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越南港口的效率 — 兩階段 DEA 之應用

Efficiency of Ports in Vietnam: A Two-stage Network DEA Application

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摘要

港口是一個國家融入區域經濟和全球經濟的重要樞紐，其效率的高低對於一個國家的國際競爭力有著顯著的影響，越南政府有鑑於該國對於進出口貨物的依賴度逐年增加，所以將港口視為維持其貿易活動成長的重要基礎設施。儘管該國海上貿易量顯著增加，但與其鄰國相比，越南的港口系統顯得相對過時、且競爭力相對較差。有鑑於此，港埠效率的測量對於如何正確改善越南港口性能提供了重要的指標。在本研究中，我們回顧越南港口的內部運營情況，並據此比較 2016 年越南的 20 個港口營運效率。實證結果顯示下列的主要發現：(1) 北部港口比其他地區的港口具有較高的營運效率；(2) 貨物和集裝箱吞吐量不足是越南港口系統效率低下的主要原因；(3) 應謹慎考慮且避免在船隻吸引力低下的港口投資，以杜絕浪費額外資源；(4) 應針對每個投入與產出進行特定的調整，以提高整體效率。

關鍵字：越南港口效率、網路資料包絡分析、差額變數基礎衡量模型

Abstract

Port is a critical linkage for a nation to integrate into the regional and global economy. The efficiency of port infrastructure contributes significantly to a nation's international competitiveness. Increasingly relying on import and export, Vietnam considers port as a critical infrastructure that sustains trading activities. Despite the

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significant increase in seaborne trade volume, the port system in Vietnam appears more obsolete, and less competitive compared with the ones of the neighboring countries. Given this, the efficiency measurement is essential for giving out the direction to improve the performance of ports in Vietnam. In this study, we examine the efficiency of 20 Vietnamese ports in 2016 with the consideration of the port's internal operation. The empirical results reveal the major findings as follows: (i) ports in the North appear to be more efficient than the ports in other regions, (ii) the insufficient cargo and container throughput is the major driver of the inefficiency of the port system in Vietnam, (iii) the investments on the ports which are inefficient in the stage of attracting vessel calls should be carefully considered to avoid the extra wasted resources, and (iv) the specific amount of adjustment that should be made for each input, output to enhance efficiency level is provided.

Keywords: Port efficiency, Vietnam, Network Data Envelopment Analysis, Slack-based measure

1. INTRODUCTION

Port is a critical linkage for a nation to integrate into the regional and global economy, its efficiency thus contributes significantly to a nation's competitiveness. It is estimated that 80% of global trade volume is transported by sea. The growth in the seaborne trade volume has put relentless pressure on port infrastructure. Furthermore, the increasing consolidation of shipping alliances and the emergence of mega-vessels have added greater volatility to the port industry. The industry which was used to be conceited of its absolute monopoly position has now been pushed into a stiff battle. Since the born of the container, the concept of transshipment has become fashionable due to cost-saving. The concern of individual port is not just about its ability to physically handle cargo, but also the competency for competing for cargo with other ports (Cullinane et al., 2006). Despite the rise in the global seaborne trade volume, the cargo throughput of some ports might standstill or even might decrease.

In the given context, efficiency assessment of port operation has been the subject of extensive discussion. Indeed, the efficiency improvement is critical for the growth and competitiveness of individual port in such a harsh market (Cullinane et al., 2006).

The port system in Vietnam also faces the common problems persisted in the global port industry. Vietnam grants strategical location with a long coastline of more than 3,000 km and lies adjacent to vital sea routes of East-West and North Asia-Southeast Asia. For Vietnam, the port system plays a crucial role in facilitating trading activities, thus sustaining the momentum of economic growth. In preparation for global integration, Vietnam has made tremendous efforts to improve port infrastructure. Regardless of the fast expansion, the Vietnamese port system has been remarked for obsolete technology, low efficiency, and lack of competitiveness compared to neighboring countries. Against this background, the study aims to examine the efficiency of the port system in Vietnam.

