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Port Efficiency Evaluation: An Application of AHP and Malmquist DEA Model

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Abstract

Purpose: This study aims to assess the efficiency in performance of 22 ports listed in Vietnamese stock market**. Research design, data, and methodology:** A hybrid method of AHP and Malmquist DEA was applied to handle the problem of efficiency measurement. The AHP method was employed to define the efficiency evaluation criteria whilst the Malmquist DEA was utilized to measure the performance efficiency. **Results:** The results showed that five input and output metrics including capital, operation expenses, labour, revenue, and cargo throughputs are important for port efficiency. In addition, it was also found that technology and management skills have great impact on the total productivity of ports. **Conclusions:** Comprehensive evaluation of port system in Vietnam may result in plenty of benefits to individual ports and the port authorities as well as in the course of port performance efficiency improvement. However, the study findings are only in compliance with the case of Vietnam. Thus, future research may be reached out to other regions or countries. The next limitation involves the small number of ports engaging in the empirical study from 2015 to 2021.

Keywords: AHP, Malmquist DEA, Performance efficiency, Port

JEL Classification Code: C44, L91, R42

1. Introduction

The fast growth of global economics has been recognized by the exceptional development of the world port systems, the hubs for transporting goods to all regions of the world, through which connects different countries to an integrated entity (Cullinane et al., 2005). Given its utmost importance in the world transportation and being an economic driver, port performance efficiency needs to be analyzed regularly (annually, even quarterly or monthly) to promptly detect uncertainties in business operations, especially those caused by the outbreak of the Covid-19 pandemic. It is, therefore, of necessity for countries and port operators to evaluate their port performance efficiency to improve the performance efficiency of ports themselves and the national port system. In this study, the author measured the port performance efficiency for a period of before and after Covid-19 from 2015 to 2021 to see the differences in ports' efficiency in this special era.

On the world maritime map, Vietnam is one of the widely-known focal transport hubs with a vast territorial sea of over one millition square kilometers and a long coast of

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more than 3,260 kilometers. From Vietnam's ports, vessels can sail to different foreign regions including the Strait of Malacca, Indian Ocean, Middle East, Europe, Africa, America … (Wang et al., 2021). Thus, any arising problems in Vietnamese port system may cause a considerable impact on the global maritime industry. Apart from its internationally important role, Vietnam's port system has shown its special one in the whole national economy, whereby transport 90% of import-export goods. For the abovementioned reasons, it can be affirmed that measuring the performance efficiency is practically necessary for Vietnamese port system in the post-Covid and global integration context.

To measure the port performance efficiency, various methodologies have been applied such as date envelopment analysis (DEA), stochastic translog cost frontier, stochastic Cobb-Douglas production function … Among them, DEA is the most common method (Wang et al., 2021), a non-parametric efficiency measurement technique, handling a multitude of inputs and outputs concurrently. There are different types of DEA for different research purposes including CCR – oriented DEA in case constant returns-to-scale (CRS) is assumed in the research whilst BCC – oriented DEA for the case of variable returns-to-scale (VRS), or Malmquist DEA to measure the performance efficiency changes over a period of time. For the purpose of studying the performance efficiency for Vietnam's port system in a long period, in this study, the author suggested to utilize Malmquist DEA. To the extent of the author's knowledge, few research applying Malmquist DEA approach to measure the efficiency for ports in Vietnam has been conducted, especially from the year 2015 to 2021.

The study is structured into five sections. Section 1 presents an introduction to the study. Section 2 presents literature reviews on previous studies, followed by Section 3 which highlights the research design and methodology. An empirical cases applying the proposed research process into measuring the performance efficiency of Vietnamese ports is then conducted in section 4. Conclusion and policy implications are finally presented in Section 5.

2. Literature Review

2.1. Common Methodologies used in Port Efficiency Measurement

Literature review depicts that numerous techniques have been applied in measuring the performance efficiency of ports, namely ratio analysis, stochastic frontier, DEA, etc. (Görçün, 2021; Quintano et al., 2020; Wiegmans & Witte, 2017; Nguyen et al., 2016). Amongst them, DEA is the most popular approach (Wang et al., 2021) because of its exact and comprehensive results. It is, therefore, in this study the author did an intense review on DEA in correspondence with time range.

2.1.1. Port Efficiency Measurement at a Point of Time

To evaluate the performance efficiency of ports at a point of time, an approach of single DEA is favorable. The first research was introduced by Roll and and Hayuth (1993) to measure the efficiency of seaports with input orientation and an assumption of constant returns-to-scale (CRS), which is named as CCR model. The same approach was also conducted by numerous later authors (Tongzon, 2001; Seo et al., 2012; Castellano et al., 2020). The CCR-DEA technique aside, other authors also made another assumption with variable returns-to-scale (VRS) (Zahran & Alam., 2017; Da Cruz & de Matos Ferreira, 2016; Lu et al., 2015; Zheng & Park, 2016; Beuren et al., 2016; Kutin, 2017; Mustafa, 2020; da Costa et al., 2021). To have comprehensive analysis, researchers have a tendency to combine the DEA with different techniques such as Free Disposal Hull (FDH), Stochastic Cobb-Douglas, Stochastic frontier analysis (SFA), DEA - Super – Efficiency, Cluster analysis, etc. to serve various research purposes. For instance, Cullinane et al. (2005) combined FDH with DEA to evaluate the port performance efficiency, in which FDH assumes input and output availability relaxing the convexity proposition. The findings depicted that the integrated approach mattered in case ranking decision-making units (DMUs) regarding their efficiency and making effort to determine the most reasonable course of action for improving the inefficient DMUs are laid emphasis on. Cullinance et al. (2006) utilized the Stochastic Cobb-Douglas approach to provide another evidence of the performance efficiency rankings of chosen ports. In 2018, Hlali applied both DEA and SFA models to compare the technical efficiency of ports. The findings show that SFA model has higher efficiency scores than those of DEA one. In 2022, Kim et al. (2022) proposed an integrated methodology of DEA and cluster analysis to make rationalization plans basing on supply base rationalization theory for the country logistics system.

