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RESEARCH ARTICLE

Evaluation of Operational Performance of Wusongkou Cruise Port Through Network Data Envelopment Analysis

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Abstract

As major hubs for cruise berthing and passenger transfers, cruise ports in China were developing rapidly in the years before the COVID-19 pandemic because of an ever-growing regional market. Wusongkou Cruise Port is the most important port for cruise ships in China, and this study evaluated the operational performance of this port during 2011–2020. To this end, two-stage network data envelopment analysis was conducted to evaluate the port's operation performance; subsequently, the change trajectory of the port's operational efficiency during 2011–2020 was determined, and the potential reasons for the identified changes are discussed. Finally, suggestions for improving the operational performance of Wusongkou Cruise Port are provided.

Key words: Operational performance, Network data envelopment analysis (DEA), Cruise port

1. Introduction

The COVID-19 pandemic severely affected the global cruise industry, which was among the fastest-growing industries prior to the pandemic [1], particularly in Asia, where it had been expanding swiftly in the 5 years preceding the pandemic (2014–2019). The overall 5-year compound annual growth rate (CAGR) for the Asian market in terms of cruise ship passengers, starting from 2014, has been reported as 19.2 %. In contrast, China's 5-year CAGR starting from 2014 reached an impressive 22.2 % [2]. The quick growth of China's cruise industry was driven by two main factors. The first is the growing number of domestic consumers generated by the country's unprecedented economic growth in recent years, which increased the affordability of cruise tours for Chinese consumers, such that it became their primary choice for leisure travel. The second factor pertains to supply; specifically, the Chinese government introduced a series of measures to support China's cruise industry, such as encouraging the construction of advanced cruise terminals, implementing a convenient entry policy for cruise ship passengers, and reducing the tax burden for cruise tourism companies. These measures successfully attracted numerous globally renowned cruise ships to berth at Chinese ports.

With the rapid growth of cruise tourism, the rapid development of China's cruise ports occurred before the pandemic. Since 2014, more than 20 ports in China have been equipped to accommodate cruise ship berthing and passenger transfers [3]. Notably, Wusongkou Cruise Port is the most crucial port for such activities. Located in Shanghai, China, Wusongkou Cruise Port is also known as Shanghai

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Baoshan Wusongkou Cruise Port. The infrastructure of Wusongkou Cruise Port was constructed in two phases. The first phase started in 2008 and included the construction of two berths and a terminal building, and the port facility became operational in 2011. The second phase, which commenced in 2015, involved the additional construction of two berths and two terminal buildings. Thus, the port became fully completed and operational in 2018.

Cruise port infrastructure is crucial for the cruise industry because cruise ships must berth and passengers must transfer at cruise terminals, berths, and terminal buildings. Although mainland China has numerous cruise ports, the insufficient experience among cruise port managers often lead to disorganized management. Accordingly, understanding how China's cruise ports operate is crucial.

The present study evaluates the operational performance of Wusongkou Cruise Port during 2011−2020. The present study mainly analyzes data spanning the years 2011−2020 because this period represents the first decade of operation of Wusongkou Cruise Port, and the challenges and experiences pertaining to its first decade of operation provide a useful reference for shaping subsequent management and operational strategies. In addition, three key events occurred during this decade, namely the start of port's operations in 2011, the start of the second phase of the port's operations in 2018, and the first year of the COVID-19 pandemic (i.e., 2020). Therefore, analyzing the data from this decade enables the determination of the effects of these three events on port performance. The present study assesses the operational efficiency of Wusongkou Cruise Port during each of these 10 years, and it also identifies and analyzes the changes in operational efficiency due to the expansion of the port and the COVID-19 pandemic. The present study further analyzes the reasons for these changes in port performance, and relevant recommendations are proposed.

The remainder of this article is organized as follows. Section 2 presents the literature review. In Section 3, the two-stage network data-envelopment-analysis (DEA) method employed in the present study is described, including how it is applied to measure the efficiency of the port. Section 4 presents the results and discussion, and Section 5 provides the conclusions of the present study.