A limited number of studies have considered the efficiency of the port system in Vietnam. For instance, Nguyen et al. (2011) was among the few authors examining Vietnamese ports performance using both Data Envelopment Analysis (DEA), and Stochastic Frontier Analysis (SFA). Continuing to extend the previous research, Nguyen et al. (2016) combined the bootstrapped technique with DEA for mitigating the statistical error in order to gain a more precise result. Their studies assess how efficiently the ports in Vietnam transform the berth length, container terminal area, and cargo handling equipment into cargo throughput.

To enrich the existing literature, our study aims to provide more insight into the efficiency of the ports in Vietnam. Specifically, instead of assuming a single production stage for the port operation as in the prior studies, the current study disentangles the port operation into two stages, namely attracting vessel calls and handling cargo, container stages. By considering the internal structure of the port operation, we expect to detect more sources of inefficiency underlying the port system. Additionally, the results derived from the study offer some helpful suggestions for Vietnamese port authorities and related managerial decision-makers who concern the efficiency of the Vietnamese seaport industry.

To integrate the internal structure of the port operation in the efficiency measurement and fully exploit the maximum potential improvement of the ports, the current study employs Slack-based measure network DEA developed by Tone and Tsutsui (2009).

The rest of the paper is organized as follows: section 2 presents a literature review on port performance measurement; section 3 contains the discussion on input and output variables selection; section 4 provides the methodology applied in the study; section 5 includes the collected data and the empirical results; finally, section 6 summarizes the results, discusses the research limitations and future research.

2. LITERATURE REVIEW ON PORT PERFORMANCE ANALYSIS

The dynamism of the port industry has activated great concern for efficiency assessment. Since the very beginning, numerous efforts have been devoted to establishing a better performance measure. Traditionally, the simple ratio analysis has been widely used to measure the port's performance. For instance, De Monie (1987) used single-factor productivity to measure port performance and productivity; Talley (1998) employed the ratio of the actual to the optimum throughput over a specific period. Despite the simplicity of the methodology, the ratio analysis is only capable of reflecting only one dimension of the port's operation. The performance evaluation thus appears incomplete. The failure of this approach has triggered the evolvement of various performance measures. In recent years, Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) have emerged as two main methods to measure efficiency (Cullinane et al., 2006).

SFA proposed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977) is a parametric approach that hypothesizes a functional form of the relationship between inputs and outputs. In contrast, DEA developed by Charnes et al. (1978) is a non-parametric approach that uses mathematical programming to identify the efficient frontier. Both the DEA and SFA have their strengths and weaknesses. In point of fact, DEA seems to be a more favorable method with proof of more impressive growth rate in number of publications using the DEA method since the very first article (Panayides et al., 2009). The main advantage of DEA over SFA is that it requires no prior assumption on the production function. DEA is a data-driven frontier technique, in which the best practice frontier is established from the given data set of decision-making units (DMUs), the efficient DMUs are on the frontier and their efficiency scores are equal to 1, and the rest are inefficient with the efficiency scores less than 1.

Today, DEA has evolved itself with substantial extensions to provide a tailored, trustworthy measurement and has been applied in different industries with specific circumstances. In this vein, DEA is appraised as one of the most appropriate approaches to measure port performance with the extensive literature. Roll and Hayuth (1993) were among the first authors to apply CCR DEA model to evaluate theoretically the efficiency of 20 container ports; Martinez-Budria et al. (1999) measured the efficiency of 26 Spanish ports 1993-1997; Tongzon (2001) adopted cross-section data from 1996 covering four Australian ports and 12 other ports from around the world; Barros (2003) analyzed the total productivity change in 10 Portuguese seaports, 1990-2000 by applying Malmquist index; Cullinane and Wang (2006) tested the differences in results derived from BCC and CCR models on a sample of 69 container terminals in Europe.

