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Performance Measure of Malaysian Seaports Using Data Envelopment Analysis (DEA)

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ABSTRACT

As shipping medium has been the primary choice of many international companies to transport imported and exported goods, seaports play important role in providing the commercial facilities for the ships to load and discharge cargo. Service efficiency of ports in Malaysia needs to be evaluated in order to know their status and position for business survival. The efficiency will reflect the input utilization of resource in relation to the output service. The main objective of this research is to measure the service efficiency of five selected ports in Malaysia. The other objective is to rank the ports based on their efficiency level. Finally, this research aimed to propose some improvement strategies to maximize the service efficiency of the selected ports in Malaysia. The performance of the ports is measured using the method of Data Envelopment Analysis (DEA) and solved using QM For Windows software. Basically, DEA is chosen because it is a non-parametric method that can measure the efficiency with the use of multiple inputs and multiple outputs. The finding of the research shows that the efficiency of all five ports is above 90%, in which Port P3 has the lowest efficiency which is only 92.42%.

Keywords:
Data Envelopment Analysis, Efficiency, Ports, Shipping, Multiple Inputs and Outputs

1. Introduction

Liner shipping industry deals with the service of transporting goods by using ocean-going ships. This shipping medium has been the primary choice of many international companies to transport cargo, either importing or exporting freight worldwide. Due to this practice, seaports play a vital role in providing the commercial facilities for the ships to load and discharge cargo for trade exchange with other countries.

Shipping industry has been the backbone of the economy in Malaysia as 95% of world trade volume is done through shipping. In the last few decades, there are massive development of ports in both East Malaysia and Peninsular Malaysia. The number of ports available is also increasing since the year 2010. Due to the vast number of ports in the country, strategic plan is needed for ports in Malaysia to maintain and continuously improve their performance.

At the end of this study, the Malaysian seaports will be ranked according to their efficiencies. From this rank, the management will be informed on the way to improve the efficiency of the seaports. The improvement will be made by means of the inputs, such as the length of berth, yard

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area, number of quay cranes and other inputs. With efficient seaports, the freight trading business will be more efficient and hence, profitable.

Seaway transportation sector give a big impact on the economic income of country. This sector play important role on export and import industry around the world. Therefore, to increase the performance of export and import industry, Malaysia has to increase the yearly throughput of goods, at the same time increasing the efficiency of the ports. Therefore, the government can plan their expenditure budget to provide funds on this industry.

This research will evaluate the relative efficiency of five ports in Malaysia using DEA method. The main objective of this research is to measure the relative efficiency of five selected seaports in Malaysia. Other objectives are to identify the rank the seaports based on their relative efficiencies and to propose improvement strategies so as to maximize the efficiencies of the seaports.

2. Literature Review

Data Envelopment Analysis (DEA) was developed by Charnes *et al*., [5] and it is a mathematical programming method that calculates the relative efficiency of decision making units (DMUs) by making use of multiple inputs and multiple outputs. DEA has been used in many areas to measure the performance of entities such as in oil and gas, banks and hospitals

One example is DEA model with output orientation is used to rank five improvement models which have undergone several modifications on the original simulation model [18]. In order to determine the efficient improvement models, DEA model with output orientation is used to rank the improvement models and to select the best improvement model. Beside this, Kamarudin, Ismail and Mohd. [11] have designed a study to measure the overall performance in terms of efficiency and effectiveness of Islamic banks in Malaysia using Two-Stage DEA approach. Another study was done by Ismail *et al*., [9] to determine the most efficient state in producing the paddy output. This study proposes the combination of Principal Component Analysis (PCA) and DEA approaches to reduce the data dimensionality problem instead of eliminating the variables with multi collinearity problem from the analysis. Johari, Hussin and Zahid [10] have investigated the monthly technical efficiency of nine stadiums usage that is maintained by the Municipal Council in the Klang Valley in the year 2014. Apart from this study, a time series DEA analysis has been implemented to determine the degree of severity of flood disaster for each district in Kelantan based on DEA analysis [8].

Measuring the performance of the system by determining its efficiency is a very important indicator in transportation management in order to identify its performance level among other entities in the system. In the case of ports in Malaysia, it is important to make comparison on the service efficiency between the seaports in Malaysia since most of world trade volume is done through shipping. Many indicators can be used to measure the performance of seaports. For example, there are many activities carried out in ports such as loading of containers, storing container in warehouse and service of maintenance provided to ships that stop at the ports.

