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Research on the Operational efficiency Evaluation of Container Terminal Based on DEA Model

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Abstract

A performance evaluation index system for container terminal operations at ports was developed, incorporating eight input indicators and one output indicator. Utilizing the BCC-DEA model under the assumption of variable returns to scale, the operational efficiency of container terminals at Guangzhou Nansha Port in 2022 and four other regions was assessed and analyzed. The results demonstrate the feasibility of using this model to evaluate the operational efficiency of container terminals, highlighting its data accessibility and its potential to assist port management departments in formulating relevant policies and guidelines to enhance productivity.

Keywords

Container terminal, Operational efficiency, BCC-DEA model, Nansha Port.

1. Introduction

With the continuous advancement of global economic integration, international economic exchanges are becoming increasingly interconnected. Shipping, as the primary mode of global goods transportation, plays a crucial role in economic development. Container transport, characterized by its high efficiency and safety, has become the predominant method in shipping. Analyzing the operational efficiency and constraints of container terminals is of significant practical importance for enhancing the influence and overall competitiveness of port shipping operations.

Research on port operational efficiency is relatively scarce. Guo Xiaona [1] employed the BCC-DEA model to study data from 18 major inland and coastal ports in China, analyzing key factors affecting port operational efficiency. Li Gongming [2] used constrained variables and virtual decision units in the Data Envelopment Analysis (DEA) model to enhance data discernment and evaluation result credibility. Sui Xiaoyan [3] applied the DEA-CA-MI method to dynamically and statically evaluate the operational efficiency of 37 coastal ports in China, concluding a relationship between overall technical efficiency and port average scale similar to an open downward parabolic function. Lai Chengshou [4] improved the DEA cross-efficiency model by introducing game cross-efficiency, constructing matrices between port asset total and efficiency, and throughput and efficiency, and proposing improvement recommendations. Ju Shuimu [5] employed panel data stochastic frontier analysis to evaluate the operational efficiency of port enterprises based on indicators such as operating revenue, operating costs, and number of employees. Liu Mingwu [6] utilized the DEA-Tobit two-stage method to research the operational efficiency of container ports in the upper and middle reaches of the Yangtze River, comprehensively analyzing influencing factors and dissecting operational efficiency by technical efficiency and scale efficiency categories.

This article primarily employs quantitative and qualitative research methods. Quantitatively, the Data Envelopment Analysis (DEA) method is mainly used to evaluate the efficiency of Nansha Port container terminal. Qualitatively, based on the evaluation results, the practical

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situation of Nansha Port container terminal is combined with theory to empirically analyze existing inefficiencies and propose measures and recommendations to improve operational efficiency.

2. Evaluation index system

The evaluation of operational efficiency at semi-automated container terminals in Tianjin Port is a comprehensive system engineering task. Several principles must be followed in constructing the evaluation framework:

1. Comprehensiveness Principle

Indicators selected should comprehensively and systematically reflect the operational status, equipment efficiency, equipment performance, and management level of the container terminal.

2. Scientific Principle.

The construction of the indicator system should be scientific and rational. If the system is too extensive or divided too finely, it may be influenced by specific local aspects, thereby affecting the evaluation efficiency. Conversely, if the system is too coarse, it may fail to adequately reflect the comprehensive characteristics of the operational efficiency of the container terminal.

3. Independence Principle.

Each indicator should be representative of a single or composite aspect and should not be unduly influenced by other evaluation indicators. Moreover, it should avoid excessive subjective factors.

4. Accessibility Principle.

Indicators used in the evaluation should have stable data sources, be quantifiable, and meet the convenience requirements for indicator calculation.

Analyzing the evaluation indicator systems for container terminal operational efficiency from domestic and international literature, two major evaluation indicator categories can generally be identified: financial indicators and production indicators. Financial indicators refer to ratios derived from the financial statements of port enterprises, evaluating the input-output relationship of port investments. Production indicators involve using infrastructure-related indicators at the terminal construction level as inputs and port throughput as output, systematically and scientifically evaluating port operational efficiency.

This article selects evaluation indicators from the production and input perspectives. Based on the principles and thoughts of constructing the evaluation indicator system for container terminals, the final evaluation indicator system is illustrated in Figure 1.