More recently, Nguyen et al. (2016) adopted bootstrapped DEA to gain more precise efficiency scores of 43 ports in Vietnam. Wang et al. (2020) used DEA to evaluate the environmental performance of ports in China. Paul and MacDonald (2017) investigated the relationships between port efficiency and vessel accidents. Mustafa et al. (2020) compared the efficiency of container ports in the Asian and Middle East region.

Most of the previous studies on port performance only measure the relative efficiency regarding the simple conversion of multiple inputs into multiple outputs, neglecting the internal or linking activities within the port operation. In practice, to maintain the service, port operations contain several stages or processes. Consequently, the efficiency of each stage or process is a critical element contributing to the efficiency of the overall system. This thus requests a measure of port performance with the consideration of the internal structure of the port operation.

Recognizing the importance of incorporating the internal structure in assessing port performance, Wanke (2013) was the first researcher to apply the network DEA to measure the efficiency of 27 Brazilian ports. In the study, the port operation is decomposed into two stages, namely physical infrastructure establishment and shipment consolidation. Specifically, in the first stage, physical infrastructure efficiency is evaluated by the utilization of the number of berths, warehousing area, and yard area to achieve a certain shipment frequency per year. In the second stage, to gauge shipment consolidation efficiency, the output of the previous stage is chosen as the input of this stage to produce solid bulk frequency (tons per year), container throughput (containers per year).

The application of network DEA in

the study by Wanke (2013) provides greater insight into the sources of inefficiency in the port operation. However, the employment of radial measurement fails to capture all potential improvements to the port operation. To bridge the gap in the current literature, we employ a non-radial measure to examine the Vietnamese port performance with the consideration of its internal structure.

3. INPUT, AND OUTPUT VARIABLES

It is important to note that the selected measurement should reflect the greatest extent of the process under the study. Given the fact that the port performs multiple activities, it is necessary to restrict the scope of the analysis to some specific activities.

Regarding the final outputs, we chose two variables, namely bulk cargo throughput and container throughput. As the ports in our data set to handle both bulk and container cargo, we thus used the two measures representing for outputs of port operation. This selection is consistent with the prior studies which evaluate multi-purpose ports (see, for instance, Barros, 2006; Wu and Goh, 2010; Mustafa et al., 2020). The bulk cargo throughput is measured in tons, reflecting the amount of dry and liquid cargo handled by a port in the year. The container throughput is measured in the number of TEUs loaded and unloaded by a port in the year.

To produce the above outputs and maintain proper operation, a variety of inputs are employed. According to Dowd and Leschine (1990), container terminal productivity deals with quantifying the utilization of the three resources, namely labor, equipment, and land. This proposal has then been widely used by Wang et al. (2003), Barros (2003), Cullinane and Wang (2006), Cullinane et al. (2006). In terms of measuring land utilization, in line with previous studies, this study uses the total port area (Barros, 2003; Wanke, 2013) and berth length (Wanke, 2013; Low and Lam, 2013; Andrade et al., 2019) for input variables. For equipment, it is hard to retrieve the data as different ports deploying different equipment. Regarding data availability and adequate references to previous studies, the number of quay cranes is chosen as an input variable (Tongzon, 2001; Wanke, 2013; Low and Lam, 2013; Andrade et al., 2019). Due to the unavailability of data, we excluded the labor variable from this research.

Following Wanke (2013), the number of vessel calls is regarded as the intermediate product connecting the two stages as depicted in Fig. 1. The variable of vessel traffic initially reflects how efficiently the port utilizes the initial inputs in Stage 1. Vessels do not just arrive or depart with air but come along with cargo, container. Also, they vary in sizes and types. As predefined, the second stage examines the efficiency of port handling bulk cargo and container.

4. METHODOLOGY

Traditional DEA models treat DMUs' operation as a black-box system, ignoring the intermediate products or linking activities (Tone and Tsutsui, 2009). Consequently, numerous inefficiencies arising from the activities within this internal structure cannot be fully addressed, restricting helpful information for the system's efficiency improvement.