Sara Bray *et al*., [3] have conducted a research to assess efficiency of transportation system and services. This research was conducted on 16 international container ports which are 4 Australian and 12 other international container ports using the combination of DEA and Fuzzy DEA. In selecting input and output, they have chosen the number of berth, yard area, number of quay cranes number of employees, delay time and number of tugs as their inputs to measure the performance. They have suggested increasing the number of cranes to improve the delay time. Hajizadeh *et al*., [2] used DEA to evaluate the relative efficiency on container seaports in Middle East region. The data selected are number of berth, berth length, yard area, number of quay cranes and yard cranes and container throughput. They have proposed to increase and expand of inputs for ports which operate under increasing return to scale.

In a research conducted by Pongpanich and Peng [16], four container ports in Thailand were observed to measure and analyze the efficiency of Thai container port using DEA. Various specifications of inputs and outputs variables were used to obtain the result. They were using number of berth, berth length, number of yard cranes and quality of product to make sure that they are using homogeneous data. The result revealed that ports in Thailand need to increase the size of their port and seek for more customers. Kutin *et al*., [14] has done a research by using an application of DEA to analyze the relative efficiencies of 50 ASEAN container ports and terminals. As for inputs and outputs, they used depth at berth, yard area, number of quay cranes, number of yard cranes and container throughput. They suggested the ports to increase their inputs in order to increase the relative efficiencies.

Carine [4] from the Shanghai Maritime University has conducted a research to evaluate the relative efficiency of 16 container ports in Sub-Sahara Africa using DEA model. The data selected are berth length, yard area, number of quay cranes, number of equipment and container throughput. She concluded that the port authorities should examine their operational scale in order to increase the efficiency in each port. DEA was also used by Zheng and Park [19] from the Korea Maritime and Ocean University to derive the implication required for efficiency improvement and management level enhancement. In the research, container terminals within major large ports of Korea and China were selected to measure its efficiency. Various specifications of inputs and outputs like berth length, yard area, number of quay cranes, number of yard cranes and container throughput were used to obtain the result that representing realistic situation. Finally, they proposed that the ports should expand the scale of their terminal and enhance the efficiency of their facilities.

Based on Valentine and Gray [19], efficiency is known as the ratio of output to the input. Input is categorized as essential feature in production such as equipment and labor. Input variable is normally selected based on the usability of elements and equipment. However, this study does not include labor as input variable due to data availability. In the context of seaport efficiency, output is based on the function of container terminal as a facility to transshipped container between land and sea. Almawsheki and Shah [1] stated that the terminal area and quay length are categorized as proxies for land factor input, while the number of quay crane and yard equipment are categorized as proxies for equipment factor input.

3. Research Methodology

The aim of this research is to measure the relative efficiency of DMUs of selected Malaysia seaports with multiple inputs and multiple outputs. The idea of DEA is that the efficiency of DMUs is determined by their ability to transform selected inputs into desired outputs. To maximize the utilization of inputs in producing outputs, precise action at container terminal should be taken. Hence, data selection is an important part in this study where the input and output variables must be chosen systematically.

Based on the literature reviews, this research has selected four input variables that consist of two different types of inputs. Two inputs in this research which are classified as proxy for land factor input are the number of berth and the length of berth, measured in meters. Other two inputs which are classified as proxy for equipment factor input are the number of rubber tyre gantry crane and the number of quay gantry crane. On the other hand, there are two output variables to apply in DEA for container ports. One output variable for this research is the total container throughput in twenty foot equivalent units (TEUs) of container loaded. Container throughput is considered as the most influential mark in container terminal output [13]. Another output variable is total number of ship calling.

Charnes *et al.*, [5] model of DEA has been chosen to be the base model for this research. The model measures the score efficiency of numerous inputs and outputs variables as described below:

$$Efficiency = \frac{Weighted\ sum\ of\ outputs}{Weighted\ sum\ of\ inputs}$$

Assuming that there are *n* DMUs each with *i* inputs and *r* outputs, the relative efficiency score of DMU can be obtained by solving the following model.

$$\text{Maximize } E_k = \sum_{r=1}^{s} u_r y_{rj} \tag{1}$$

Subject to

$$\text{Maximize } E_k = \sum_{r=1}^{s} u_r y_{rj} \tag{2}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \ , \tag{3}$$

where

E_k is the relative efficiency of the k^{th} DMU

y_{rj} is the amount of r^{th} output produced by j^{th} DMU, $j = 1,2,\ldots,k; r = 1,2,\ldots,s$

x_{ij} is the amount of i^{th} input used by j^{th} DMU, $j = 1,2,\ldots,k; i = 1,2,\ldots,m.$

u_r is the weight given to r^{th} output , $r = 1,2,\ldots,s$

v_i the weight given to i^{th} input, $i = 1,2,\ldots,m$

m and *s* is the number of inputs and outputs, respectively.