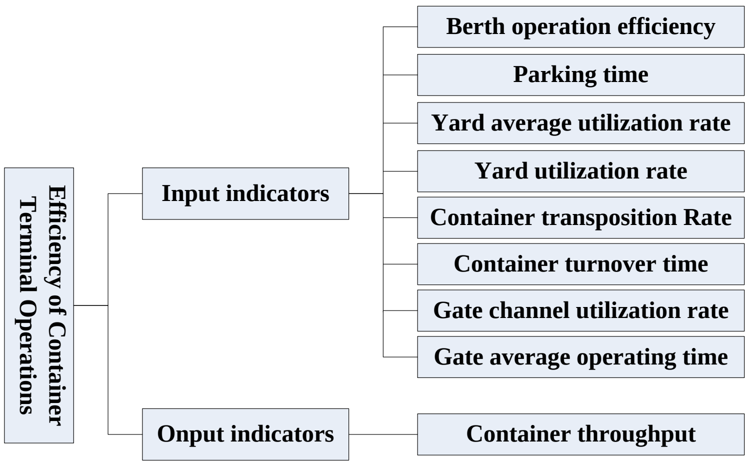

Figure 1: Index system for operational efficiency evaluation of container terminals

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3. DEA evaluation model

DEA (Data Envelopment Analysis) model is a classic non-parametric analysis method often applied in efficiency evaluations across different sectors. Its fundamental concept is to treat each evaluated unit as a decision-making unit (DMU). Each DMU has inputs and outputs, and based on these, a production frontier can be calculated. By comparing the actual output level of each DMU with the frontier output level, the efficiency evaluation value of each DMU can be obtained. DEA models exist in various forms; this study employs the classical CCR model and the BCC model under variable returns to scale assumptions.

1. Classical CCR Model

Suppose there are n decision-making units (DMUs), each with m types of inputs and s types of outputs denoted as X_i and Y_i, respectively. Where $X_i = \{x_{1i}, x_{2i}, \cdots, x_{mi}\}$ and $Y_i = \{x_{1i}, x_{2i}, \cdots, x_{mi}\}$. Define μ and v represent the inputs and outputs for the *i*-th DMU. Where $\mu = \{\mu_1, \mu_2, \cdots, \mu_m\}$ and $v = \{v_1, v_2, \cdots, v_m\}$. The basic CCR model can be formulated as follows in a fractional programming form:

$$o.b. \max Z = \sum_{r=1}^{s} \mu_r y_{r0} \Big/ \sum_{i=1}^{m} v_i x_{i0}$$
$$s.t. \begin{cases} \sum_{r=1}^{s} \mu_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij} \le 1 \\ \mu_r, v_i \ge 0; r = 1, \cdots, s; i = 1, \cdots, m \end{cases} \tag{1}$$

Where, the objective function represents the ratio of the weighted sum of outputs to the weighted sum of inputs for each decision-making unit (DMU), aiming to evaluate the efficiency of each DMU. There are two constraints: one ensures that the efficiency of all DMUs is less than or equal to 1, while the other ensures that all weights assigned to inputs and outputs of the DMUs are greater than 0.

2. Variable Returns to Scale BCC Model

According to DEA model theory, the efficiency scores obtained from the CCR model are based on the assumption of constant returns to scale. However, in practical applications, we often encounter situations where returns may increase or decrease with increased inputs. Therefore, the BCC model under variable returns to scale assumptions was introduced to address this issue. Its basic form is as follows:

$$o.b. \min \theta$$
$$s.t. \begin{cases} \sum_{j=1}^{n} x_{ij} \lambda_j \le \theta x_{i0}; i = 1, \cdots, m \\ \sum_{j=1}^{n} y_{rj} \lambda_j \le y_{r0}; r = 1, \cdots, s \\ \sum_{j=1}^{n} \lambda_j = 1; j = 1, \cdots, n \\ \lambda_j \ge 0; j = 1, \cdots, n \end{cases} \tag{2}$$

We choose BCC-DEA Model to evaluate the operational efficiency of container terminal.