In recent years, to open up the "black-box", network structure in DEA has continuously expanded in varied shapes such as series systems, parallel systems, dynamic systems, unstructured systems (Kao, 2009). Two-stage network DEA is a special case of series systems where inputs of the first stage are used to produce the intermediate outputs that then join the process to produce the final outputs in the second stage. Unlike the traditional DEA, which treats the whole production as an aggregated process, the two-stage network structures allow a more profound analysis of the internal structure of DMUs by modeling the operation into the two stages.

Both radial and non-radial measures can be applied to measure the efficiency of a network structure. For radial measurement, the efficiency measurement only accounts for the radial improvements while ignoring the possible improvements derived from slack values. The maximum possible improvement to enhance DMU's efficiency is not fully taken

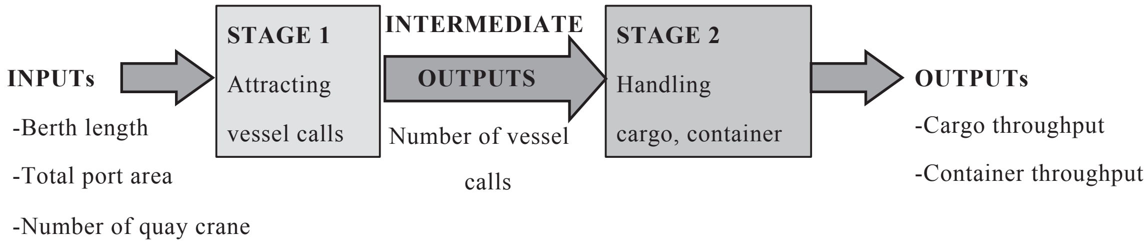

Figure 1 The network structure of port operation

into account. Moreover, the radial measure in network DEA only allows the option of a unique orientation for improvements such as either input or output orientation. In contrast, the non-radial measure with the representative of slacks-based measure (SBM) could accounts for all the potential inefficiency, thus helping the user to detect the largest possible improvement. Furthermore, SBM is also more flexible in the orientation of improvement.

Tone (2001) proposed SBM, which was applied to the "black-box" system in 2001. In 2009, Tone and Tsutsui extended this measure to the network structure. To detect all potential improvement, SBM accounts for all inefficiency represented in the form of input excesses and output shortfalls (input and output slacks). Differing from the conventional DEA such as BCC or CCR models, SBM model allows a greater flexible choice of the direction to improve such as input, output, non-orientation. To the given advantages of SBM, the current study applies this approach with the consideration of network structure to examine the port performance in Vietnam.

Before describing the applied model, some assumptions and terms need to be clarified. First, the intermediate products are assumed to be freely adjusted. According to Chen et al. (2016), models developed on the free-link assumption address potential conflicts between the two stages that the fixed link case cannot solve. Secondly, since the ports in the data set are greatly varied, variable returns to scale assumption is adopted. Thirdly, the first stage is assumed to be equally important as the second stage, then two stages share the same relative weight of 0.5. Table 1 shows the description of variables / notations used in the model.

We deal with n ports ($j = 1, \ldots, n$) with their operation be divided into two stages. In the first stage, the ports consume m inputs $x_{io} (i = 1, \ldots, m)$ to produce h intermediate products $z_{go} (g = 1, \ldots, h)$. In the second stage, h intermediate products $z_{go} (g = 1, \ldots, h)$ produced in previous stage are used to achieve s final outputs $y_r (r = 1, \ldots, s)$. The non-oriented SBM network models by Tone and Tsutsui (2009) under VRS assumption can be presented as follows:

$$\text{Min} \ \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}^-}{x_{io}}}{1 + \frac{1}{s}\sum_{r=1}^{s}\frac{s_{ro}^+}{y_{ro}}} \quad (1)$$

$$\text{S.t:} \quad x_{io} - s_{io}^- = \sum_{j=1}^{n}\lambda_j^1 x_{ij}, \ (i = 1, \ldots, m), \quad (1.1)$$

$$\sum_{j=1}^{n}\lambda_j^1 z_{gj} = \sum_{j=1}^{n}\lambda_j^2 z_{gj}, \ (g = 1, \ldots, h), \quad (1.2)$$