2.1.2. Port Efficiency Measurement over a Period of Time

To analyze the performance efficiency of ports for a period, some researchers applied single because of its easy-to-use feature. Martinez-Budria et al. (1999), for instance, applied DEA – BCC model to evaluate the efficiency of 26 Spanish ports during 1993 – 1997 period or Chao et al. (2018) utilized DEA to measure the performance efficiency of 13 global container shipping companies from 2013 to 2015. Additionally, to understand more the impact of input and output on the performance efficiency, researchers proposed to use hybrid approach, whereby DEA was combined with other techniques like Tobit regression to determine the efficiency drivers of seaport after conducting DEA analysis steps (Barros, 2003; Nikolaou & Dimitriou, 2021; Liu et al., 2021), Mann-Whitney U-test to check the importance of size, containerization and labour in the performance efficiency of seaports (Barros, 2006) or principal component analysis to validate the suggested input and output variables before analyzing the efficiency of ports. In addition to single DEA method, numerous researchers extended DEA into Malmquist DEA (Barros, 2003; Park & Lee, 2015; Schøyen & Odeck, 2017; Monteiro, 2018; Tovar & Wall, 2019; Iyer & Nanyam, 2021; Wang et al., 2021), a useful approach for the measurement of ports' productivity, which is divided into technical and technological efficiency (Malmquist, 1953). Many of these authors also considered to integrate Malmquist DEA with other approaches, namely Tobit regression (Barros, 2003), slack-based measure to minimize the slack issues in efficiency measurement (Wang et al., 2019), Epsilon-based measure (Wang et al., 2021) to compute the inefficiency and efficiency scores of each port.

For the case of Vietnam, there has been a few research on Vietnamese port system performance efficiency measurement. In 2019, Pham and Yeo evaluated the service quality of container terminals by proposing to use the Consistent Fuzzy Preference Relation. Another research was conducted in 2020 by Kuo et al., which utilized DEA to evaluate the performance efficiency of 53 ports in Vietnam from 2012 to 2016. In 2021, Wang et al. introduced an integrated methodology of Malmquist DEA and Epsilon-based measure to analyze the performance efficiency of 14 ports in Vietnam for a period of 2015 – 2020. In 2022, Nong solved the efficiency problem of 22 Vietnamese ports by combining Delphi method, Kamet principle and DEA, whereby Delphi and Kamet approaches were proposed to determine the input and output metrics whilst DEA was employed to calculate the efficiency scores.

To summarize, there have been a multitude of methodologies to the performance efficiency measurement for a period of time, in which Malmquist DEA is the most preferable one because of its effectiveness. For this reason, the author proposed to use Malmquist DEA to evaluate the efficiency of 22 ports in Vietnam in their performance from 2016 to 2021.

2.2. Input-Output Metrics

In order to measure the performance efficiency, it is of utmost importance for researchers to identify efficiency variables including input and output variables (Cullinane et al., 2005). It is noted that the port operations involve a wide ranges of subjective and objective factors including government regulation, weather, labour, infrastructure, etc., which causes complexity in their management activities. Additionally, research results on efficiency assessment often vary because of various objectives and strategies of different areas (Cullinane et al., 2006). It is, therefore, the reason the author of this study paid her only attention to Vietnamese port system context. Until now there have been three articles studying the efficiency in performance of Vietnamese port system (Nong, 2022; Wang et al., 2021; Nguyen et al., 2016). In terms of output, cargo throughputs and sales revenue are the two most concerned variables of researchers (Nong, 2022; Wang et al., 2021), followed by net profit (Wang et al., 2021). In regard to input, operational expenses, port area, quay length are those most considered by all authors. Additionally, Nong (2022) also proposed capital, labour, water depth, and area as needed inputs for efficiency measurement whilst Wang et al. (2021) considered total assets, owner's equity, and liabilities, and Nguyen et al. (2016) used warehouse capacity, and cargo handling equipment for their port performance efficiency evaluation. These variables remain valid for the operation efficiency assessment problem in the Vietnamese port system context.

To derive input and output indicators, most of authors base on literature review to select the most suitable ones for their studies. Apart from literature review, Min et al. (2017) proposed applying Analytic Hierarchy Process (AHP) to identify factors that improve port performance. In 2022, Nong (2022) employed Delphi method with Kamet principle to explore input and output indicators basing on the high agreement of experts and port operators.

In this study, the set of input and output metrics applied for Vietnamese port system was shortlisted from the above criteria by using Analytic Hierarchy Process (AHP) since it has been known as one of the simplest, easy-to-use, and effective methods which may be used in any industry (Nong & Ha, 2021).

