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Article

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Asian Journal of Shipping and Logistics (AJSL)

Provided in Cooperation with:

Korean Association of Shipping and Logistics, Seoul

Suggested Citation: Nhu-Mai Thi Nong (2023) : Performance efficiency assessment of Vietnamese ports: An application of Delphi with Kamet principles and DEA model, Asian Journal of Shipping and Logistics (AJSL), ISSN 2352-4871, Elsevier, Amsterdam, Vol. 39, Iss. 1, pp. 1-12,
<https://doi.org/10.1016/j.ajsl.2022.10.002>

This Version is available at:

<https://hdl.handle.net/10419/329707>

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Performance efficiency assessment of Vietnamese ports: An application of Delphi with Kamet principles and DEA model^{*}

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ARTICLE INFO

Article history:

Received 9 June 2022

Received in revised form 4 August 2022

Accepted 17 October 2022

JEL classification:

C44

L91

R42

Keywords:

DEA

Delphi

KAMET

Performance efficiency

Port

ABSTRACT

Ports form important links in the overall trade chain and act as driving forces for marine economic development. However, the operation of ports also has certain difficulties and challenges that port operators need to overcome. As such, this research aims to measure the performance efficiency of 22 ports listed in the stock market in Vietnam – a developing country with notable progress and role in global seaborne transport. The hybrid method of Delphi technique with KAMET principle and input and output – oriented DEA method was applied to solve the problem of efficiency assessment. The Delphi technique with KAMET principle was used to determine the efficiency evaluation criteria whilst the input and output – oriented DEA was employed to measure the efficiency. The findings show that capital, operation expenses, labour, port area, quay length, depth, revenue, and cargo throughputs are considered as input and output variables in the port efficiency evaluation. Additionally, it is also concluded in the research that scale and management skills are the dominant source of efficiency and Vietnamese ports show rather high management skills. Moreover, comprehensive and multi-variable assessment of port system may bring lots of benefits not only to the decision-making units but also the maritime authorities within constraint funds.

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1. Introduction

The maritime industry with its outstanding growth over years has made significant contributions to the global economies and remained the main driver of economic growth. According to the United Nations Conference on Trade and Development, it is expected to increase the value of the global maritime trade by about 3.4 % at the end of 2024. To make the exceptional growth of the maritime industry, port system is the nucleus of development, the focal point for receiving and transporting import - export goods to all parts of the country and connecting different countries in the integrated world (Cullinane, Song, & Wang, 2005).

Managing ports, particularly their performance efficiency is of an utmost task because performance efficiency evaluation is regarded as a pivotal activity for all types of enterprises in their business administration, especially after the outbreak of the Covid-19 pandemic in the world. The overall efficiency of a country's port system

depends on the performance efficiency of each individual port. As such, it is of significance and necessity for a country to measure its port system performance efficiency. Should there be any differences among them, the causes could be worked out with the aim of improving the efficiency of individual port in particular and of the whole port system in general.

Vietnam is well-known as a coastal country with a large territorial sea and exclusive economic zone, covering an area of over 1 million square kilometers. Vietnam's sea area and continental shelf contain many rich resources and potentials, which are very favorable for marine economic development. Vietnam's coast stretches over 3260 km, with many trade gateways and close to international maritime routes, creating great advantages for the marine economic development strategy. Vessels from Vietnam's ports could sail to the Strait of Malacca, Indian Ocean, Middle East, Europe, and Africa while crossing the Bashi Strait into the Pacific Ocean for seaports of Japan, Russia, and America (Wang, Nguyen, Fu, Hsu, & Dang, 2021), which emphasizes the importance of Vietnam on the global maritime map. Accordingly, any changes in Vietnam's port system may have a multitude of effects on the world maritime lines.

Vietnamese waterway transport currently accounting for 90 % of import and export goods is the main lifeline in the economy's cargo transportation and distribution system. With its particularity, great

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potential and high internationalization, with its position as both a focal point and a bridge in domestic maritime traffic with countries in the region and the world, all the industry's activities have certain impacts on the development of the whole national economy, especially sectors and fields related to the marine economy, trade economy, and tourism. This places a great responsibility on Vietnam's maritime industry, whereby further improvement on the effectiveness of specialized state management needs to be focused in order to contribute to promoting the maritime economy. For the above reasons, it can be noted that studying the performance efficiency assessment problem for Vietnamese port system is of practically and theoretically paramount significance in the context of global integration. This research, therefore, aims to assess the performance efficiency of ports listed in the stock market in Vietnam from the years 2019–2021, a period that has not been evaluated by any authors before.

To assess the efficiency of ports, data envelopment analysis (DEA) is the most frequently used method (Park & De, 2004; Wang et al., 2021) since this is a non-parametric efficiency assessment approach addressing a wide range of performance metrics, which comprise multiple inputs and multiple outputs. In this study, the author proposed a process of Delphi with KAMET principle and DEA methods to define the input and output metrics and to evaluate the performance efficiency of seaports, respectively. This integrated approach was proposed as to the extent of the author's knowledge there is room for combining Delphi with KAMET principle and DEA methods in the field of port performance efficiency evaluation. In addition, this approach offers a logic process for evaluating port performance and ensures the conformity between the individual port efficiency results and the development strategy of the maritime industry.

Excluding Section 1, the research is structured as follows. Section 2 generalizes a review of literature on previous studies. Research design and methodology regarding Delphi technique, KAMET principle, and DEA method are presented in Section 3. In Section 4, an empirical case applies the proposed process into the port performance efficiency of Vietnam. Conclusion is finally withdrawn in Section 5.

2. Literature review

2.1. Methods to measure port efficiency

Review of the literature shows that many scientific methods of efficiency analysis, namely DEA, ratio analysis, stochastic frontier, etc. have been utilized for the evaluation of performance efficiency of ports.

A research conducted by Roll and Hayuth (1993) is regarded as the first work about port performance efficiency analysis. The authors proposed to use DEA – CCR model to evaluate the efficiency of seaport by using cross-sectional data in financial reports. The proposed model had an input orientation and was assumed to have constant returns-to-scale (CRS), which is deemed as the CCR model. From then, numerous articles on port performance efficiency measurement by applying DEA method have also been conducted. However, the later authors have customized the original DEA to make the research results more comprehensive. Seo, Ryoo, and Aye (2012) applied DEA – CCR approach under output orientation to analyze 32 container ports in ASEAN. Martinez-Budria, Diaz-Armas, Navarro-Ibanez, and Ravelo-Mesa (1999) applied DEA – BCC model to measure the efficiency of 26 ports Spanish ports during 1993 – 1997 period, in which BCC assumes to have variable returns-to-scale (VRS). In 2004, Park and De combined DEA – BCC with DEA CCR to assess the performance of 11 Korean seaports for the year 1999. The results affirmed that DEA was a powerful method to the assessment of seaports' efficiency. The traditional DEA model aside, DEA-