Objective function (1) is the relative efficiency E_k where it must be between 0 and 1. The data for this project is secondary data which is collected from the Malaysia Port Statistics, Department of Statistics Malaysia and some official webpage of ports in Malaysia. The data needed is related to the current performance of the ports involved. Table 1 shows that the data selected for input and output variables for five selected seaports in Malaysia.

Table 1
Inputs and outputs for selectd five ports in Malaysia

Inputs	**P1**	**P2**	**P3**	**P4**	**P5**
Number of berth (units)	24	14	10	3	3
Length of berth (meter)	6.1	5.04	1.67	0.7	0.6
Number of rubber tyre gantry crane (units)	163	180	37	19	4
Number of quay gantry crane (units)	60	50	15	8	4
Outputs					
Total container throughput (20 ft eq. unit) in millions	13.2	8.2	1.4	0.8	0.1
Total number of ship calling (units)	16 323	4 470	7 008	4 044	1 820

Source: Malaysia Port Statistics, CEIC Data, Department of Statistics Malaysia

In this research, there are four inputs and two outputs that are used to measure the efficiency of the selected ports in Malaysia. This model consists of sets, parameters, decision variables, objective function and constraints. Therefore, the model sets can be written as below:

DMUs, $j = \{1,2,3,4,5\}$
Inputs, $i = \{1,2,3,4\}$
Outputs, $r = \{1,2\}$

4. Findings

By using *QM for Windows* software the efficiency of selected ports in Malaysia are calculated. DEA has the abilities to explain some possible factors that can enable the ports to acquire better relative efficiency and obtain a better performance. Table 2 shows the result obtained on the relative efficiency of selected ports in Malaysia.

Table 2
The relative efficiencies of selected five ports in Malaysia

Port	Relative Efficiencies (%)
P1	100.00
P2	100.00
P3	92.42
P4	99.95
P5	100.00

In terms of scale efficiency, there are three ports that have favorable result of 100% relative efficiency, which are Port P1, Port P2 and Port P5. The first analysis that can be made is on Port P1, as it is categorized as one of the biggest port in Malaysia. Port P2 has also perfectly utilized their input to produce the output. It can be highlighted that some inputs technically give big impact in generating output. This is because Port P2 with 5.04 km length of berth is equipped with sufficient number of berth which is 14 berths. Port P2 has also the highest number of rubber tyre gantry crane (180) which indicates that Port P2 know the importance of this input to load and unload cargo. In addition to this, Port P5 has the smallest value of inputs from the other ports but it does not affect their management to have a great performance. It has the smallest number of 3 berths and the shortest length of berth of 0.6 km therefore it can be assumed that Port P5 has maximized the utilization of its inputs.

On the other hand, P4 with 99.95% slightly has lower performance relative efficiency. This indicates that P4 has some inputs that are not fully utilized since the values of inputs are mostly higher to get the best result. Lastly, Port P3 recorded 92.42% of efficiency which is the lowest result among five selected ports. The efficiency of Port P3 is in an unsatisfactory state and needs a large improvement.

As the Port P3 has the lowest relative efficiency among those five selected ports, therefore, improvements need to be done in order for Port P3 to improve its efficiency so that it can be on par with the other ports in Malaysia. Suggested value for input and output will be obtained by utilizing the constraints and weight of dual of Port P3. Table 3 indicates the reference set and weight of dual for Port P3.

Table 3
The reference set for Port P3

Port	Relative Efficiency (%)	Reference Set	Weight of Dual
P3	92.42	{P1,P4}	0.0004,1.7313

Reference set and weight of dual are obtained by solving the reduced linear programming model for every port. Reference sets are basically consists of ports that have greater relative efficiencies and will be served as a basis for inefficient port to be rated to increase the efficiency level by improving their input and output values. The weight of dual is used as an indicator represented by each reference set to obtained the suggested value for improvement.

Therefore, based on the result obtained, only Port P3 with only 92.42% of efficiency need to be revised its input and output values by checking whether the current values are adequate to surpass its present efficiency percentage. In this study, the inputs comprise of number of berth, length of berth, number of rubber tyre gantry crane and number of quay gantry crane whereas the outputs include total container throughput and total ship calling.