Table 1: List of researches on methods used in port performance efficiency measurement

Ordinal No.	Papers	Methods	Measurement duration	Number of units
At a specific point of time				
1	Kim et al. (2022)	- DEA - Cluster analysis	2018	8 ports
2	Li et al. (2021).	SE-DEA	2018	20 container terminals
3	Görçün (2021)	- Entropy and OCRA - Entropy and EATWIOS	2018	9 ports in Black Sea area
4	da Costa et al. (2021)	DEA-CCR and BCC	2018	10 Brazilian ports

Ordinal No.	Papers	Methods	Measurement duration	Number of units
5	Quintano et al. (2020)	- SBM	2019	24 European ports
6	Castellano et al. (2020)	DEA	2016	24 Italian ports
7	Mustafa (2020)	DEA-CCR and BCC	2018	15 container ports in South & Middle Eastern and East Asian region
8	Hlali (2018)	- DEA - SFA	2015	26 world main container ports
9	Kutin (2017)	DEA-CCR and BCC	2014	50 ports in Asia
10	Wiegmans and Witte (2017)	- Stochastic frontier - DEA	2016	44 ports in Europe
11	Beuren et al. (2016)	DEA-CCR and BCC	2013	15 Brazilian ports
12	Zheng and Park (2016)	DEA-CCR and BCC	2014	30 container terminals in Korea and China
13	Lu et al. (2015)	- DEA-CCR and BCC - DEA - Super - Efficiency	2012	28 world's leading container ports
14	Cruz and Ferreira (2015)	DEA-CCR and BCC	2009	10 Iberian ports
15	Nguyen et al. (2016)	- Stochastic frontier analysis - Bootstrapped DEA	2013	43 Vietnamese ports
16	Zahran et al. (2015)	DEA-CCR and BCC	2012	18 ports
17	Seo et al. (2012)	DEA-CCR	2010	32 ports in Asean
18	Cullinane et al. (2006)	- Stochastic Cobb-Douglas - DEA	2001	57 global container ports
19	Cullinane et al. (2005)	- DEA - CCR and BCC - FHD	2001	57 global container ports
20	Park and De (2004)	- DEA	1999	11 seaports in Korea
21	Cullinane and Song (2003)	- Stochastic Cobb-Douglas production frontier		05 Korean container ports
22	Tongzon (2001)	DEA	1996	16 ports
23	Liu (1995)	- Translog production function		28 British port
24	Roll and Hayuth (1993)	- DEA - CCR		20 ports
Over a period of time				
25	Nong (2022)	- Delphi & Kamet principle - DEA	2019 - 2021	22 ports in Vietnam
26	Adler et al. (2021)	- Non-parametric SBM - Regression	1995 - 2005	Main ports in India
27	Wang et al. (2021)	- Malmquist DEA - Epsilon-based measure	2015 - 2020	14 ports in Vietnam
28	Iyer and Nanyam (2021)	Malmquist DEA	2015 – 2018	26 container terminals in India
29	Liu et al. (2021)	- Super - SBM - DEA - Tobit regression	2010 – 2017	9 ports in China
30	Nikolaou and Dimitriou (2021)	- DEA - Tobit regression model	2013 - 2017	Top 50 global container ports
31	Périco and Silva (2020)	- Principal component analysis - DEA	2010 – 2017	24 largest Brazilian ports
32	Kuo et al. (2020)	DEA	2012 – 2016	53 ports in Vietnam
33	Zarbi et al. (2019)	Window DEA	2012 – 2018	05 containers port in Iran
34	Wang et al. (2019)	- Super SBM - Malmquist	2010 - 2015	03 shipping companies
35	Tovar and Wall (2019)	Malmquist DEA	1993 – 2016	26 ports in Spain
36	Ferreira et al. (2018)	- Stochastic multicriteria acceptability analysis with the order-α model	2015 - 2016	27 Europe seaports in 2015, 20 European ports in 2016
37	Monteiro (2018)	- Malmquist DEA	1996-1997 to 2013 - 2014	12 Indian seaports
38	Chao et al. (2018)	DEA	2013 - 2015	13 global container shipping companies
39	Schoyen and Odeck (2017)	Malmquist DEA	2009 – 2014	6 Norwegian ports and 14 ports in the Nordic countries and the UK

Ordinal No.	Papers	Methods	Measurement duration	Number of units
40	Ding et al. (2015)	- Malmquist DEA - Tobit regression	2008 - 2012	21 container ports in China
41	Park and Lee (2015)	- Malmquist DEA - CCR and BCC	2007 - 2011	6 Korean logistics providers
43	Barros (2006)	- DEA - CCR and BCC - Mann–Whitney U-test	2002 - 2003	24 seaports in Italia
45	Barros (2005)	- Stochastic Translog cost frontier	2002 - 2003	10 Portuguese seaports
47	Barros (2003)	- Malmquist DEA - Tobit regression		10 Portuguese seaports
48	Cullinane et al. (2002)	- Stochastic Cobb-Douglas production frontier	1989 - 1998	15 container terminals in Asia
49	Estache et al. (2002)	- Translog and Cobb-Douglas production frontier	1996 - 1999	14 Mexican ports
50	Coto-Millan et al. (2000)	- Translog Cost production frontier	1985 - 1989	27 Spanish ports
51	Martinez-Budria et al. (1999)	- DEA - BCC	1993 - 1997	26 Spanish ports

Source: Nong and Ha

3. Research Design and Methodology

3.1. Research Design

As presented in the abovementioned sections, AHP and Malmquist DEA are considered to measure the efficiency of Vietnamese port system, which is illustrated in the research process of Fig. 1. Accordingly, the first step involves research objective determination, followed by input and output selection using AHP method in step 2. Then, Malmquist DEA method is employed to assess the efficiency of Vietnamese ports. Research result analysis are finally implemented before managerial implications and recommendations are suggested for the efficiency improvement of Vietnamese port system.

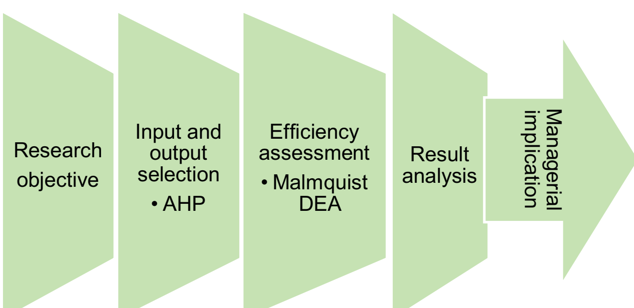


Figure 2: Research process

Justification for the choice of AHP and Malmquist DEA techniques.