Malmquist, slack-based measure (SBM), and super-efficiency DEA (SE-DEA) are other extensions. The DEA-Malmquist model is useful for measuring decision-making units' (DMUs) productivity, by which changes total productivity into technical and technological efficiency (Malmquist, 1953). Applications of DEA-Malmquist method in seaport performance measurement are considered in the research of Barros (2003), Park and Lee (2015), Ding, Jo, Wang, and Yeo (2015), Monteiro (2018), and Wang et al. (2021). In terms of SBM model, it is an influential approach in diminishing the slack issues, ranking the efficiency of DMUs, and optimizing the deficiencies to acquire rational metrics, which has been utilized by many authors in their research like Wang, Li, and Xiao (2019), Quintano, Mazzocchi, and Rocca (2020), to mention just a few. Regarding SE-DEA model, it is functional in evaluating and ranking the efficient DMUs in a more accurate and all-inclusive approach. Accordingly, the efficient DMUs will get their efficiency value of over 1 instead of 1 as usual. This method was proposed to use in the research article of Li, Seo, and Ha (2021). Additionally, to have deeper and wider analysis, researchers tend to integrate the DEA with other methods such as Tobit regression, Stochastic Cobb-Douglas, Free Disposal Hull (FDH), Mann-Whitney U-test, Principal Component Analysis (PCA), Epsilon-Based Measure Efficiency or cluster analysis to meet diversified purposes of the case. For example, Barros (2003) used Tobit model to define the seaport performance efficiency drivers after taking DEA analysis steps. Cullinane, Song, and Gray (2002) and Cullinane, Wang, Song, and Pi (2006) applied the Stochastic Cobb-Douglas model to provide evidence of the performance efficiency rankings of selected DMUs. Cullinane et al. (2005) integrated FDH model with DEA to analyze the efficiency of seaport system, whereby FDH assumes strong input and output disposability relaxing the convexity assumption. The results revealed that the hybrid methodology mattered if ranking DMUs in regard to their efficiency and making efforts to define the most appropriate course of action for improving the production of the inefficient DMUs are paid attention to. Barros (2006) proposed to use Mann-Whitney U-test to test for the significance of size, containerization and labour in the efficiency of seaports. Périco and Ribeiro da Silva (2020) suggested to utilize PCA-DEA to validate the proposed input and output variables before measuring the efficiency of DMUs. Wang et al. (2021) proposed to combine Epsilon-Based Measure with DEA-Malmquist, through which DEA-Malmquist was considered to evaluate the productivity growth rates of DMUs whilst Epsilon-Based Measure was to calculate the inefficiency and efficiency score of each DMU. The last but not the least for the case of DEA extension, Kim, Kim, Kim, and Choi (2022) introduced a hybrid approach of DEA and cluster analysis to suggest rationalization plans for the national logistics system based on supply base rationalization theory.

In addition to the DEA method, Cullinane and Song (2001) proposed ratio analysis for the assessment of Asian container ports. In terms of econometric frontier analysis, in 1995 Liu employed a translog cost frontier to compare the performance efficiency between private and public ownership in Britain. Baños-Pino, Coto-Millán, and Rodríguez-Álvarez (1999) employed a translog function to the main Spanish ports including the cost function and the input distance function. Coto-Millán, Banos-Pino, and Rodriguez-Alvarez (2000) applied a stochastic frontier cost function to measure the economic efficiency of Spanish ports by comparing a Cobb-Douglas function with a translog. This methodology was then employed by many other researchers as well (Barros, 2006; Cullinane et al., 2002; Cullinane & Song, 2003; Estache, González, & Trujillo, 2002; Ferreira, Marques, & Pedro, 2018). In 2017, Min, Ahn, Lee, and Park (2017) suggested to apply AHP to define the utmost success factors for improving the efficiency of terminal operation. In 2021, Görç ün introduced two hybrid methods of the entropy with OCRA technique and the entropy with EATWIOS method to discuss whether these suggested models could be used to analyze the performance for the

Table 1
List of studies on seaport performance efficiency.

Ordinal No.	Papers	Inputs	Outputs	Methods	Units
1	Kim et al. (2022)	Quay length, Twenty-foot ground slot, depth of water, number of cranes	Cargo volume, Loading capacity per hour	- DEA	8 ports in Korea
2	Li et al. (2021)	Berth length, yard area, Number of Bridge Crane and Rubber Tire container Gantry, Dock front water depth	Throughput	- Cluster analysis SE-DEA	20 Chinese container terminal companies
3	Adler, Hirtle, Kumar, and Niemeier (2021)	Capital, Variable costs, Labour, Number of cranes	Total number of vessels handled, Total volume of cargo handled, Quality of service	- Non-parametric SBM - Measure of specialization and a berth-level measure of ownership structure	Major seaports in India
4	Wang et al. (2021)	Total assets, Owner's equity, Liabilities, Operation expenses	Revenue, Net profit	- DEA Malmquist - Epsilon-based measure	14 ports in VN
5	Görçün (2021)	Number of Staff, Quay Length, Depth, Number of Handling Equipment (cranes), Total Storage Area, Intended Vessel Length, Total Port Area, Number of Shipping Lines, Container Handling Capacity	Number of arrivals, Annual Income, Total Handled TEU in a Year, Number of Handled Container	- Entropy and OCRA - Entropy and EATWIOS	9 container ports in Black Sea region
6	Périco and Silva (2020)	Waiting time to dock, Number of berths, Dock areas, Storage area	Total load handle	- Principal component analysis - DEA	19 ports in Brazil
7	Quintano et al. (2020)	Labor, Energy products	Emissions relevant, Total gross weight	- SBM	24 leading container ports in Europe
8	Wang et al. (2019)	Number of employees, Energy consumption, Water consumption	Revenue, Total solid waste	- Super SBM - Malmquist	03 shipping companies
9	Ferreira et al. (2018)	Terminal area, Quay length Operational expenses without personal costs, Personal costs, Capital expenses	Containers throughput (TEU), Dry bulk cargo (ton) Solid bulk cargo (ton), Ro-Ro traffic (ton), General non-containerized cargo (ton)	Stochastic multicriteria acceptability analysis with the order- α model	47 seaports in Europe
10	Monteiro (2018)	Land, Labour, Number of cranes, Number of other equipments, Number of berths	Volume of cargo traffic in million tonnes, Number of vessels handled.	Malmquist DEA	12 seaports in India
11	Ding et al. (2015)	Terminal length, Handling equipment quantity, Staff quantity	Number of containers	- Malmquist DEA - Tobit regression	21 container ports in China
12	Park and Lee (2015)	Assets, Capital, Number of employees	Total revenue	Malmquist DEA - CCR and BCC	6 Korean logistics providers
13	Seo et al. (2012)	Number of berth, Berth length, Container yard size, Number of Cranes	Cargo throughput	DEA-CCR	32 ports in Asean
14	Barros (2006)	Number of personnel, Value of capital invested, Size of operating costs.	Liquid bulk, Dry bulk, Number of ships, Number of passengers, Number of containers with TEU, Number of containers with no TEU, Total sales	- DEA - CCR and BCC - Mann-Whitney U-test	24 seaports in Italia
15	Cullinane, Wang, Song, and Ji (2006)	Container throughput	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries	- Stochastic Cobb-Douglas	57 International container seaports
16	Cullinane et al. (2005)	Container throughput	Terminal length, terminal area, quayside gantry, yard gantry and straddle carries	- DEA - CCR and BCC	57 international container seaports
17	Barros (2005)	Price of labour, Price of capital, Ships, Cargo, Trend	Total cost	- FHD - Stochastic Translog cost frontier	10 Portuguese seaports
18	Park and De (2004)	Berthing capacity, Cargo handling capacity (million ton), Cargo throughputs (ton)	Number of ship calls, Revenue, Customer satisfaction	DEA	11 seaports in Korea
19	Barros (2003)	Number of employees, Book value of assets	Ships, Movement of freight, Break-bulk cargo, Containerized freight, Solid bulk, Liquid bulk	- Malmquist DEA - Tobit regression	10 Portuguese seaports
20	Cullinane and Song (2003)	Fixed capital in Euros (1998 = 100)	Turnover (excluding property sales)	Stochastic Cobb-Douglas production frontier	05 Korean container ports
21	Cullinane et al. (2002)	Number of employees	Annual container throughput in TEUs	Stochastic Cobb-Douglas production frontier	15 Asian container ports
22	Esache, González, and Trujillo (2002)	Containers handled (tons)	Volume of merchandise handled	Translog and Cobb-Douglas production frontier	14 Mexican ports
23	Coto-Millan et al. (2000)	Cargo handled (ton)	Aggregate port output	Translog Cost production frontier	27 Spanish ports
24	Martínez-Budría et al. (1999)	Labour expenditure, Depreciation charges, Other expenditure	Total cargo moved through docks, Revenue obtained from rent of port facilities	DEA - BCC	26 Spanish ports
25	Liu (1995)	Movement of freight (tons)	Turnover	Translog production function	28 British port (continued on next page)