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4. Case study

4.1. Basic data

To objectively evaluate the operational efficiency of Guangzhou Nansha Port container terminal, this study selected container terminals in Shanghai, Shenzhen, Xiamen, Qingdao, and other coastal cities as a comparative group. The evaluation is based on 2022 input and output indicator data. By horizontally comparing Guangzhou Nansha Port container terminal with these five other terminals, the study aims to better determine its operational efficiency.

Data for the evaluation objects were sourced from port websites, the Ministry of Transport's port yearbooks, relevant research literature, internal staff surveys, and well-known port and shipping consulting firms. After standardizing the data, the results are presented as shown in Table 1.

Table 1: Basic data of DEA evaluation indicators for docks (Standardization)

Evaluating indicator	Nansha Port	Port 1	Port 2	Port 3	Port 4
Berth operation efficiency	0.60	0.91	0.36	0.27	1.00
Parking time	0.14	0.00	0.45	0.76	0.44
Yard average utilization rate	0.32	1.00	0.48	0.45	0.59
Yard utilization rate	0.77	1.00	0.46	0.14	0.36
Container transposition rate	0.15	0.10	0.41	0.32	0.57
Container turnover time	0.58	0.00	0.42	0.73	0.50
Gate channel utilization rate	0.89	1.00	0.54	0.33	0.67
Gate average operating time	0.11	0.00	0.58	0.67	0.33
Container throughput	0.58	1.00	0.49	0.07	0.35

It can be observed that the main factors constraining the operational efficiency of Guangzhou Nansha Port container terminal are the average yard utilization rate and container turnover time. This indicates that the terminal experiences prolonged periods of yard idle time and overall extended container handling process times. These issues are primarily attributed to inefficient scheduling of the terminal's overall operational processes and congestion in certain port areas.

4.2. Evaluation result

According to the operational efficiency evaluation index system constructed in this study for Guangzhou Nansha Port container terminal, and based on the collected data, the BCC-DEA model was solved using mathematical programming methods. The input indicators included berth operation efficiency, berth time, average yard utilization rate, yard usage rate, box handling ratio, container turnover time, gate channel utilization rate, and average gate operation time. The output indicators were container throughput and container throughput growth rate. The solved results are presented in Table 2.

Table 2: Operational efficiency Evaluation of Nansha Port

Port	Comprehensive efficiency	Technical efficiency	Scale efficiency	Ranking
Nansha Port	0.73	1.00	0.73	2
Port 1	1.00	1.00	1.00	1
Port 2	0.47	1.00	0.47	4
Port 3	0.36	1.00	0.36	5
Port 4	0.52	1.00	0.52	3

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From Table 2, it is evident that the pure technical efficiency of each port calculated using the BCC-DEA model is 1. Pure technical efficiency theoretically signifies the efficiency brought about by institutional and managerial practices, primarily influenced by factors such as management and technology within the enterprise. A pure technical efficiency of 1 indicates that the current resource utilization by the enterprise is effective.

In terms of horizontal comparison among ports, Guangzhou Nansha Port container terminal ranks above average nationally in overall operational efficiency. Its efficiency is slightly behind Port 1 (Shanghai Port) and Qingdao Port among the reference group of ports. However, it is important to note that there is significant room for improvement in comprehensive efficiency scores. Benchmarking against Shanghai Port is crucial, and continuous investment in funds and technology is necessary to complete the upgrade and transformation of Nansha Port container terminal.

5. Conclusion

This study focuses on the operational efficiency of container terminals at ports. Based on the characteristics and practical considerations of container terminal operations, the study employs a hierarchical evaluation index system that includes eight input indicators such as berth operation efficiency, berth time, container throughput growth rate, average yard utilization rate, and yard usage rate. Additionally, it incorporates one output indicator, container throughput, adhering to principles of comprehensiveness, scientific rigor, independence, and accessibility in indicator selection. Furthermore, the study constructs a scale variable returns BCC-DEA model for evaluating the operational efficiency of container terminals. Finally, using empirical research data from Guangzhou Nansha Port and terminals in Shanghai, Shenzhen, Xiamen, and Qingdao, the study conducts a case analysis to provide evaluation results for Guangzhou Nansha Port's container terminal and offers recommendations for improvement.

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