Table 1 Description of variables/ notations

Variable/ Notation	Definition/ Item
o	The denotation for the observed port/ DMU
n	Number of ports/ DMUs
m	Number of inputs
s	Number of outputs
h	Number of intermediate outputs
E_0	Efficiency of overall process of DMU_0
E_0^1	Efficiency of first stage of DMU_0
E_0^2	Efficiency of second stage of DMU_0
w_1	Weight of the first stage
w_2	Weight of the second stage
$x_i (i=1,\ldots,m)$	Input i^{th}
$z_g (g=1,\ldots,h)$	Intermediate product g^{th}
$y_r (r=1,\ldots,s)$	Output r^{th}
λ_j^1	Intensity variables of first stage
λ_j^2	Intensity variables of second stage
s_i^-	Input slack of input i^{th}
s_r^+	Output slack of output r^{th}

$$y_{ro} + s_{ro}^+ = \sum_{j=1}^{n} \lambda_j^2 y_{rj}, \ (r=1,\ldots,s), \quad (1.3)$$

$$\sum_{j=1}^{n} \lambda_j^1 = 1, \quad (1.4)$$

$$\sum_{j=1}^{n} \lambda_j^2 = 1, \quad (1.5)$$

$$s_{io}^- \geq 0, \ (i=1,\ldots,m), \quad (1.6)$$

$$s_{ro}^+ \geq 0, \ (r=1,\ldots,s), \quad (1.7)$$

$$\lambda_j^1 \geq 0, \ \lambda_j^2 \geq 0, \ (j=1,\ldots,n). \quad (1.8)$$

In the objective function (1) we deleted the relative weights of the stage for the sake of simplicity as they all equal to 0.5. If the DMU is efficient, it plots on the frontier, and values of slack s_i^-, s_r^+ are all equal to zero. On the other hand, inefficient DMUs possess the slack values larger than 0, which indicates the input excesses and output shortfalls. Constraint (1.2) indicates the free link imposed on intermediate products. The two constraints (1.4), (1.5) deal with the variable returns to scale case. If these two constraints are taken away from the model, the constant returns to scale assumption is adopted.

The efficiency of the system, stage 1 and 2 of DMU_0 can be respectively calculated as follows:

System efficiency: $$E_o = \frac{w_1\left(1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}^-}{x_{io}}\right)}{w_2\left(1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_{ro}^+}{y_{ro}}\right)}$$

Stage 1 efficiency: $$E_o^1 = 1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}^-}{x_{io}}$$

Stage 2 efficiency: $$E_o^2 = \frac{1}{1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_{ro}}}$$

5. EMPIRICAL ANALYSIS

5.1 The data

Based on the availability of data, 20 ports[4] were selected. The selected ports are among the biggest ports locating scatteringly from the North to the South of Vietnam. They provide combined services for handling oil, bulk cargo, and containerized cargo. The data was collected from the Vietnam Seaports Association website (http://www.vpa.org.vn/).

The number of DMUs in the data set strictly follows the rule of thumb relating to the number of DMUs and the number of inputs/outputs, in which the number of DMUs is three times higher than the total number of inputs and outputs. The statistical description of the collected data is reported in Table 2.

5.2 Empirical results and discussion

The empirical results are obtained by solving the mathematical programming (1).

5.2.1 Efficiency of port by region

Table 3 reports efficiencies of the system, stages 1 and 2 of the ports in Vietnam by region. Regarding the system efficiency of Vietnam ports, it appears that the top-

Table 2 Statistical description of 20 ports in Vietnam in 2016

Variables		Min	Max	Range	Mean	Standard deviation
Inputs	Berths' length (km)	6	174.1	168.1	70.81	44.77
	Total port's area (ha)	2.3	89	86.7	29.01	21.16
	Number of quay cranes	2	19	17	6.4	4.41
Interme-diate product	Number of vessel calls	87	2,839	2,752	809.25	739.14
Outputs	Cargo throughput (tons)	456	10,046,722	10,046,266	3,108,193	771,417.58
	Container throughput (TEUs)	320	1,086,630	1,086,310	214,363.4	299,359.69

[4] In 2016, there were 67 ports listed on the website of the Vietnam Seaports Association (VSA). We did not consider the other 47 ports due to the lack of reliable data on the number of vessel calls and the berth length.

