405 | 540.80 | 626.32 | hundred million yuan |
Container throughput growth rate | 1.64 | 1.48 | 3.26 | 0.7 | -0.91 | %

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References
[1] Yeo, G.T., Song, D.W. (2006) An application of the hierarchical fuzzy process to container port competition. Policy and Strategic Implication Transportation, 33(4): 409-422.
[2] Yang, Y.Y., Liu, N. (2009) The research of the co-competition strategy and competence evaluation of port logistics in the Pearl River Delta region. Zhejiang University.
[3] Song, C.C., Jia, H.Y. (2010) Based on DEA approach for evaluating the competitiveness of port. Dalian Maritime University.
[4] Jiao, X.L., Ma, T.S. (2010) Study on evaluation system of port logistics performance. Chang'an University.
[5] Xiao, H.H., Wu, J.C. (2011) Comparative study of the competitiveness of port logistics between Pearl River Delta and Yangtze River Delta. Guangdong Institute of Business.
[6] Zhu, R.Z. (2014) Comprehensive evaluation index and synergy analysis of port logistics enterprise competitiveness. China Water Transport (next month), 06: 63-64.
[7] Chen, S.Y., Peng J. (2012) Port logistics performance evaluation based on PCA and DEA analysis method. Logistics Engineering and Management, 34(2).
[8] Li, M.J., Chen, G.H. (2003) Research and application of data envelopment analysis (DEA). Engineering Science in China, 5(6).
[9] Wang, S.G., Zhong, M. (2011) Port logistics competitiveness evaluation of the ports around Bohai. Dalian Maritime University.