Table 1 (continued)

Ordinal No.	Papers	Inputs	Outputs	Methods	Units
26	Roll and Hayuth (1993)	Manpower, Capital, Cargo uniformity	Cargo throughput, Level service, Consumer satisfaction, Ship calls	DEA - CCR	20 ports

maritime industry. The results revealed that these two methods could be friendly and easily implemented for seaport selection. Additionally, both methods had very similar results to each other in regard to the assessment of the DMUs. Also in this year, Adler, Hirte, Kumar, and Niemeier developed a two-phase formulation including non-parametric, slacks-based measure and an absolute measure of specialization and a berth-level measure of ownership structure to evaluate the seaport performance and explore the efficiency drivers.

For the case of Vietnam, the literature on the port efficiency assessment problem is still limited with two articles of Pham and Yeo (2019) and Wang et al. (2021). The former introduced the Consistent Fuzzy Preference Relation to measure the service quality of transshipment container terminals from the lens of shipping companies whilst the latter developed a hybrid method of Epsilon-Based Measure with DEA-Malmquist to measure the efficiency of 14 ports in Vietnam.

To sum up, there have been a variety of methods to the efficiency assessment, in which DEA is the most preferred one for the evaluators because of its effectiveness in the performance evaluation (Krmac & Mansouri Kaleibar, 2022) (see Table 1). However, to the best of the author's knowledge, there is yet no research integrating the application of Delphi method with KAMET principle, and DEA method in measuring the efficiency of the port system, especially in a developing country like Vietnam. In so doing, this research offers a novel approach to assess port performance employing Delphi with KAMET principle and DEA technique. The Delphi technique with KAMET principle are employed to arrive at a group of port operators and experts' opinion on the input and output variables. It is usual and significant to consider those variables from managerial perspectives (Norman & Stoker, 1991). In regard to the DEA method, it is particularly well fit to be applied in the performance efficiency measurement field. This hybrid approach contributes to the literature of efficiency measurement on port system.

2.2. Input-output measures

The operations of ports are complicated and involve numerous subjective and objective factors such as labour, capital infrastructure, weather, government regulation, environmental impacts, to name just a few (Barros, 2006; Cullinane et al., 2005). Lots of research has been given interesting insight into port management, particularly efficiency problem in different regions (Barros, 2006). These research results often vary because of different objectives and strategic and operational policies among regions (Cullinane et al., 2006). Given the importance of the DEA method in the efficiency evaluation, application of suitable input and output variables is of utmost element (Cullinane et al., 2005). Output expansion or input reduction are value to the efficiency evaluation. Generally, outputs refer to monetary units such as revenue and profits (see Table 1), in which revenue is obtained from port operations (Barros, 2006; Cullinane & Song, 2003; Görçün, 2021; Liu, 1995; Martinez-Budria et al., 1999; Park & De, 2004; Park & Lee, 2015; Wang et al., 2019, 2021, etc.) or and profit can be net (Wang et al., 2021). Much other research has also devoted to diversified measures in non-monetary units involving total handled cargo including non-containerized and containerized ones (Barros, 2003, 2006; Coto-Millan et al., 2000; Cullinane et al., 2002, 2005, 2006; Ding et al., 2015; Estache et al., 2002; Ferreira et al., 2018; Martinez-Budria et al., 1999; Monteiro, 2018; Périco & Silva, 2020; Roll & Hayuth, 1993), customer satisfaction (Park & De, 2004; Roll & Hayuth, 1993), number of passengers (Barros, 2006), number of arrivals (Adler et al., 2021; Barros, 2003, 2006; Görçün, 2021; Monteiro, 2018; Park & De, 2004; Roll & Hayuth, 1993), quality of service (Adler et al., 2021), ro-ro traffic (Ferreira et al., 2018) ... as outputs for the efficient evaluation.

The input variables applied for the port efficiency measurement in the DEA technique are usual classified into non-financial and

financial groups or controllable and non-controllable groups. Controllable variables involve those metrics that can be managed by firms. As depicted in Table 1, financial input variables involve capital (Adler et al., 2021; Barros, 2005, 2006; Cullinane & Song, 2003; Ferreira et al., 2018; Park & Lee, 2015; Roll & Hayuth, 1993), operational expenses (Barros, 2006; Ferreira et al., 2018; Martinez-Budria et al., 1999; Wang et al., 2021), variable costs (Adler et al., 2021), owner's equity (Wang et al., 2019), liabilities (Wang et al., 2019) and personal cost (Martinez-Budria et al., 1999), whereas non-financial input variables range from labour (Adler et al., 2021; Barros, 2003, 2005, 2006; Cullinane et al., 2002; Ding et al., 2015; Görçün, 2021; Monteiro, 2018; Park & Lee, 2015; Quintano et al., 2020; Wang et al., 2019), cargo handling capacity / cargo throughputs (Coto-Millan et al., 2000; Liu, 1995; Estache et al., 2002; Park & De, 2004; Barros, 2005; Görçün, 2021), total port area (Cullinane et al., 2005, 2006; Ding et al., 2015; Ferreira et al., 2018; Görçün, 2021), number of cranes (Adler et al., 2021; Görçün, 2021; Monteiro, 2018), number of berths (Monteiro, 2018; P é rico and Silva, 2020), storage area (Görçün, 2021; Monteiro, 2018; P é rico and Silva, 2020), quay length (Ferreira et al., 2018; Görçün, 2021), terminal length (Cullinane et al., 2006; Ding et al., 2015), waiting time to dock (P é rico and Silva, 2020), dock area (P é rico and Silva, 2020), intended vessel length (Görçün, 2021), ship (Barros, 2005), number of ship lines (Görçün, 2021), berth capacity (Park & De, 2004), quayside gantry (Cullinane et al., 2005, 2006), yard gantry (Cullinane et al., 2005, 2006), straddle carries (Cullinane et al., 2005, 2006), and number of other equipments (Monteiro, 2018). All the abovementioned financial and non-financial variables may be controlled by port operators. As such, they may also be classified into controllable groups. In contrast, non-controllable metrics are referred to depth (Görçün, 2021). Nonetheless, with the development of technology and financial capacity, natural deep water ports aside, man-made ones are common as well such as Yangshan Port, Tianjin port, or Jebel Ali port.