In regard to the AHP technique, literature in selection decision making indicates that among MCDM methods, AHP is considered as the most effective approach for defining weights of quantifiable as well as unquantifiable variables which are then ranked easily (Hoang & Nguyen, 2020; Nong & Ha, 2021; Nguyen, 2021). It is, therefore, applied to rank the current input and output variables for Vietnamese port operational efficiency evaluation. The highest weighted variables would be chosen for the study and must fit with the required number of variables used in DEA model.

Regarding Malmquist DEA, an extensive review of common methods in the port performance efficiency measurement shows that it is of paramount necessity and effectiveness for researchers to consider this approach in case of efficiency assessment in a time range

3.2. Research Methodology

3.2.1. Analytic Hierarchy Process – AHP

Introduced by Saaty in 1980, the AHP method is got familiar with its process as follows:

Step 1: Pairwise comparisons between variables are constructed basing on questionnaires. Equal significance to extreme significance is presented through a scale from 1 to 9 (Tzeng & Huang, 2011). The pairwise comparison matrix is set up as following:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix},$$

Where, a_{ij} is the degree of significance between the i^{th} and the j^{th} variables.

$aij > 0$, $aij = 1/aji$, $aii = 1$.

Step 2: Compute the priority vectors.

The priority matrix is illustrated as following:

$$W = \begin{array}{c} \\ w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{array} \begin{array}{c} \begin{array}{ccccc} w_1 & \cdots & w_j & \cdots & w_n \end{array} \\ \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ \vdots & & \vdots & & \vdots \\ w_i/w_1 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & & \vdots & & \vdots \\ w_n/w_1 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix} \end{array}.$$

Multiply W with w:

$$W \times w = \begin{array}{c} \\ w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{array} \begin{array}{c} \begin{array}{ccccc} w_1 & \cdots & w_j & \cdots & w_n \end{array} \\ \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ \vdots & & \vdots & & \vdots \\ w_i/w_1 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & & \vdots & & \vdots \\ w_n/w_1 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix} \end{array} \begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix}$$

or (W-nI) w = 0

The priority vectors may be developed by multiplying the variable priority vector w by λmax such that $Aw = \lambda max.w$, in which λmax is the greatest value of the matrix A, which means finding the variable priority vector w with corresponding λmax in order that $(A - \lambda max\ I)w = 0$.

Step 3: Examine the consistency ratio (CR)

The room for CR value is 10%. If the CR is lower than 0.1, the result is reliable, or else there remains inconsistency in the expert's assessment which then need to be re-assessed. The formula of CR is as follows:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

With Consistency Index: $\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1}$

Where $\lambda_{\max}$ is the most significant value of the matrix, and n is the number of variables.

The Random Index (RI) may be defined by basing on the number of variables (Tzeng & Huang, 2011).

3.2.2. Malmquist DEA

DEA model

Performance efficiency analysis applying output-oriented DEA including both BCC and CCR models was employed for this study. DEA – CCR model assumes to have constant returns-to-scale (CRS) (Roll & Hayuth, 1993) whilst DEA – BCC model assumes to have variable one (VRS) (Martinez-Budria, Diaz-Armas, Navarro-Ibanez, & Ravelo-Mesa, 1999). The BCC - DEA score presents the overall technical efficiency whilst the CCR – DEA score includes pure technical efficiency and scale efficiency which is constituted by a ratio of the CRS efficient score and the VRS efficient score (Barros, 2006).

Malmquist productivity index

The performance efficiency of ports is evaluated from year t to year t+1, including technical efficiency (catch-up, $C^{t\text{->}t+1}$), technological gap (frontier shift, $F^{t\text{->}t+1}$), and total productivity (Malmquist productivity index – $MPI^{t\text{->}t+1}$), which can be illustrated in following equations (Bichou, 2018).

$$C^{t\text{->}t+1} = \frac{\text{Efficiency of (x,y)}^{t+1}}{\text{Efficiency of (x,y)}^{t}}$$

$$F^{t\text{->}t+1} = \sqrt{\frac{\text{Efficiency of (x,y)}^{t}}{\text{Efficiency of (x,y)}^{t+1}}\, x\, \frac{\text{Efficiency of (x,y)}^{t+1\rightarrow t}}{\text{Efficiency of (x,y)}^{t\rightarrow t+1}}}$$

where x and y represent ports.

$$MPI^{t\text{->}t+1} = C^{t\text{->}t+1} \text{ x } F^{t\text{->}t+1}$$

MPI scores are based on to rank ports. If $MPI^{t\text{->}t+1} < 1$, performance efficiency is decreasing. If $MPI^{t\text{->}t+1} > 1$, performance efficiency is increasing. If $MPI^{t\text{->}t+1} = 1$, performance efficiency remains unchanged.

Sample size and data collection

This study measured the efficiency in performance of 22 port companies listed on the Vietnamese stock market from 2015 to 2021. The data were extracted from the financial statements, annual reports, the website of these companies and the page of Vietnam Seaport Association (vpa.gov.vn). The minimum sample size in the DEA method must be larger than three times the number of input and output indicators (Raab & Lichty, 2002).

DEAP1 version 2.1 was utilized to estimate the performance efficiency in the study.