2. Literature review

Cruise ships initially served both tourism and transportation functions [4]. The cruise industry consists of three main players, which are cruise passengers, cruise ports and cruise companies. A cruise port primarily provides services to cruise ships and their passengers. If a region lacks a suitable port for cruise operations, cruise berthing cannot be conducted, which prevents the development of the cruise tourism industry. Thus, ports are crucial for the development of cruise tourism. Several studies have examined cruise ports, with most of them focusing on port infrastructure [5,6], port environment and sustainability [7,8], port competition [9], and port services for passengers [10,11]. However, few have evaluated the performance of cruise ports. According to the research [12], they pointed out that port efficiency is often regarded as cruise port performance in many cruise port authorities' opinion. In other words, measuring the performance of the cruise port is tantamount to measuring its efficiency.

Numerous scholars have explored how to evaluate port efficiency in the past few decades. Generally, two methods are applied to measure the efficiency of a port. The first is stochastic frontier analysis (SFA), and the second is DEA. Notably, SFA is based on strong assumptions, whereas DEA involves nonparametric evaluation. Researchers are increasingly employing DEA to measure efficiency. In this respect, Roll and Hayuth [13] are the pioneers, being the first researchers to employ DEA to measure port efficiency in 1993. Researchers have then used DEA to evaluate port efficiency in specific areas such as Spain [14] and the Asia−Pacific region [15] or at the global level [16].

In contrast to the aforementioned studies employing standard DEA, Wanke [17] implement a two-stage network DEA model to evaluate the efficiency of ports in Brazil, and the shipment frequency is used as the intermediate output between the input and final output to accurately reflect the actual operations of each port. His study considers six variables, which comprise two inputs (number of berths and warehousing area), two intermediates (solid bulk frequency and container frequency), and two outputs (solid bulk throughput and container throughput).

Although scholars are increasingly using DEA to measure port efficiency, most studies are still focused on container or cargo ports, and research involving the evaluation of cruise port efficiency is limited. A literature review reveals a study that uses the traditional DEA model to evaluate the performance of cruise ports [4]. In that study, the author uses the total berth length of each port and the number of terminals as input variables and the number of cruise ships as the output variable. Di Vaio et al. [18] uses SFA instead of DEA to evaluate the efficiency of 14 Italian cruise terminals. They use the land and infrastructural characteristics of a terminal as the input and the cruise passenger flow as the outputs, and they identify substantial differences in the level of technical efficiency (TE) of the assessed terminals.

Additionally, research involving the evaluation of the operational efficiency of Wusongkou Cruise Port is limited, even though several scholars have started to explore the operational theme of Wusongkou Cruise Port. For example, Jiang [19] evaluates the satisfaction of tourists with Wusongkou Cruise Port.

In the present study, a two-stage network DEA model is employed to measure the efficiency of Wusongkou Cruise Port, and this study addresses the key research gaps identified in the literature review.

3. Methods

3.1. DEA

DEA measures the relative efficiency of a set of decision-making units (DMUs) that apply the same inputs to produce the same outputs. The results of DEA indicate how efficient a given DMU is at converting inputs into outputs relative to other DMUs. The application of DEA method mainly consists of five steps. The first step is identifying the subjects for evaluation, the second step is selecting suitable variables, the third step is constructing a suitable evaluation model, the fourth step is collecting data, and the fifth step is obtaining and analyzing the efficiency results. The CCR model proposed by Charnes et al. is regarded as the first DEA model [20]. This model assumes the existence of n DMUs, which uses m inputs to produce s outputs. Model (1) is the initial CCR model, and E_k is the relative efficiency of DMU k in a set of n DMUs. Model (1) is a linear fractional program that can be transformed into a linear program, as shown in model (2). Models (1) and (2) can be expressed as

$$Max\ E_k = \sum_{r=1}^{s} u_r Y_{rk} \Big/ \sum_{i=1}^{m} v_i X_{ik}$$

$$s.t.\ \sum_{r=1}^{s} u_r Y_{rj} \Big/ \sum_{i=1}^{m} v_i X_{ij} \le 1, j = 1, \cdots, n \tag{1}$$

$$u_r, v_i \ge 0, r = 1, \cdots, s; i = 1, \cdots, m$$

$$Max\ E_k = \sum_{r=1}^{s} u_r Y_{rk}$$

$$s.t.\ \sum_{i=1}^{m} v_i X_{ik} = 1$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0, j = 1, \cdots, n \tag{2}$$