To sum up, multiple inputs and outputs can be considered to evaluate the performance efficiency of the port systems mentioned capital, labour, cargo handling capacity/ cargo throughputs, total port area, number of cranes, number of berths, storage area, quay length, terminal length, waiting time to dock, dock area, intended vessel length, ship, number of ship lines, berth capacity, quayside gantry, yard gantry, straddle carries, number of other equipments, variable costs, owner's equity, liabilities, personal costs for the inputs and revenue, profits, total handled cargo, customer satisfaction, number of passengers, number of arrivals, quality of service, and ro-ro traffic for the outputs. Nonetheless, research in different areas may not always produce coherent outcomes when working with multiple indicators at different strategic, tactical, and operational extent (Wu & Goh, 2010). Therefore, the input and output variables for the DEA should be considered to fit well the strategic objective and situation of each region.

3. Research design and methodology

3.1. Research design

As mentioned in the above sections, to evaluate the efficiency of ports in Vietnam, a hybrid approach of Delphi, KAMET, and DEA techniques is proposed to be applied in this study. The research process for the mentioned approach is presented in Fig. 1. In the first two steps, after defining the research objective, input and output variables are explored by applying Delphi method with KAMET principle. Then, CCR and BCC - oriented DEA methods are employed to measure the performance efficiency of ports in Vietnam, respectively. Finally, research results are analyzed and discussed before managerial implications are proposed to improve the efficiency of the whole port system in Vietnam.

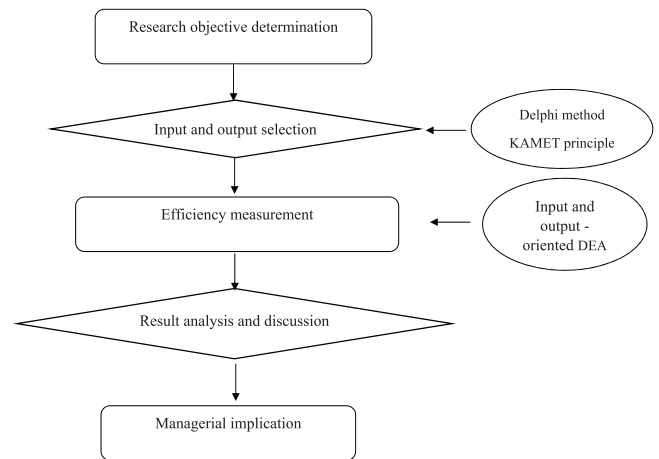


Fig. 1. Research process.

3.2. Research methodology

3.2.1. Delphi and KAMET principle

Delphi method was first developed by Olaf Helmer and Norman Dalkey of the Rand Corporation in the 1950s. The objective of the Delphi is to reach consensus of experts on complex issues (Grime & Wright, 2014) through a process basing on the results of multiple rounds of questionnaires distributed to a group of experts. The Delphi procedure is depicted as follows:

Firstly, the moderator selects a group of experts based on an initial set of criteria subject to the needs of the project.

Secondly, a questionnaire is delivered to each expert to give responses anonymously.

Thirdly, the moderator collects the responses, removes unrelated materials, synthesizes and analyzes the results basing on the KAMET principle and finally delivers feedback to the group.

The KAMET principle gives an assessment of the importance of each index (q_i) at different periods on the basis of a combination of statistical values including Median (Md_{q_i}); Quartile deviation (Q_{q_i}); Mean (M_{q_i}) and Variance (V_{q_i}). The Variance here is the percentage of experts changing their rating, in % (Table. 2).

Fourthly, the experts revise their responses by basing on the feedback. The experts' responses are then sent back to the moderator for the next round.

The feedback process is kept on going until a common consensus among experts is reached.

3.2.2. DEA

The DEA method was introduced by Charnes, Cooper, and Rhodes (1978) as a technique to measure the performance efficiency with multiple inputs and outputs, yet it had emerged more than 20 years before. In 1957, Farrell used to suggest the approach of employing the Production Possibility Frontier (PPF) as a benchmark for measuring efficiency among units (Decision Making Units – DMUs) in an industry; by which those DMUs lying on the PPF curve will be regarded (more) efficient and their technical efficiency score (TE) is equal to 1, otherwise will be considered less efficient (than others) and their efficiency score will be less than 1.

The DEA employed a non-parametric linear optimization problem to build up a PPF curve from a given data of a panel of DMUs and to estimate the efficiency scores for those units. This method involves two different models mentioning Constant returns to scale (CRS) and variable Returns to Scale (VRS). With regard to CRS, an increase in inputs brings about a growth in outputs in proportion whilst under VRS an increase in inputs does not result in a proportionate change in outputs.

Table 2

The KAMET rule analyzes reviews from experts using the Delphi method.

Source: [Chu and Hwang \(2008\)](#)

Condition	Round t for Delphi questions	Round t + 1 for Delphi questions
1	If $M_{qi} \geq 3.5$ and $Q_{qi} \leq 0.5$ and $V_{qi} < 15\%$ then q_i is accepted and no need to consult the experts about q_i anymore	
2	If $M_{qi} \geq 3.5$ and $V_{qi} > 15\%$, perform round 2	If $M_{qi} \geq 3.5$ and $Q_{qi} \leq 0.5$ and $V_{qi} < 15\%$ then q_i is accepted and no need to consult the experts about q_i anymore
3	If $M_{qi} \geq 3.5$ and $Q_{qi} \geq 75\%$, perform round 3	If $M_{qi} \geq 3.5$ and $Q_{qi} \leq 0.5$ and $V_{qi} < 15\%$ then q_i is accepted and no need to consult the experts about q_i anymore
4	If $M_{qi} < 3.5$ and $Q_{qi} \leq 0.5$ and $V_{qi} \leq 15\%$ then q_i is disqualified and no further q_i consultation is required.	

Efficiency is estimated from the acquired outputs in response to the given inputs and may be measured using Input or Output - oriented DEA model. In the input - oriented cases, the objective of the efficiency measurement is to determine the optimal quantity of resources (inputs) to minimize production costs without diminishing outputs whilst with output-oriented cases, the inefficient ports are proposed to push up their outputs within a given set of inputs. In general, input - oriented model focuses on managerial and operational issues whilst output - oriented model is for planning and strategy ([Cullinane et al., 2006](#)).

With respect to the multiple input and multiple output case, suppose a situation with n DMUs, each of them makes q outputs utilizing m different inputs. In this study, to measure each DMU's efficiency, a set of linear equations must be formulated and solved. This problem will be solved by using both Input - Oriented DEA and Output - Oriented DEA for the comparative purpose.

The Input Oriented DEA model is shown, as can be seen in the following form:

$$\begin{aligned} &\text{Min}_{\lambda_i, x_i^*} w_i^* x_i^*, \\ &\text{Subject to:} \end{aligned}$$

$$\sum_{i=1}^N \lambda_i X_{ji} - X_{ji}^* \leq 0, \quad \forall j$$

$$\sum_{i=1}^N \lambda_i y_{ki} - y_{ki} \leq 0, \quad \forall k$$

$$\lambda_i \geq 0, \quad \forall i$$

where: w_i = the input price vector of the i^{th} DMU,

x_i^* = the cost minimization - oriented vector of input quantities for the i^{th} DMU, given the w_i input price and y_k output levels,

$i = 1$ to n (DMUs),

$k = 1$ to q (outputs),

$j = 1$ to m (input variables),

y_{ki} = quantity of output k produced by the i^{th} DMU,

x_{ji} = quantity of input j used by the i^{th} DMU,

λ_i = dual variables.