4. Findings

4.1. Input and Output Metrics

Figure 1 presents the research process, whereby inputs and outputs are defined by AHP method. A meeting among the author and three experts was executed via Google Meet. They were requested to make pairwise comparisons among input variables and output variables. Superdecision software 3.2 was used concurrently to calculate the inconsistency ratio. The result of priority is presented in Table 2. It is noted that cargo throughput, sales revenue, capital, operational expenses, and labour are the most important output and input variables, which will be used in this study and satisfied the rule that the total number of inputs and outputs must be three times larger than the number of DMUs (Raab & Lichty, 2002). In addition, according to the experts, these variables are necessary and able to be well used in port performance efficiency assessment regardless of regions of the country.

Table 2: Input and output results from AHP analysis

Metrics	Normalized by cluster	Limiting	Ranking
Input			
Capital	0.29677	0.148386	3
Operational expenses	0.21468	0.107342	4
Labour	0.14521	0.072603	5
Total assets	0.11341	0.056704	6
Quay length	0.0648	0.032399	7
Depth	0.04799	0.023996	9
Area	0.0430	0.021499	10
Owner's equity	0.03011	0.015056	11
Liabilities	0.02896	0.014478	12
Warehouse capacity	0.01507	0.007536	13
Cargo handling equipment	0	0	14
Output			
Cargo throughput	0.47059	0.235294	1
Sales revenue	0.47059	0.235294	2
Net profit	0.05882	0.029412	8

Source: Nong and Ha

4.2. Data used in the DEA Method

This study assesses the operational efficiency of 22 port companies listed in Vietnamese stock market including 07 ports in the South, 09 ports in the Central and 06 ports in the North of Vietnam. Data were extracted from these companies' financial reports and annual reports from 2015 to 2021 which were downloaded from their official websites or from Vietstock page.

4.3. Efficiency Scores

4.2.1. Technical Efficiency Change

The technical efficiency changes of 22 Vietnamese ports for the period 2015 – 2021 are shown in Table 3. The efficiency index with its score higher than one expresses DMU's technical efficiency growth whereas less-than-one score corresponds to its inefficient status (Wang et al., 2021). As can be seen in Table 3, only 5 out of 22 achieved progressive technical efficiency on average, namely Sai Gon port (1.003), Nha Trang port (1.314), Quang Ninh port (1.024), Doan Xa port (1.251) and Cua Cam port (1.358). Among these, Nha Trang port and Cua Cam port are the two best technical efficiency achievers for the whole period. All remaining ports got regressive technical efficiency with their scores of less than one on average, in which Cai Lan port and Vip Greenport and Phu Huu port are the three least technical efficient ports whilst other ports got their scores of around 0.9.

In terms of yearly changes, also from Table 3, it can be noted that most of ports achieved high progressive technical efficiency in 2016 compared to 2015 (except Cai Lan port with its score of 0.365), and in 2019 compared to 2018 (except Can Tho port with a score of 0.573). The number of efficient performers decreased a lot in 2020 compared to 2019, from 21 to 12. Most ports show their regressive performances during 2017 - 2018, 2020 - 2021. Especially, Doan Xa port showed its deep slump from 9.359 in 2015-2016 to 0.293 in 2016-2017, as did Dong Nai port, Tan Cang port, Phu Huu port, An Giang port, Da Nang port, Quy Nhon port, Thanh Hoa port, Nghe Tinh port, Cam Ranh port and Chan May port. The slump in technical efficiency re-occurred in the period of 2021compared to 2020.

In terms of region, ports in the North have higher average efficiency scores than those in the South and Central.

4.2.2. Technological Efficiency Change

Technological change reflects DMUs' performance in terms of different situations such as technological, legal and political environmental change, innovations, competition, etc., which is expressed through frontier-shift indexes. Table 4 shows the detailed frontier-shift values of 22 Vietnamese ports. Accordingly, more than three fourth ports (18 out of 22) achieved progressive efficient frontier-shift indexes on average, excluding Hai Phong port, Chan May port, Quang Ninh port, and Vip Greenport. Da Nang port (1.202) and Dinh Vu port (1.218) are the two best frontier-shift achievers for the whole period, contributing to the high overall average technological efficiency gain of Vietnamese port industry (1.056).

It can be seen in Table 4 that all ports had significantly low technological performance in 2016 compared to 2015 and 2019 compared to 2018 with their frontier-shift values of far less than one. However, these ports reached high performance in 2016-2017 and 2020-2021. Specifically, in 2020 – 2021, Cai Lan port experienced the remarkable frontier-shift progress from 0.949 in 2019-2020 to 8.975 in 2020-2021. Cat Lai port and Cua Cam port are the two exceptional cases of 2020 – 2021 period, whereby they had the least stable performance with a slump from 0.977 to 0.703 and from 11.838 to 0.424, respectively.

In terms of region, three regions (North, Central, and South) in Vietnam got technological efficiency with their scores of more than one, in which the ports in the South have a little bit higher average efficiency scores than those in the South and Central

4.2.3. Total Productivity Change

Productivity change is expressed through Malmquist Productivity Indexes. It can be seen from Table 5 that half of ports obtained performance efficiency on average, namely Cat Lai, Dong Nai, Tan Cang, Sai Gon, An Giang, Da Nang, Nha Trang, Quang Ninh, Dinh Vu, Doan Xa and Cua Cam. Among these, Sai Gon, Nha Trang, Doan Xa and Cua Cam port had more stable performance in both technical and technological efficiency than the others did. The others in this group only performed well in technical or technological efficiency. Take Tan Cang port as a case in point, which got total productivity efficiency with its index of 1.045, but its technological performance score was 0.875. Similar pattern was also obtained by Cat Lai, Dong Nai, An Giang, Da Nang, Quang Ninh and Dinh Vu port.