$$u_r, v_i \ge 0, r = 1, \cdots, s; i = 1, \cdots, m$$

However, the CCR model cannot distinguish between scale efficiency (SE) and pure technical efficiency (PTE). Banker et al. [21] decompose the aggregate efficiency of a DMU into SE and PTE by introducing a BCC model as model (3), where ϵ is a small non-Archimedean number and u_0 is not subject to any specific conditions. CCR efficiency can be regarded as aggregate efficiency or TE, and BCC efficiency can be regarded as PTE. Therefore, SE is obtained by dividing TE by PTE, and it reflects the decomposition structure of aggregate efficiency. Furthermore, aggregate efficiency can be obtained by multiplying PTE by SE. Notably, models (1), (2), and (3) are all traditional DEA models. Model (3) can be expressed as

$$Max\ E_k = \sum_{r=1}^{s} u_r Y_{rk} - u_0$$

$$s.t.\ \sum_{i=1}^{m} v_i X_{ik} = 1$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} - u_0 \le 0, j = 1, \cdots, n \tag{3}$$

$$u_r, v_i \ge \epsilon, r = 1, \cdots, s; i = 1, \cdots, m$$

A tandem system is the most basic example of a complex production process that consists of at least two subprocesses connected in series. The traditional DEA model measures efficiency through initial inputs and final outputs and disregards intermediate products. Consequently, it cannot measure the efficiency of subprocesses. Thus, some scholars have expanded the DEA model to examine the efficiency of a production process that comprises two stages [22–24]. The expanded model is assumed to have n DMUs, each of which initially uses m inputs to produce final outputs with q intermediate products. Model (4) is a two-stage network DEA model proposed by Kao and Hwang [22] that measures the overall efficiency of DMUs, and the researchers highlight that the overall efficiency of E_k can be divided into two components, namely the efficiency components E_k^1 and E_k^2. After the optimal multipliers u_r^*, v_i^*, and w_t^* are solved, the following efficiency components are obtained: $E_k = \sum_{r=1}^{s} u_r^* Y_{rk}$, $E_k^1 = \sum_{t=1}^{q} w_t^* Z_{tk} / \sum_{i=1}^{m} v_i^* X_{ik}$, and $E_k^2 = \sum_{r=1}^{s} u_r^* Y_{iK} / \sum_{t=1}^{q} w_t^* Z_{tk}$. Presented by Liang et al. [24], the next model, namely model (5), is not subject to any specific conditions, and it can be expressed as $\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0$. The conditions $\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0$ can be inferred to be redundant in model (4) because $\sum_{t=1}^{q} w_t Z_{tj} - \sum_{i=1}^{m} v_i X_{ij} \le 0$ and $\sum_{r=1}^{s} u_r Y_{rj} - \sum_{t=1}^{q} w_t Z_{tj} \le 0$ indicate that $\sum_{r=1}^{s}$

$u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0$. Furthermore, Wanke [17] applies model (5) to measure the efficiency of 27 bulk or container ports in Brazil, obtaining the overall efficiency ($E_k = \sum_{r=1}^{s} u_r^* Y_{rk}$), the efficiency in the first stage ($E_k^1 = \sum_{t=1}^{q} w_t^* Z_{tk}$), and the efficiency in the second stage ($E_k^2 = \sum_{r=1}^{s} u_r^* Y_{rK} / \sum_{t=1}^{q} w_t^* Z_{tk}$). Models (4) and (5) can be expressed as

$$
\begin{aligned}
& Max\ E_k = \sum_{r=1}^{s} u_r Y_{rk} \\
& s.t. \sum_{i=1}^{m} v_i X_{ik} = 1 \\
& \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, j = 1, \cdots, n \\
& \sum_{t=1}^{q} w_t Z_{tj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, j = 1, \cdots, n \qquad (4) \\
& \sum_{r=1}^{s} u_r Y_{rj} - \sum_{t=1}^{q} w_t Z_{tj} \leq 0, j = 1, \cdots, n \\
& u_r, v_i, w_t \geq \epsilon, r = 1, \cdots, s, i = 1, \cdots, m; t = 1, \cdots q
\end{aligned}
$$

$$
\begin{aligned}
& Max\ E_k = \sum_{r=1}^{s} u_r Y_{rk} \\
& s.t. \sum_{i=1}^{m} v_i X_{ik} = 1 \\
& \sum_{t=1}^{q} w_t Z_{tj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, j = 1, \cdots, n \qquad (5) \\
& \sum_{r=1}^{s} u_r Y_{rj} - \sum_{t=1}^{q} w_t Z_{tj} \leq 0, j = 1, \cdots, n \\
& u_r, v_i, w_t \geq 0, r = 1, \cdots, s, i = 1, \cdots, m; t = 1, \cdots q
\end{aligned}
$$