Table 3 Efficiency of port by region

No	Port	System efficiency	Ranking based on system efficiency	Stage 1 efficiency	Stage 2 efficiency
	The north	***0.641***		***0.748***	***0.649***
1	Quang Ninh	1.000	1	1.000	1.000
2	Hai Phong	0.999	2	0.999	0.999
3	Dinh Vu	0.859	3	0.736	0.979
4	Doan Xa	0.191	12	0.380	0.160
5	Transvina	0.157	14	0.624	0.107
	The center	***0.097***		***0.850***	***0.064***
6	Da Nang	0.002	20	1.000	0.0008
7	Nghe Tinh	0.192	11	0.701	0.127
	The south	***0.331***		***0.712***	***0.342***
8	Ben Nghe	0.387	8	0.467	0.358
9	Bong Sen	0.185	13	0.660	0.125
10	My Tho	0.006	19	1.000	0.003
11	Vinh Long	0.010	18	1.000	0.005
12	Can Tho	0.129	16	1.000	0.069
13	VICT	0.788	5	0.575	0.999
14	Can Tho	0.342	9	1.000	0.207
15	Dong Nai	0.038	17	0.497	0.026
16	VITC	0.788	5	0.575	0.999
17	Sai Gon	0.799	4	0.598	0.999
18	Hiep Phuoc	0.398	7	0.583	0.333
19	Tra Noc	0.141	15	0.783	0.086
20	SPCT	0.294	10	0.514	0.241
	Average	0.385		0.735	0.391
	Max	1.000		1.000	1.000
	Min	0.002		0.380	0.0008
	St Dev	0.350		0.219	0.4177

performing ports locate in the North of Vietnam. Specifically, Quang Ninh, Hai Phong, Dinh Vu ports are among the three top ports in the data set. A possible explanation for the high-efficiency levels of these ports is the high concentration of industrial zones and the high exploitation of natural resources, which contributes to the higher number of vessel calls and the amount of throughput. Meanwhile, the ports in the Central and the South of Vietnam seem to be less efficient compared to the ones in the North. Particularly, the ports in the Central display relatively low-efficiency levels.

To exploit how the efficiency of each stage contributing to the efficiency of the system, we examine the efficiency of each stage. Specifically, in the first stage, we examine whether the ports own over-sufficient resources to handle the given number of vessel calls. Regarding the efficiency scores of stage 1 reported, in average terms, ports in Vietnam achieve an efficiency level of 73.5%, suggesting that given the number of vessels calling at ports in Vietnam, the 26.5% of input resources should have been saved to improve the efficiency of the ports. The results indicate that the maximum wasted resources in this stage account for 62% of the consumed resources. This is the case of Doan xa port. Among the three areas, in the first stage, the ports in the central of Vietnam appear to be more efficient than ports in the north and the south. In general, for the ports which are inefficient in this stage, the investment into these ports should be carefully examined as extra consumed resources with no changes in the number of vessel calls would decrease the efficiency levels of those ports.

In the second stage, we examine the number of vessel calls that the port attracts is equivalent to the number of bulk cargo and container throughput it handles. On average, the ports in Vietnam obtain 39.1% of the efficiency level. Such a low-efficiency level indicates the mismatch between the number of vessels calling at the port and the amount of cargo, container throughput handled by the port. To improve the efficiency level of this stage, more than 60.9% of the current throughput is expected. Among three regions, the north seems to achieve higher efficiency levels while the central appears to display the low-efficiency level. The increase in the amount of cargo and container throughput would enhance the performance of the ports in this stage. A possible approach to boost the amount of cargo throughput handled in each port is to accelerate the trading activities of the regions. To understand how the ports should consume adequate resources and produce sufficient outputs, we continue to examine the slack of each variable in the next section.