For the less productivity efficiency group (Phu Huu, Can Tho, Quy Nhon, Thanh Hoa, Thi Nai, Nghe Tinh, Hai Phong, Cam Ranh, Chan May, Vip Greenport, and Cai Lan port), Hai Phong and Vip Greenport got the lowest scores of total productivity on average for the whole. This result was conspicuous as they experienced the worst performance in both technical and technological efficiency.

In terms of time range, Fig.2 depicts that Vietnamese ports had lower productivity efficiency in the period from 2015 to 2019 than they did in 2020 and 2021, in which many ports achieved remarkable progressive efficiency. For instance, in 2019-2020 Cua Cam port obtained its efficiency score at 12.513 or Cam Ranh port got 4.671; in 2020 – 2021, Nha Trang reached the peak of 14.292 - the highest index in the whole period, followed by Vip Greenport at 8.512 and Doan Xa at 5.265.

In terms of region, ports in the North have higher average efficiency scores than those in the South and Central.

Table 3: Technical efficiency change from 2015 to 2021

Ordinal No.	Port name	2015 => 2016	2016 => 2017	2017 => 2018	2018 => 2019	2019 => 2020	2020 => 2021	Mean
1	Cat Lai	1.000	1.000	0.275	1.627	0.988	1.443	0.928
2	Dong Nai	3.324	0.891	0.425	1.624	1.043	0.286	0.921
3	Tan Cang	3.100	0.527	0.228	2.279	2.202	0.241	0.875
4	Phu Huu	2.004	0.354	0.356	2.227	1.748	0.188	0.754
5	Sai Gon	4.308	1.000	1.000	1.000	0.319	0.740	1.003
6	Can Tho	5.035	1.082	1.000	0.573	0.790	0.233	0.912
7	An Giang	5.842	0.937	0.481	1.798	2.287	0.063	0.938
8	Da Nang	3.737	0.869	0.718	1.281	0.580	0.388	0.936
9	Quy Nhon	4.700	0.835	0.737	1.009	3.900	0.062	0.944
10	Nha Trang	5.138	1.000	1.000	1.000	0.418	2.391	1.314
11	Thanh Hoa	8.270	0.634	1.108	1.050	1.156	0.101	0.945
12	Thi Nai	8.132	1.016	0.561	1.608	1.744	0.041	0.899
13	Nghe Tinh	5.690	0.796	0.551	1.621	1.891	0.065	0.889
14	Hai Phong	1.484	0.725	0.569	1.893	1.085	0.179	0.780
15	Cam Ranh	4.890	0.695	0.639	1.311	2.099	0.063	0.849
16	Chan May	5.899	0.725	0.633	1.897	0.292	0.529	0.962
17	Quang Ninh	6.532	1.534	1.064	1.505	1.203	0.060	1.024
18	Vip Greenport	1.000	1.000	0.197	2.489	0.226	2.024	0.779
19	Dinh Vu	3.511	0.513	0.533	2.146	1.025	0.293	0.923
20	Doan Xa	9.359	0.293	1.088	3.548	0.342	1.060	1.251
21	Cua Cam	3.512	3.178	0.716	1.321	1.057	0.562	1.358
22	Cai Lan	0.365	1.121	0.279	1.896	1.741	0.189	0.644
Mean		3.521	1.121	0.572	1.555	0.998	0.253	0.933

* Geometric mean Source: Nong and Ha

Table 4: Technological change from 2015 to 2021

Ordinal No.	Port name	2015 => 2016	2016 => 2017	2017 => 2018	2018 => 2019	2019 => 2020	2020 => 2021	Means*
1	Cat Lai	0.326	3.048	3.994	0.663	0.977	0.703	1.103
2	Dong Nai	0.323	1.268	2.358	0.524	0.808	4.557	1.109

Ordinal No.	Port name	2015 => 2016	2016 => 2017	2017 => 2018	2018 => 2019	2019 => 2020	2020 => 2021	Means*
3	Tan Cang	0.324	1.991	4.535	0.437	0.643	3.514	1.194
4	Phu Huu	0.237	1.628	3.150	0.414	0.728	4.244	1.076
5	Sai Gon	0.177	0.933	1.338	0.986	1.080	5.893	1.056
6	Can Tho	0.221	2.897	0.896	0.565	1.886	2.219	1.052
7	An Giang	0.176	1.331	1.724	0.560	1.005	7.261	1.087
8	Da Nang	0.284	1.349	1.644	0.673	1.031	6.902	1.202
9	Quy Nhon	0.236	0.901	1.351	0.952	1.146	4.311	1.052
10	Nha Trang	0.195	1.085	2.838	0.467	0.949	5.977	1.080
11	Thanh Hoa	0.151	1.132	1.261	0.802	1.324	6.099	1.058
12	Thi Nai	0.154	1.284	1.694	0.616	2.115	3.298	1.063
13	Nghe Tinh	0.149	1.283	1.692	0.598	0.884	6.302	1.013
14	Hai Phong	0.161	1.545	1.809	0.492	0.506	3.778	0.866
15	Cam Ranh	0.166	1.220	1.512	0.713	2.226	2.218	1.013
16	Chan May	0.127	1.233	1.591	0.600	1.891	3.084	0.977
17	Quang Ninh	0.177	1.237	1.492	0.790	1.910	1.769	0.977
18	Vip Greenport	0.086	0.865	3.938	0.322	0.662	4.205	0.801
19	Dinh Vu	0.271	1.948	2.077	0.578	1.012	5.088	1.218
20	Doan Xa	0.201	3.888	0.842	0.575	1.046	4.965	1.119
21	Cua Cam	0.263	0.986	1.167	0.914	11.838	0.424	1.057
22	Cai Lan	0.212	0.933	3.010	0.483	0.949	8.975	1.161
Mean		0.200	1.410	1.873	0.601	1.211	3.614	1.056