Following denotes the Output - Oriented DEA technique:

$$\text{Max} \sum_{i=1}^q u_i y_{ko}$$

Subject to:

$$\sum_{i=1}^q u_i y_{ki} - \sum_{j=1}^m v_j X_{ji} \leq 0, \quad \forall j = 1, \dots, j_o, \dots, n$$

$$\sum_{i=1}^m v_j X_{ij} = 1$$

$$u_i \geq 0, \quad \forall i = 1, q; v_j \geq 0 \quad \forall j = 1, m$$

Where:

u_i and v_j : input and output weight sets, non-negative shadow prices.

The estimation of performance efficiency can be performed by various computer programs. However, for convenience, the author used DEAP1 version 2.1 for estimating the performance efficiency in the study.

4. Empirical study

4.1. Input - output measures

The determination of input and output metrics is of paramount significance in employing DEA successfully. Thus, they should be chosen in accordance with the development strategies, objectives, and operational policies of the region ([Cullinane et al., 2006](#)). As depicted in the research process ([Fig. 1](#)), input and output metrics in this research were identified through Delphi method combining with the KAMET principle. After three rounds of consideration from seven experts in port companies and universities, 6 inputs and 2 outputs were selected mentioning capital, operational expenses, labour, area, quay length, and depth for the inputs, and sales revenue and cargo throughputs for the outputs. The values of these metrics meet the statistical requirements (see [Table 3](#)).

Capital is regarded as the whole invested capital and all its facilities on average of a year ([Roll & Hayuth, 1993](#)). This input variable was also utilized by many authors naming [Roll and Hayuth \(1993\)](#), [Cullinane and Song \(2003\)](#), [Barros \(2005, 2006\)](#), [Park and Lee \(2015\)](#), [Ferreira et al. \(2018\)](#), and [Adler et al. \(2021\)](#).

Operational expenses relate to all expenses needed to run the port covering staff costs, costs for services purchased from outside such as utility costs, telecommunication costs ..., cost of materials and stationery, etc. This metric can constrain the port performance because of its limited source and was considered as a monetary input variable in the research of [Martinez-Budria et al. \(1999\)](#), [Barros \(2006\)](#), [Ferreira et al. \(2018\)](#), and [Wang et al. \(2021\)](#).

Labour mentions the total number of labourers working in the port. This input variable was also employed in the study of many researchers such as [Cullinane et al. \(2002\)](#), [Barros \(2003, 2005, 2006\)](#), [Park and Lee \(2015\)](#), [Ding et al. \(2015\)](#), [Monteiro \(2018\)](#), [Wang et al. \(2019\)](#), [Görçün \(2021\)](#), [Quintano et al. \(2020\)](#), and [Adler et al. \(2021\)](#).

Port area is the total usable size of the port measured in square meters. This metric directly refers to the port's performance as the larger the port area is, the more the number of services may be

Table 3

Input and output results from KAMET analysis.

Metrics	Median	Mean	Variance	Quartile deviation
Capital	5	4.86	14.3 %	0.25
Operational expenses	5	4.86	14.3 %	0.25
Labour	5	5.00	0 %	0
Area	5	4.86	14.3 %	0.25
Quay length	5	4.86	14.3 %	0.25
Depth	5	4.86	14.3 %	0.25
Sales revenue	5	5.00	0 %	0
Cargo throughput	5	5.00	0 %	0

offered to the clients and the greater may be the stored cargo. This input metric was applied in numerous previous studies of Cullinane et al., (2005, 2006), Ding et al. (2015), Ferreira et al. (2018), Görçün (2021).

Quay length measured in meters is of extreme importance as the cargo handling and many operations like transshipment, part location, or storage are conducted on the quay. As such, the longer the quay is, the more the number of cranes are, which accordingly more ships may be moored. This variable is considered as a non-monetary input and was used by Ferreira et al. (2018) and Görçün (2021).

Water depth relates the depth of water measured in meters to which a vessel is immersed upon fully loaded. Improved water depth is a competitive advantage of the port as it allows large vessels, and attract more direct lines, whereby higher performance efficiency levels are achieved. In case a port has got different depths, the greatest depth will be chosen as its input metric. This input was introduced by Görçün in his research published in 2021.

Sales revenue is the turnover of the port within a fiscal year denoted in Vietnam Dong. This output variable has been used in most of previous studies namely Liu (1995), Martinez-Budria et al. (1999), Cullinane and Song (2003), Park and De (2004), Barros (2006), Park and Lee (2015), Wang et al., (2019, 2021), Görçün (2021), etc.

Cargo throughput is the total annual handled cargo volume measured in tons. This metric is directly related to the port terminal performance because the greater the cargo handled is, the more the sales revenues are obtained. Given its importance, numerous researchers applied this metric in their research, namely Roll and Hayuth (1993), Coto-Millan et al. (2000), Estache et al. (2002), Barros (2003), Cullinane et al., (2005, 2006), Ding et al. (2015), Ferreira et al. (2018), and Görçün (2021).

4.2. Data in the DEA method

This study measures the performance efficiency of 22 port companies locating from the South to the North of Vietnam, of which seven ports in the Southern Vietnam, nine ports in the Central Vietnam, and six ports in the Northern Vietnam (see Table 4). The dataset was extracted from financial reports and annual reports of those companies in the Vietnamese stock market (IET Stock, 2022) and from the official website of Vietnam Seaports Association. Table 5 reports the summary statistics of the ports analyzed. The standard deviations are high relative to the means of some variables, depicting heterogeneity in those ports, which motivated the author to apply the VRS model for the efficiency assessment.

4.3. Efficiency scores

4.3.1. General assessment

The DEA index may be calculated in output or input – oriented ways. As mentioned above, in this study, the author estimates the efficiency of 22 ports in Vietnam by using both methods with the purpose of seeking to minimize the inputs, maximize the outputs, and finally maximize the efficiency.

4.3.1.1. Output-oriented efficiency evaluation. Table 6 shows the results of performance efficiency evaluation for 22 ports in Vietnam from 2019 to 2021 based on the output-oriented model with technical efficiency from CRS DEA, VRS DEA, and scale efficiency. The efficiency was decomposed into two different components: technical efficiency and scale efficiency. The VRS score measures the pure technical efficiency whereas the CRS score composes of pure technical efficiency and scale efficiency. As such, a ratio of the CRS efficient score and the VRS efficient score constitutes a measurement of scale efficiency (Barros, 2006).

Table 4
List of DMUs.