5.2.2 Adjustments for port efficiency enhancement

The excess of each input and the

shortfall of each output are shown in Table 4. The value of slack explicitly refers to the remedy for the inefficient ports to enhance their performance. For instance, Nghe Tinh port, which ranks 11th, can improve its performance by reducing berth's length by 6.44 m, the number of quay crane by 13, while simultaneously increasing cargo throughput by 1,717,856.09 tons, and container throughput by 609,310.6 TEUs.

6. CONCLUSION

This study applies the non-oriented SBM-NDEA to examine the efficiency of the 20 Vietnamese ports in 2016. Up to now,

Table 4 Adjustments for port efficiency

No	Port	Berths' length	Total port's area	Number of quay cranes	Cargo throughput	Container throughput
	The north					
1	Quang Ninh	0.00	0.00	0.00	0.00	0.00
2	Hai Phong	−0.01	0.00	0.00	1,505.24	0.00
3	Dinh Vu	−2.01	0.00	−5.00	256,293.76	8,971.64
4	Doan Xa	−23.0	−52.93	−2.00	6,367,821.09	689,009.88
5	Transvina	−35.0	−15.13	0.00	6,641,542.84	739,015.55
	The center					
6	Da Nang	0.00	0.00	0.00	0.00	852,428.46
7	Nghe Tinh	−6.44	0.00	−13.12	4,489,566.86	734,855.29
	The south					
8	Ben Nghe	−71.27	0.00	−6.00	1,717,856.09	609,310.60
9	Bong Sen	−23.64	−2.71	−3.25	7,143,103.84	590,871.90
10	My Tho	0.00	0.00	0.00	3,340,603.04	266,730.94
11	Vinh Long	0.00	0.00	0.00	1,120,679.00	12,873.00
12	Can Tho	0.00	0.00	0.00	4,841,709.35	478,954.61
13	VICT	−49.72	0.00	−4.77	0.00	73.05
14	Can Tho	0.00	0.00	0.00	130,406.97	742,748.65
15	Dong Nai	−116.52	0.00	−9.03	1,548,903.62	949,075.78
16	VITC	−49.72	0.00	−4.77	0.00	73.05
17	Sai Gon	−73.98	−16.78	0.00	0.00	429.06
18	Hiep Phuoc	−77.90	0.00	−1.00	4,371,759.53	589,927.50
19	Tra Noc	−48.00	0.00	−1.00	2,627,602.04	253,741.94
20	SPCT	−54.08	−5.42	−3.00	6,759,202.16	497,200.15

the applications of network DEA to detect more underlying sources of inefficiency in the port industry are relatively scarce. This paper is the first one to apply this approach in an attempt to provide more insight into Vietnamese port performance.

The results show that most ports in Vietnam display relatively low-efficiency level. On average, the ports achieve an efficiency level of 38.5%. Considering the three areas, the ports in the North appear to be more efficient while the ports in the Central seem to lag far behind. This can be explained by the high concentration of industrial zone in the North compared to other regions.

By decomposing the port operation in Vietnam into two stages, namely attracting vessels stage and cargo, container handling stage, the significant lack of cargo and container throughput is detected as the major driver of low efficiency of ports in Vietnam. Also, in the stage - attracting vessels, some ports exhibit low efficiency level, suggesting the wasted resources of ports in handling given number of vessel calls. The investments in these ports should be carefully considered to avoid extra wasted resources. Furthermore, relying on the input and output slacks, the individual port can find their specific remedy to enhance the performance.

Due to the unavailability of data on labor, the current study cannot consider the port utilization of this input. In future research, the data of labor should be included to offer better measurement. Additionally, the sphere of this study limits to handling containers and cargo activities, there still exist some activities that have not been covered. For instance, the logistics, warehousing, tugging activities, future research might take these activities into account for a more comprehensive picture of port efficiency.

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