3.2. Structure and data used in calculations

During DEA, how to combine the characteristics of an assessed object and screening for suitable research variables are crucial. Through expert interviews, four main variables are selected for the present study, namely two initial input variables (number of berths and area of terminal buildings), one intermediate output/input variable (number of ships), and one final output variable (number of passengers). Fig. 1 presents the two-stage structure of the network DEA model applied to measure cruise port efficiency in the present study. On the basis of the characteristics of the two-stage network, the production aspect of cruise ports is divided into two stages, namely the berthing of ships and the transfer of passengers. In the first stage (the ship-berthing stage), the number of berths and the area of terminal buildings are the initial inputs for determining the number of berthing ships. In the second stage (the passenger-transfer stage), the number of transferring passengers is the final output determined on the basis of the number of ships. In this case, the number of ships can be regarded as the intermediate output/input. After the two-stage structure is established, model (5) is applied to measure the operational efficiency of Wusongkou Cruise Port, including its overall efficiency ($E_k = \sum_{r=1}^{s} u_r^* Y_{rk}$), the efficiency of ship berthing in the first stage ($E_k^1 = \sum_{t=1}^{q} w_t^* Z_{tk}$), and the efficiency of passenger transfers in the second stage ($E_k^2 = \sum_{r=1}^{s} u_r^* Y_{rK} / \sum_{t=1}^{q} w_t^* Z_{tk}$). To meet the objectives of the present study, the data reported in two studies are used [25,26]. Specifically, the data spanning from 2011 to 2020 are used, and each year can be regarded as a DMU (Table 1).

4. Results and discussion

The overall operational efficiency of Wusongkou Cruise Port and its efficiency at each stage for the years 2011−2020 were calculated using model (5). Table 2 lists the efficiency estimates for Wusongkou Cruise Port obtained using the two-stage network DEA model; they comprise the overall efficiency of the port and its efficiency at each stage (i.e., ship-berthing stage and passenger-transfer stage). In addition, the trends for these three types of efficiencies are presented in Fig. 2.

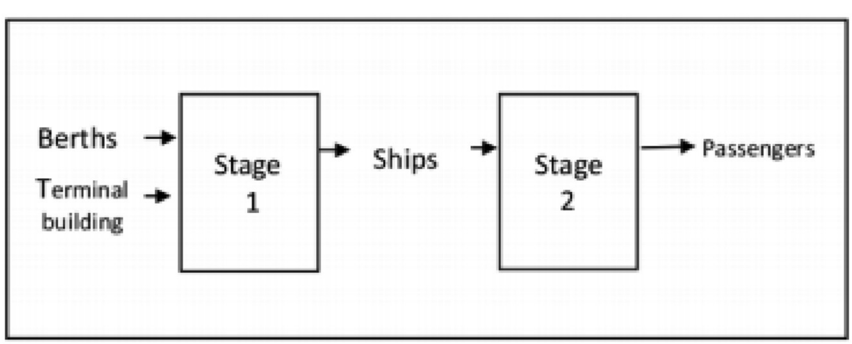

Fig. 1. Two-stage structure of production of cruise ports.

Table 1. Data set.

DMU(Year)	Berths (X1)	Terminal Building area (X2) (thousands of square meters)	Ships (Z1)	Passengers (Y1) (thousands of person times)
2011	2	24	9	23
2012	2	24	60	300
2013	2	24	127	620
2014	2	24	216	1110
2015	2	24	278	1520
2016	2	24	471	2650
2017	2	24	466	2915
2018	4	79	375	2715
2019	4	79	240	1871.4
2020	4	79	25	115.8

Table 2. Efficiency scores and rankings.