The approach to acquire the fitted values of input and output can be done by using El-Mahgary and Lahdelma [7] model as the following,

$$x_{iE'} = x_{iM}\lambda_{iM} + x_{iQ}\lambda_{iQ} \tag{4}$$

where

$x_{iE'}$ is the value that need to be revised

x_{iM} the value of the reference set M

x_{iQ} the value of the reference set Q

λ_{iM} the dual weight of reference set M

x_{iQ} the dual weight of reference set Q

M and Q is the reference set for improvement

5. Improvement on input values

Based on Equation (4), the equation will be modified to calculate suggested number of berth for Port P3 to improve its efficiency. These input values can also be found out by using the same equation by replacing the number of berth with other input values. The computations to find the proposed values for inputs of Port P3 are shown below.

In order to check the most appropriate value of number of berth for Port P3:

$$x_i(P3) = x_i(P1)\lambda_i(P1) + x_i(P4)\lambda_i(P4) \tag{5}$$

where

$x_i(P3)$ is the value of input that should be reduced from the input available for Port P3

$x_i(P1)$ is the value for number of berth for Port P1

$x_i(P4)$ is the value for number of berth for Port P4

$\lambda_i(P1)$ is the weightage for Port P1

$\lambda_i(P4)$ is the weightage for Port P4

6. Improvement on output values

By using the same Equation (4), improvement for output values can also be figured out by modifying the equation. The computations to find the suggested output values are shown below.

In order to check the most appropriate value of total container throughput for Port P3:

$$y_i(P3) = y_i(P1)\lambda_i(P1) + y_i(P4)\lambda_i(P4) \quad (6)$$

where

$y_i(P3)$ is the value of output that should be increased from the output available for Port P3

$y_i(P1)$ is the value for total container throughput for Port P1

$y_i(P4)$ is the value for total container throughput for Port P4

$\lambda_i(P1)$ is the weightage for Port P1

$\lambda_i(P4)$ is the weightage for Port P4

Equation (6) can be used to find the proposed value for outputs of Port P3. Table 4 shows the current values and suggested values of the inputs and outputs for Port P3, based on the result analysis. The table portrays the improvement that should been taken by Port P3 to improve its efficiency level to 100%. It can be seen that the inputs of Port P3 should be reduced in order to improve the efficiency. Number of berth originally was 10 and the length of berth was 1.67 km, but they are suggested to be reduced to 5 berths and 1.21 km, respectively. This is because, there is an excessive berths available in terms of number and length, and those berths are not fully utilized. Next, the number of rubber tyre gantry cranes and number of quay gantry cranes are also proposed to be reduced. Rubber tyre gantry crane is suggested to be reduced to 33 cranes and quay gantry crane is suggested to be reduced to 14 cranes. When the number of rubber tyre gantry crane and number of quay gantry crane are reduced, it is shown that those two inputs are being used at the maximum level.

Table 4
Suggested value of inputs and outputs for Port P3

	Port P3	
Port	**Current Value**	**Suggested Value**
Number of berth (unit)	10	5
Length of berth (km)	1.67	1.21
Number of rubber tyre gantry crane (unit)	37	33
Number of quay gantry crane (unit)	15	14
Total container throughput (TEU)	1437120	1437091
Total ship calling (unit)	7008	7008

From the output, the new relative efficiency for Port P3 is calculated as below:

$$E_3 = \frac{14.3712W_{CT} + 7.008W_{SC}}{10W_{NOB} + 1.67W_{LOB} + 37W_{RTG} + 15W_{QG}}$$

The calculation indicates the expected relative efficiency for P3 to be 99.88%. This efficiency has been improved from the previous reading of 92.42%.

7. Conclusion

This research was carried out using non-parametric DEA method to measure the efficiency of selected Malaysian seaports by utilizing its multiple inputs and outputs. Upon measuring the efficiencies of five selected ports using DEA, the ports were then ranked and their performances were observed. In this research, Port P3 is the most inefficient with 92.42% efficiency. Port P1, Port P2 and Port P5 has 100% efficiency. Other than that, Port P4 has 99.95% efficiency. Inefficiency of Port P3 might be due to resources that are not fully utilized and ineffectively managed.

The proposed improvement strategy on Port P3 is to maximize its efficiency. For the port with lowest efficiency, a reference set was provided to produce the improvement values for inputs and outputs. As a result of the improvement, a recommendation was made to this port to improve its efficiency. Upon reducing the inputs like number of berth, length of berth, number of rubber tyre gantry crane and number of quay gantry crane to a suitable level, the utilization of the input resources are balanced with the output produced, which are total number of container throughput and total number of ships calling.

As for future research, it is suggested to measure the annual performance of seaports in entire Malaysia, not only the major seaports. With this action, we can identify the weaknesses of the seaports and improve its efficiency by upgrading the infrastructures and facilities. This can give opportunity for ports in Malaysia to maximize their productivity and expand the seaports operation, so as to be at par as compared to other seaports in the global shipping industry.

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