* Geometric means Source: Nong and Ha

Table 5: Total factor productivity changes from 2015 to 2021

Ordinal No.	Port name	2015 => 2016	2016 => 2017	2017 => 2018	2018 => 2019	2019 => 2020	2020 => 2021	Mean*
1	Cat Lai	0.326	3.048	1.100	1.079	0.965	1.015	1.024
2	Dong Nai	1.073	1.130	1.003	0.851	0.843	1.303	1.022
3	Tan Cang	1.006	1.049	1.035	0.996	1.415	0.846	1.045
4	Phu Huu	0.474	0.577	1.120	0.921	1.272	0.796	0.812
5	Sai Gon	0.761	0.933	1.338	0.986	0.345	4.360	1.059
6	Can Tho	1.112	3.136	0.896	0.324	1.489	0.517	0.959
7	An Giang	1.026	1.248	0.829	1.007	2.298	0.458	1.019
8	Da Nang	1.060	1.172	1.180	0.862	0.598	2.676	1.124
9	Quy Nhon	1.112	0.753	0.996	0.960	4.469	0.268	0.993
10	Nha Trang	1.001	1.085	2.838	0.467	0.397	14.292	1.419
11	Thanh Hoa	1.253	0.718	1.397	0.843	1.531	0.614	0.999
12	Thi Nai	1.253	1.304	0.951	0.991	3.689	0.134	0.955
13	Nghe Tinh	0.850	1.021	0.933	0.970	1.671	0.408	0.901
14	Hai Phong	0.239	1.120	1.029	0.932	0.549	0.677	0.676
15	Cam Ranh	0.813	0.848	0.966	0.935	4.671	0.139	0.860
16	Chan May	0.749	0.894	1.007	1.138	0.553	1.632	0.940
17	Quang Ninh	1.155	0.898	1.588	1.189	2.297	0.105	1.000
18	Vip Greenport	0.086	0.865	0.775	0.800	0.149	8.512	0.624
19	Dinh Vu	0.952	1.000	1.106	1.241	1.037	1.490	1.124
20	Doan Xa	1.882	1.138	0.916	2.040	0.358	5.265	1.400
21	Cua Cam	0.925	3.134	0.836	1.207	12.513	0.238	1.435
22	Cai Lan	0.077	1.046	0.841	0.915	1.653	1.698	0.748
Mean		0.703	1.177	1.072	0.934	1.209	0.914	0.985