No.	DMUs	Port name	Region
1	Cat Lai Port Joint Stock Company	Cat Lai	South
2	Dong Nai Port JSC	Dong Nai	South
3	Tan Cang Port Logistics and Stevedoring JSC	Tan Cang	South
4	Phu Huu New Port Corporation	Phu Huu	South
5	Saigon Port Joint Stock Company	Sai Gon	South
6	Can Tho Port JSC	Can Tho	South
7	An Giang Port Joint Stock Company	An Giang	South
8	Da Nang Port Joint Stock Company	Da Nang	Central
9	Quy Nhon Port Joint Stock Company	Quy Nhon	Central
10	Nha Trang Port JSC	Nha Trang	Central
11	PTSC Thanh Hoa Joint Stock Company	Thanh Hoa	Central
12	Thi Nai Port JSC	Thi Nai	Central
13	Nghe Tinh Port Holding Joint Stock Company	Nghe Tinh	Central
14	Port of Hai Phong Joint Stock Company	Hai Phong	Central
15	Cam Ranh Port Joint Stock Company	Cam Ranh	Central
16	Chan May Port Joint Stock Company	Chan May	Central
17	Quang Ninh Port	Quang Ninh	North
18	Vip Greenport Joint Stock Company	Vip Greenport	North
19	Dinh Vu Port Investment and Development JSC	Dinh Vu	North
20	Doan Xa Port Joint Stock Company	Doan Xa	North
21	Cua Cam Hai Phong Port JSC	Cua Cam	North
22	Cai Lan Port Invest JSC	Cai Lan	North

Taking the efficiency results into account, it can be observed that about four out of 22 ports have reached the efficient frontier during the whole period, namely Cat Lai, Tan Cang, Thanh Hoa, and Cua Cam. Four ports show outstanding performance by moving from inefficient points in 2019 to efficient ones in 2020 and 2021, including Da Nang, Quy Nhon, Hai Phong, and Vip Greenport. Almost all these ports have large scale in terms of capital, port area, number of labour, and quay length, which reveals that the dominant efficiency source is scale. These ports not only got CRS efficiency but also VRS efficiency. This finding reconfirms that scale is the key source of efficiency (Barros, 2006). Six inefficient ports experience good growth, moving from low efficient scores in 2019 or 2020 to higher ones in 2021, specifically Saigon, Can Tho, An Giang, Thi Nai, Nghe Tinh, Cam Ranh and Dinh Vu. The remaining ports perform in a fluctuating manner by providing up and down scores (Chan May and Cai Lan), or negative growth (Dong Nai, Phu Huu, Nha Trang, Quang Ninh, and Doan Xa).

Table 6 also depicts that owing to management skills, more than half of ports operated at a high level of pure technical efficiency (VRS efficiency score) in the period. As presented above, the ratio between CRS and VRS provides the measurement of scale efficiency. Efficiency is assumed to be due to scale and management skills, the VRS is, therefore, interpreted as management skills (Barros, 2006).

The next finding which can be seen from the scale efficiency is that 17 ports are efficient and nearly efficient (with their scores of more than 0.9) whereas the remaining 5 ports are not. The efficient ports had constant returns to scale during the period, revealing that a rise in inputs by a specific amount would lead to a rise in output by the same amount. Most of the remaining ports with increasing returns to scale are small in dimension for their production results. Thus, they need to double inputs rather than double outputs (Barros, 2006). Nghe Tinh was the only port with decreasing returns to scale during the entire period and some ports transformed from increasing in 2019 or 2020 to decreasing returns to scale in 2021 namely Dong Nai and Dinh Vu, implying that they are too large in dimension for their production results, so any rises in inputs would lead to a rise in outputs less than one percent. As a result, they should double inputs less than double outputs.

Table 5
Descriptive statistics of metrics utilized in the study.

	2019					2020				2021		
Variables	Min	Max	Mean	SD*	Min	Max	Mean	SD*	Min	Max	Mean	SD*
Outputs												
Sales revenue (billion VND)	2.02	1312.97	521.84	470.48	7	1564	478	446	17	5590	677.88	1161.56
Cargo throughputs (million Tons)	0.03	76.06	12.04	20.14	0.07	83.78	12.71	22.97	0.11	84.74	12.81	22.86
Inputs												
Capital (billion VND)	36.47	5233.12	1069.65	1425.59	46.04	5061.12	1031	1332	45.11	5188.33	1082.11	1436.71
Operational expenses (billion VND)	4.23	201.27	53.49	47.21	4.69	401.64	62.02	86.97	3.34	480.01	64.82	100.66
Labour	8	1498	375	363	6	1494	370	357	6	1359	363	343
Area (hectare)	3.07	73.79	31.48	21.76	3.07	73.79	31.48	21.76	3.07	73.79	31.48	21.76
Quay length (meter)	216	3567	979.48	875.80	216	3567	957.35	880.19	216	3567	957.35	880.19
Water depth (meter)	7	14	11.34	1.67	7	14.3	10.91	2.05	7	13.30	10.83	1.89

*SD: Standard deviation.

4.3.1.2. Input-oriented efficiency evaluation. It can be noted that four points emerge from Table 7. Firstly, input – oriented efficient ports are efficient under output – oriented model as well. Secondly, CRS efficient scores under input – oriented model remain the same as those of output – oriented one. Thirdly, VRS efficient scores of inefficient ports are inefficient under both input and output – oriented model, but the input – oriented scores are a little bit higher, meaning that they are inefficient in utilization of inputs during the period, whereby their scale efficiency is also lower. As consequence, some measures should be done by the port authorities to make them more efficient by reducing inputs or planning to exploit using input resources more (Birafane & El Abdi, 2019). Fourthly, the overall ranks of 22 ports remain unchanged during the whole period.

In terms of both input and output – oriented efficient scores, it can be seen from Tables 6 and 7 that Vietnamese port system had fluctuating performance, accordingly it got more efficient in 2020 than in 2019 but a slight reduction in 2021 compared to 2020. The rationale for this contraction may be due to the fierce spread of

Covid-19 pandemic throughout Vietnam and the globe in 2021. Additionally, ports in the North got higher average efficient scores than those in the South and the Central.

4.3.2. Assessment by ports

Based on the technical efficiency results in 2021 shown in Tables 8 and 9 and Fig. 2, 8 out of 22 ports reached the CRS and VRS efficient frontier. Thus, they do not need to make any changes to their input and output management. However, more investment will be beneficial as they are obtaining constant returns to scale. Additionally, they are also peers of other ports in the industry. For example, Thanh Hoa and Tan Cang are peers of seven other ports; Cat Lai and Vip Greenport are peers of four ports; Cua Cam, Quy Nhon, and Hai Phong are peers of five, three, two ports respectively. This result is a benchmarking feature of DEA method, which helps port operators define the best DMUs to set variables of improvement measures (Nong, 2022).

For five ports which have VRS efficient scores of 1 but scale efficient scores of less than 1, namely Phu Huu, Nha Trang, Thi Nai,

Table 6
Output – oriented efficient scores of 22 ports in Vietnam from 2019 to 2021.

Ordinal No.	Port name	2019				2020				2021			
		CRS efficient scores	VRS efficient scores	Scale efficiency	Return to scale	CRS efficient scores	VRS efficient scores	Scale efficiency	Return to scale	CRS efficient scores	VRS efficient scores	Scale efficiency	Return to scale
1	Cat Lai	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst
2	Dong Nai	0.500	0.952	0.525	irs	1.000	1.000	1.000	cst	0.830	0.841	0.987	drs
3	Tan Cang	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst
4	Phu Huu	0.558	0.872	0.640	irs	0.957	1.000	0.957	irs	0.844	1.000	0.844	irs
5	Saigon	0.442	0.445	0.994	drs	0.785	0.818	0.960	drs	0.888	0.895	0.992	irs
6	Can Tho	0.201	0.240	0.841	irs	0.254	0.268	0.948	drs	0.276	0.284	0.971	irs
7	An Giang	0.296	1.000	0.296	irs	0.288	1.000	0.288	irs	0.315	0.317	0.994	irs
8	Da Nang	0.556	0.563	0.989	drs	0.929	1.000	0.929	drs	1.000	1.000	1.000	cst
9	Quy Nhon	0.755	0.762	0.990	drs	0.989	0.989	1.000	cst	1.000	1.000	1.000	cst
10	Nha Trang	0.390	1.000	0.390	irs	0.218	1.000	0.218	irs	0.050	1.000	0.050	irs
11	Thanh Hoa	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst
12	Thi Nai	0.332	1.000	0.332	irs	0.429	1.000	0.429	irs	0.739	1.000	0.739	irs
13	Nghe Tinh	0.448	0.452	0.990	drs	0.514	0.529	0.973	drs	0.572	0.575	0.996	drs
14	Hai Phong	0.506	0.764	0.662	irs	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst
15	Cam Ranh	0.280	0.285	0.985	drs	0.330	0.332	0.990	drs	0.452	0.452	0.999	cst
16	Chan May	0.167	0.171	0.981	irs	0.277	0.28	0.990	drs	0.255	0.257	0.994	irs
17	Quang Ninh	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst	0.727	0.738	0.984	irs
18	Vip Greenport	0.858	1.000	0.858	irs	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst
19	Dinh Vu	0.442	0.458	0.965	irs	0.658	0.671	0.980	drs	0.717	0.742	0.967	drs
20	Doan Xa	0.244	1.000	0.244	irs	0.358	1.000	0.358	irs	0.232	1.000	0.232	irs
21	Cua Cam	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst	1.000	1.000	1.000	cst
22	Cai Lan	0.709	1.000	0.709	irs	0.567	0.567	0.342	irs	0.840	1.000	0.840	irs
Mean		0.577	0.771	0.79		0.707	0.859	0.845		0.715	0.823	0.89	