DMU(year)	Overall [rank]	Stage 1[rank]	Stage 2[rank]
2011	0.0063 [10]	0.0191 [10]	0.3277 [10]
2012	0.0817 [8]	0.1274[8]	0.6412 [8]
2013	0.1688 [7]	0.2696[6]	0.6261 [7]
2014	0.3022 [5]	0.4586 [4]	0.6590 [6]
2015	0.4139 [3]	0.5902 [3]	0.7012 [5]
2016	0.7216 [2]	1.0000 [1]	0.7216 [4]
2017	0.7937 [1]	0.9894 [2]	0.8022 [3]
2018	0.3696 [4]	0.3981 [5]	0.9285 [2]
2019	0.2548 [6]	0.2548 [7]	1.0000 [1]
2020	0.0158 [9]	0.0265 [9]	0.5940 [9]
Average	0.3128 [-]	0.4134 [-]	0.7002 [-]

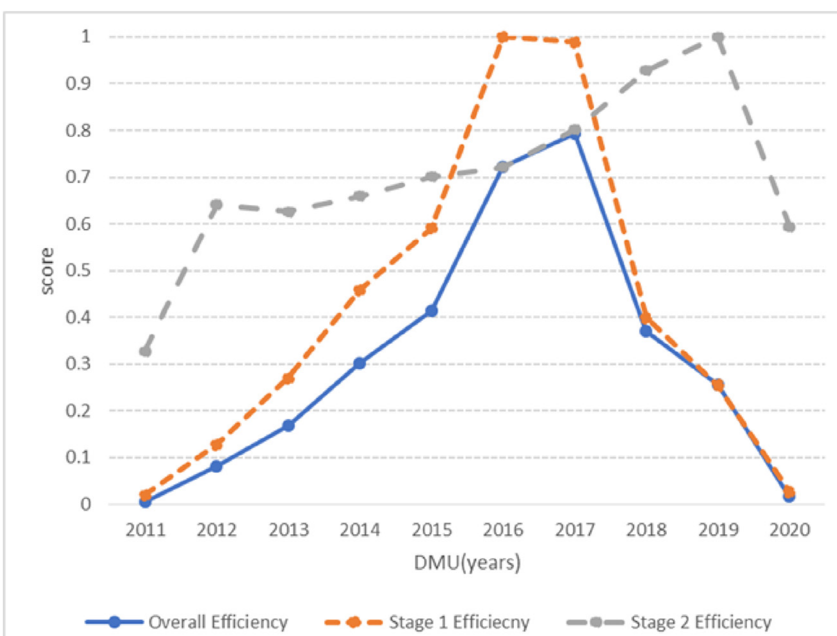

Fig. 2. Efficiency trends for Wusongkou Cruise Port (2011–2020).

Regarding overall efficiency, the highest efficiency level was achieved in 2017. Notably, the overall efficiency of Wusongkou Cruise Port for the years 2011–2017 exhibited an upward trend, and in the past 7 years, the efficiency of the port consistently improved. This consistent upward trend for overall efficiency may have been driven by the accumulation of operational experience by the port and the growing Chinese market. In 2015, the management team of Wusongkou Cruise Port decided to expand its infrastructure, perhaps anticipating the increasing demand for cruise tours in China or because they felt that they had achieved the level of operating efficiency and had acquired the experience required to do so.

However, during the 3 years of operation (2018−2020) after two berths and two terminal buildings were added to Wusongkou Cruise Port, the operating efficiency for each of those years was lower than that in 2017. This finding suggests that after new port facilities were added to Wusongkou Cruise Port, some time was required for achieving familiarity with the facilities and their operation, which could have contributed to the decrease in efficiency. A through comparison of the operational efficiency of Wusongkou Cruise Port from 2011 to 2020 revealed that the efficiency of the port from 2018 to 2020 was lower than that the peak efficiency achieved in 2017 but still higher than that in 2011. This finding indicated that the 7 years of accumulated operating experience enabled a higher level of overall operational efficiency of the port to be maintained after its infrastructural expansion relative to when it started operating in 2011. Notably, within the 10-year period, the level of efficiency in 2020 (i.e., when the COVID-19 pandemic started) was only higher than that in 2011 (i.e., the first year of operation). The COVID-19 pandemic clearly had an adverse effect on the efficiency of Wusongkou Cruise Port. For example, cruise ship berthing was suspended because of pandemic control measures, and the passengers of cruise ships had to cope with cumbersome pandemic prevention measures during passenger transfers.