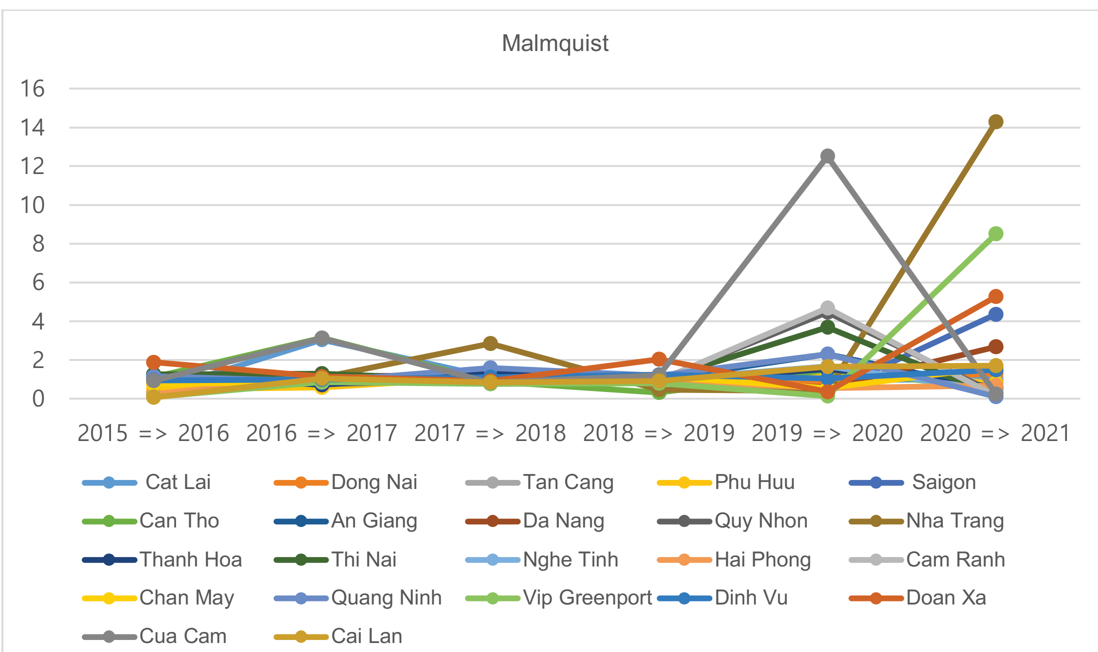
* Geometric mean Source: Nong and Ha

Table 6: Scale efficiency changes from 2015 to 2021

Ordinal No.	Port name	2015 => 2016	2016 => 2017	2017 => 2018	2018 => 2019	2019 => 2020	2020 => 2021	Mean*
1	Cat Lai	1	1	0.275	1.627	0.988	1.443	0.928
2	Dong Nai	2.448	1.016	0.581	1.573	1.084	0.162	0.858
3	Tan Cang	2.917	0.647	0.257	2.187	1.853	0.163	0.827
4	Phu Huu	2.004	0.855	0.377	2.155	1.368	0.181	0.837
5	Sai Gon	4.308	1	1	1	0.974	0.242	1.003
6	Can Tho	2.162	1	1	0.998	0.971	0.176	0.848
7	An Giang	2.275	0.998	0.692	1.42	0.8	0.179	0.827
8	Da Nang	3.561	0.88	0.802	1.262	1.088	0.129	0.874
9	Quy Nhon	5.392	0.998	0.93	1.097	0.762	0.117	0.888
10	Nha Trang	1.478	1	1	1	0.418	2.391	1.067
11	Thanh Hoa	3.843	0.992	0.912	1.128	0.904	0.259	0.986
12	Thi Nai	0.795	1.974	0.889	0.833	1.512	0.102	0.751
13	Nghe Tinh	2.726	1.116	0.674	1.292	1.067	0.072	0.768
14	Hai Phong	1.484	0.725	0.569	1.893	1.085	0.179	0.78
15	Cam Ranh	1.879	0.994	0.815	1.248	1.085	0.124	0.788
16	Chan May	2.135	1.102	0.764	1.329	1.017	0.14	0.835
17	Quang Ninh	3.394	1.22	0.829	1.216	1.003	0.111	0.881
18	Vip Greenport	1	1	0.197	2.489	1.883	0.242	0.779
19	Dinh Vu	3.11	0.653	0.704	1.826	1.162	0.222	0.936
20	Doan Xa	2.555	0.413	1.135	2.141	0.257	1.169	0.958
21	Cua Cam	0.327	3.178	0.716	1.321	1.057	0.562	0.914
22	Cai Lan	0.365	1.121	1.193	2.028	0.381	0.671	0.795
Mean		1.901	1.001	0.675	1.436	0.941	0.243	0.866

* Geometric mean

Source: Nong and Ha



Source: Nong and Ha

Figure 2: Total productivity change

4.2.4. Discussion

Taking the results from Malmquist DEA model into consideration, it can be revealed that many Vietnamese port companies achieved high performance over the period, except in 2018 with only 7 efficient performers. Especially, in 2020 and 2021, numerous ports gained impressively significant efficiency values like Nha Trang (14.292), Vip Greenport (8.512), Quy Nhon (4.469), Cam Ranh (4.671), Sai Gon (4.36), Thi Nai (3.689), An Giang (2.298), Quang Ninh (2.297), Da Nang, (2.676) (see Table 5) regardless of the great impact of Covid-19. As a matter of fact, this result is compatible with the steadily growing trade volume of the country, especially the spectacular growth from 6.54% in 2016 to 21.76% in 2021 or 5.4% in 2020 to 22.6% in 2021. This finding is also confirmed by the research of Wang et al. (2021) and Nong (2022).

Looking at Table 4 and Figure 2, we can see that total productivity efficiency of port companies follows the same pattern as that of technological one, which means that technology has significant impact on port's productivity efficiency (Wang et al., 2021). However, through Table 3 and Fig. 2, it is obvious that technical efficiency values of ports over years have different patterns from those of malmquist indexes from 2015 to 2018, but have similar pattern with malmquist from 2019 – 2021, the time of Covid-19 breakout. This result confirms the impact of technical efficiency on port's performance in the special case – Covid-19 pandemic, the time required high management skills of port operators to overcome the hassle era.

Taking each port into consideration, following points should be considered:

- Saigon, Nha Trang and Doan Xa port have had high and stable average performance on technical, technologocial, and productivity efficiency over the whole period. Therefore, it is suggested that they should remain their current activities and scope.

Cua Cam port has had high average performance in Malmquist, technical and technological efficiency over years as well. However, it had regressive performance in the period of 2020 – 2021. It is, therefore, suggested that Cua Cam port should have measures to utilize its input endownments more efficiently as its scale efficiency is less than one (Table 6).

- Cat Lai, Dong Nai, Tan Cang, An Giang, Da Nang, Quang Ninh and Doan Xa port are the group of efficient average productivity and technological performance. However, this group has low technical and scale efficiency. Is is, thus, recommended that these ports should improve its management skills (Nong, 2021) and have measures to boost outputs or effectively exploit input resources.

The other ports have had less efficient total productivity, technical performance, and scale although they have good technological adoptability. As a result, they should implement numerous solutions to improve their overall efficiency simultaneously and decisively including management skill improvement, full and effective use of input resources and output boost

5. Conclusion

The study employed a hybrid method of AHP and Malmquist DEA into the efficiency assessment of 22 Vietnamese ports from 2015 to 2021, in which AHP was utilized to choose input and output metrics while Malmquist DEA was employed for the efficiency evaluation. The AHP result shows that capital, operational expenses, labour, cargo throughputs, and sales revenue are the most suitable variables in the Vietnamese port efficiency evaluation. Additionally, some significant points emerge from Malmquist DEA analysis as followed: Firstly, Sai Gon port, Nha Trang port, Doan Xa port, and Cua Cam port are the four most efficiency performers over the period whilst Hai Phong port and Vip Greenport are the least efficiency performers; Secondly, technology has great impact on the total productivity of ports; Thirdly, management skills affect the port's total productivity. Sixthly, ports in the North got higher average efficiency scores than those in the South and Central of Vietnam.

This study theoretical contribution is the suggestion of a hybrid methodology (AHP and Malmquist DEA) to deal with various inputs and outputs to assess the efficiency in performance of ports over a period of time. In addition, the proposed input and output metrics may have a contribution to the literature in the assessment of the port performance efficiency. In regard to practical contribution, the overall assessment of ports may help port operators assume a strategic policy for their ports to reach the efficient frontier. In a similar vein, the analysis result on efficiency also helps port authorities improve the operation of Vietnamese port system within the limited endowment. However, the study findings are only in compliance with the case of Vietnam. Thus, future research may be reached out to other regions or countries. The next limitation involves the small number of ports engaging in the empirical study from 2015 to 2021. Accordingly, it is recommended to enlarge the data size in terms of geographic or time-series basis.

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