* cst: constant

* irs: increasing

* drs: decreasing.

Table 7
Input – oriented efficient scores of 22 ports in Vietnam from 2019–2021.

Ordinal No.	Port name	2019			2020			2021		
		CRS efficient scores	VRS efficient scores	Scale efficiency	CRS efficient scores	VRS efficient scores	Scale efficiency	CRS efficient scores	VRS efficient scores	Scale efficiency
1	Cat Lai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	Dong Nai	0.500	0.993	0.504	1.000	1.000	1.000	0.830	0.847	0.980
3	Tan Cang	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	Phu Huu	0.558	0.969	0.576	0.957	1.000	0.957	0.844	1.000	0.844
5	Salgon	0.442	0.682	0.648	0.785	0.802	0.979	0.888	0.929	0.956
6	Can Tho	0.201	0.694	0.290	0.254	0.589	0.432	0.276	0.588	0.461
7	An Giang	0.296	1.000	0.296	0.288	1.000	0.288	0.315	0.589	0.534
8	Da Nang	0.556	0.691	0.805	0.929	1.000	0.929	1.000	1.000	1.000
9	Quy Nhon	0.755	0.758	0.996	1.000	0.989	0.989	1.000	1.000	1.000
10	Nha Trang	0.390	1.000	0.390	0.218	1.000	0.218	0.050	1.000	0.050
11	Thanh Hoa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	Thi Nai	0.332	1.000	0.332	0.429	1.000	0.429	0.739	1.000	0.739
13	Nghe Tinh	0.448	0.761	0.588	0.514	0.757	0.680	0.572	0.795	0.720
14	Hai Phong	0.506	0.936	0.540	1.000	1.000	1.000	1.000	1.000	1.000
15	Cam Ranh	0.280	0.540	0.520	0.330	0.533	0.618	0.452	0.564	0.802
16	Chan May	0.167	0.664	0.252	0.277	0.663	0.418	0.255	0.528	0.483
17	Quang Ninh	1.000	1.000	1.000	1.000	1.000	1.000	0.727	0.859	0.846
18	Vip Greenport	0.858	1.000	0.858	1.000	1.000	1.000	1.000	1.000	1.000
19	Dinh Vu	0.442	0.702	0.629	0.658	0.791	0.832	0.717	0.819	0.876
20	Doan Xa	0.244	1.000	0.244	0.358	1.000	0.358	0.232	1.000	0.232
21	Cua Cam	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	Cai Lan	0.709	1.000	0.709	0.567	1.000	0.567	0.840	1.000	0.840
		0.726	0.934	0.577	0.881	0.644	0.707	0.915	0.759	0.715

Table 8
Input targets of 22 ports in Vietnam.

No.	Port name	Peers	Input target			Compared to original value					
			Capital	Operational expenses	Labour	Port Area	Quay length	Water Depth	Capital	Operational expenses	Labour
1	Cat Lai		640.14	15.25	37	60	216	10.8	0	0	0
2	Dong Nai	3–18	913.072	77.725	271	33.23	1227	11.32	-228.78	-1.755	0
3	Tan Cang		839.91	81.96	304	38.19	1537	12	0	0	0
4	Phu Huu		383.63	30.48	154	21.12	320	12	0	0	0
5	Saigon	9–14–18	1471.38	94.25	169	16.61	1273	12	-3741.84	-107.02	-87
6	Can Tho	1–3–11–21	365.07	28.72	114	6.80	658	8.96	0	0	0
7	An Giang	1–21	155.53	10.05	728	21.87	384	7.7	0	0	-6
8	Da Nang		1784.1	119.3	822	31	1700	12	0	0	0
9	Quy Nhon		1053.91	95.97	8	10.3	1068	12	0	0	0
10	Nha Trang		216.51	28.28	437	9.4	552.2	11.8	0	0	0
11	Thanh Hoa		805.07	36.46	219	3.07	390	11	0	0	0
12	Thi Nai		107.71	12.18	146	12.63	655.7	8.4	0	0	-276
13	Nghe Tinh	3–11–21	273.98	25.47	1498	71.96	3567	9.4	0	0	0
14	Hai Phong		5233.1	97.73	166	14	696.93	8.7	0	0	-27
15	Cam Ranh	3–11–21	326.68	29.16	309	23.86	546.5	10.84	0	0	0
16	Chan May	1–3–11–21	722.96	37.63	617	27.74	926	11.7	0	0	-81
17	Quang Ninh	3–9–11–14–18	1045.58	83.72	183	20	400	9.5	0	0	0
18	Vip Greenport		1108.17	66.43	242	19.45	425	9.8	-437.53	0	-190
19	Dinh Vu	1–9–11–18	1061.86	63.27	202	8.1	225	8.4	0	0	0
20	Doan Xa		533.81	20.12	71	3.5	350	7	0	0	0
21	Cua Cam		36.47	4.23	38	28	600	13	0	0	0
22	Cai Lan		45.47	9.6					0	0	0

Doan Xa, and Cai Lan, although they do not need to make changes to their input and output variables according to the result of DEA analysis, they could increase their inputs to get scale efficiency as they are obtaining increasing returns to scale (Barros, 2006; Birafane & El Abdi, 2019).

For the remaining ports, following the results shown in Tables 8 and 9, they may have a general look at what they should perform to reach the efficient frontier. For example, in terms of input management, Dong Nai port should reduce its capital an amount of VND 228.78 billion, cut its operational expenses of VND 1.755 billion, or should resize its area of 25.72 ha or quay length of 6 m while maintaining the same output. In regard to output management, Dong Nai port should improve its cargo throughputs from 6.6 million tons to 52.32 million tons or its revenue from VND 892.51 billion to VND 1061.29 billion in case it prefers to keep the input metrics unchanged. Nonetheless, Dong Nai has increasing returns to scale, so input focus would be better for it. Apart from input and output management, Dong Nai should take Tan Cang and Vip Greenport as models to learn from. Similar input and output management activities should also be implemented by other inefficient ports including Saigon, Can Tho, Cam Ranh, Chan May, Quang Ninh, and Dinh Vu. For the case of Nghe Tinh with decreasing returns to scale, it is better to change its outputs rather than its inputs. Generally, it may be of hard duty for these ports; however, to become efficient, they should have proper actions.