After the overall efficiency of Wusongkou Cruise Port was calculated, the efficiency of the two stages was analyzed. The port's average ship-berthing efficiency was 0.4134, and the average passenger-transfer efficiency was 0.7002. These findings indicated that the port was operationally more efficient at conducting passenger transfers than at conducting ship berthing. A possible reason is that the operational difficulty of ship berthing is considerably greater than that of passenger transfers.

The level of efficiency in the first stage peaked in 2016, which was not the year in which peak overall efficiency was achieved (the peak was achieved in 2017). A possible reason is that for Wusongkou Cruise Port, numerous tests and simulations had to be conducted in 2017 prior to the official opening of two new berths and two terminals in 2018, which could have disrupted the operations of existing berths and affected their efficiency.

The trend for efficiency in the second stage indicated that the port's efficiency had been increasing continuously from 2011 to 2019 but decreased in 2020. This finding suggests that passenger transfers require the cooperation of the port, cruise ship lines, and passengers. The process of transferring passengers is very straightforward such that accumulating experience in this area is easy. In addition, the decreased efficiency of passenger transfer in 2020 could mainly be due to the COVID-19 pandemic. Because of the pandemic, the port introduced numerous pandemic prevention measures pertaining to passenger transfers, such as testing passengers for COVID-19, requiring passengers to provide health certificates, and implementing on-board quarantines, and these changes could have collectively reduced the efficiency of passenger transfers.

A notable phenomenon for efficiency ranking is that all three categories of efficiency were at their lowest and second lowest levels in 2011 and 2020, respectively. These findings can be attributed to the lack of operating experience during the initial year of operation (i.e., 2011) and the adverse effect of the COVID-19 pandemic on the operating efficiency of Wusongkou Cruise Port in 2020.

5. Conclusions

The present study conducts two-stage network DEA to measure the efficiency of Wusongkou Cruise Port. Thus far, few studies have applied two-stage network DEA to study cruise ports. A key contribution of the present study is the decomposition of the port's overall efficiency into two subcategories, namely ship-berthing efficiency and passenger-transfer efficiency. The results of the present study can help the management of Wusongkou Cruise Port to understand the efficiency and operational situation of the port at various stages. In addition, the findings revealed that the COVID-19 pandemic had a considerable adverse effect on the operating efficiency of Wusongkou Cruise Port, which indicates that port authorities must prioritize addressing this challenge.

The operational efficiency of Wusongkou Cruise Port from 2011 to 2020 is clarified in the present study. The findings for the overall efficiency and the two efficiency subcategories provide a clear overview of the changes in the port's operational efficiency. Specifically, the port's overall efficiency increased from 2011 to 2017 before the second-phase infrastructure of the cruise port was put into operation but decreased thereafter. The change during the second stage suggests that the port's overall operational efficiency should be further improved in the future.

An analysis revealed that Wusongkou Cruise Port's operational efficiency substantially decreased because of the COVID-19 pandemic. Accordingly, for the port, plans should be developed for coping with the adverse effects of a pandemic in the future. For instance, when the circumstances permit, pandemic prevention measures can be appropriately loosened to improve operational efficiency. To improve passenger-transfer efficiency, more self-service check-in counters and self-service clearance counters should be added to reduce passenger wait times. The port's average passenger-transfer efficiency being higher than its ship-berthing efficiency suggests that it is more competent at conducting passenger transfers than at performing ship berthing. Accordingly, the management of Wusongkou Cruise Port should accumulate further experience in cruise ship berthing, particularly the berthing of large cruise ships. The manager of Wusongkou Cruise Port can implement advanced planning systems to optimize ship scheduling and to streamline the port's berthing process. These improvements involve coordinating arrival and departure times, prioritizing berthing on the basis of based on ship size, and minimizing wait times.

Although the present study thoroughly examines the efficiency of Wusongkou Cruise Port and discusses the implications of its findings, it is not without limitations. First, the outputs of the present study are all desirable outputs, even though a cruise port can also produce undesirable outputs (e.g., ship wastewater and ship exhaust gas). Thus, future studies should conduct efficiency evaluations that consider undesirable outputs. Furthermore, given that the present study focuses only on the 10-year operational efficiency of a single port (i.e., Wusongkou Cruise Port), future studies should perform comparative research on data from multiple ports for the same study period. Such comparisons (and the corresponding analyses) should involve the application of the two-stage DEA model to clarify the operating efficiency of multiple cruise ports.

Conflicts of interest

No conflict of interest.

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