5. Discussion

Taking the findings from the input and output-oriented efficiency evaluation into consideration, there are a large number of ports achieving their efficiency frontier for the whole period from 2019 to 2021 or for two years from 2020 to 2021 regardless of the effect of Covid-19 pandemic. As a matter of fact, according to General Statistics Office of Vietnam, despite the great impact of the COVID-19 pandemic, the total volume of cargo throughput through Vietnam's seaports in 2021 still reached more than 703 million tons, up 2 % compared to 2020. In particular, the volume of imported and exported goods of Vietnam's shipping fleet achieved a rare growth, up 54 % (reaching nearly 5 million tons) compared to 2020. This research's findings are good recommendations for port operators as well as port authorities and investors in making investment decisions. Accordingly, Cat Lai, Tan Cang, Thanh Hoa and Cua Cam are the four best candidates for attracting enormous investments from socialization, FDI ... because these ports got CRS efficiency, which an increase in inputs would lead to an increase in outputs. Special attention should be paid to the case of Cua Cam. Being compared to other ports in this group, Cua Cam is considerably small in input size (capital, labour, port area, quay length, and water depth), which requires an enormous amount of investment. In this circumstance, integration with other ports may result in positive effects such as improving its competitiveness, decreasing its operational costs, etc.

Moreover, those ports obtained good performance with increasing returns to scale are also qualified for receiving more investment, namely Phu Huu, Da Nang, Quy Nhon, Nha Trang, Hai Phong, Cam Ranh, Vip Greenport, Cua Cam, Doan Xa, Cai Lan and Thi Nai. Notably, port operators in the world and Vietnam are constantly investing to ports' infrastructure and scale to optimize port performance. As such, scale can be a pivotal factor affecting the port efficiency and its competitiveness (Barros, 2006). On the contrary, Nghe Tinh, Dong Nai and Dinh Vu port's operators may consider enlarging the output to improve their efficiency as recommended in Table 9. For the remaining ports with increasing returns to scale but low efficient scores (Saigon, Can Tho, An Giang, Chan May, and Quang Ninh), they should resize their scale by reducing their labour, re-sizing their area or quay length while maintaining the same outputs.

Table 9
Output targets of 22 ports in Vietnam.

No.	Port name	Peers	Output target		Compared to original value	
			Cargo throughputs	Revenue	Cargo throughputs	Revenue
1	Cat Lai		76.06	191.84	0	0
2	Dong Nai	3–18	52.32	1061.29	45.72	168.78
3	Tan Cang		67.18	1153.23	0	0
4	Phu Huu		4.86	328.66	0	0
5	Saigon	9–14–18	12.79	1279.56	2.61	134.02
6	Can Tho	1–3–11–21	22.68	429.88	21.05	307.93
7	An Giang	1–3–11–21	4.70	168.42	3.21	115.07
8	Da Nang		12.90	1078.89	0	0
9	Quy Nhon		11.50	1311.23	0	0
10	Nha Trang		0.14	2.02	0	0
11	Thanh Hoa		4.50	735.19	0	0
12	Thi Nai		1.74	95.25	0	0
13	Nghe Tinh	3–11–21	17.42	371.90	12.82	158.11
14	Hai Phong		23.79	1312.97	0	0
15	Cam Ranh	3–11–21	19.82	430.84	17.38	235.90
16	Chan May	1–3–11–21	28.93	650.08	25.81	483.14
17	Quang Ninh	3–9–11–14–18	16	1147.64	7.90	300.13
18	Vip Greenport		12.68	816.10	0	0
19	Dinh Vu	1–9–11–18	12.16	820.42	3.14	211.84
20	Doan Xa		1.02	87.07	0	0
21	Cua Cam		0.03	65.72	0	0
22	Cai Lan		1.2	57.31	0	0

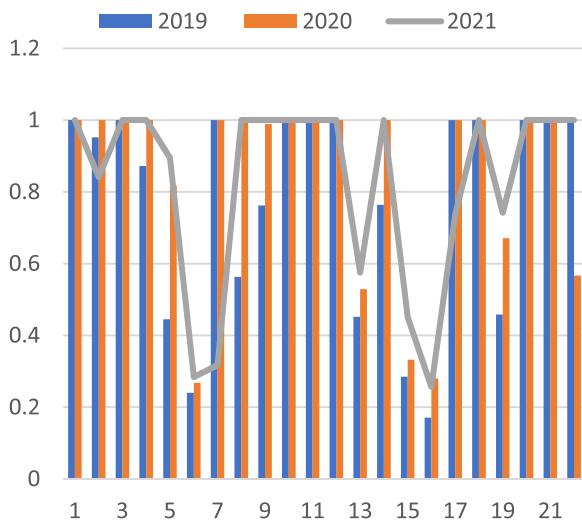


Fig. 2. Efficiency scores of 22 ports in Vietnam from 2019 to 2021.

6. Conclusion

The research proposed an integrated method of Delphi with KAMET and DEA methods into the performance efficiency evaluation of 22 ports in Vietnam. The successful evaluation verifies the practicality of Delphi, KAMET and DEA application in the port industry. In addition, it can be noted that capital, operation expenses, labour, port area, quay length, water depth, revenue, and cargo throughputs are considered as input and output metrics in the port performance efficiency evaluation. On top of that, many emerging points are withdrawn from the research findings as follows: scale and management skills are the dominant source of efficiency; the efficient ports have constant returns to scale; the input – oriented efficient ports are also efficient under output – oriented model; under input – oriented method VRS efficient scores are fairly higher than the ones of output orientation; and the CRS efficient scores and the overall ranks of ports remain unchanged under both input and output – oriented models.

The general conclusion for Vietnamese ports is that they show rather high management skills as most of them are VRS-efficient.

Nonetheless, for inefficient VRS ports, there is room for them to improve their inefficiency by changing their inputs for increasing returns to scale ports or changing their outputs for decreasing returns to scale ones. For inefficient scale ports, they could alter their scale through M&A (mergers and acquisitions), or investment.

The theoretical contribution of this study is the proposition of an integrated techniques (Delphi, KAMET, and DEA) to handle with a variety of inputs and outputs and evaluate the efficiency of ports. Further, the input and output metrics suggested in this study may contribute to the literature in the concept and evaluation of the port efficiency. As well, in terms of managerial contribution, the comprehensive evaluation of ports may help not only the DMUs but also the port authorities or association with limited budget. For individual ports, the operators may assume a systematic policy to enable their ports to reach the efficient frontier. For port authorities, the efficiency analysis result helps them improve and perfect the performance efficiency of port system without wasting the public funds due to limited endowment. In a similar vein, the study results also provide influential information on the efficiency of ports functioning in regards to other ports with similar scope of activities.

The proposed integrated approach could be applied to the port performance efficiency in other regions or countries. However, the research findings only apply to the case of Vietnam. Future research, therefore, may be extended to other higher-ranking countries. The other limitation pertains to the data set with only 22 ports listed on the stock market from 2019 to 2021. On that account, it is suggested to enlarge the data size on geographic or time-series basis.

Funding

This work was supported by University of Finance - Marketing under the contract number 873/HĐ-DHTCM.

Acknowledgements

The author expresses their appreciation to the colleagues who reviewed this paper and offered useful recommendations for improving it. The author greatly appreciates the time and useful suggestions from guest editors and reviewers.

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