Measuring technical efficiency of dry bulk terminal performance using the frontier application of data envelopment analysis: A proposed framework

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Abstract. The usage of performance indicators in measuring seaport efficiency is undeniable especially towards increasing the port performance. There are numerous studies on applying data envelopment analysis (DEA) which demonstrates the relationship between technical efficiency and port performance. Conversely, there has been a significant problem of port inefficiency in terms of port performance. DEA application is being applied between the technical efficiency and port performance. It is important for indicators to be initiated on port efficiency which may lead to the increase of the port performance. However, the challenges to be implemented in the port as a whole will be difficult due to broad technical factors from various port activities. Implementation of DEA has been done commonly in container operations but not in dry bulk terminal area. Therefore, this conceptual paper discussed the potential of using the technical port indicators and DEA application specifically in dry bulk terminal.

1. Introduction
Seaport terminal performance are debatable issues and has widely been discussed regionally, nationally and internationally. Basically, port performance is a figure data that shows the indicator index between one port to another as to which port performs better than the other. A current report [1] indicated that more than 80% of the international trades are commuted through seaborne and this projects the efficiency of port terminal operations as important either inbound or outbound for the country. Another
report by Bank Negara Malaysia [2] reported that 54.4% of Gross Domestic Product (GDP) from services activity had contributed to the increase of Malaysia revenue.

Despite of the ports performance, technical performance found to be the most challenging issue among ports globally. The increase in containerization, development of new production system, distribution and different port markets has affected the overall port management and operation. In order for the ports to know their achievements, they need to measure their technical performance. This is to enable them to strategically address the needs of the port users that eventually will increase the competitiveness where it may also influence the decision making strategies at various levels of management and operational outcomes.

Currently in Malaysia, there are seven major federal ports namely Port Klang, Johor Port, Port of Tanjung Pelepas, Kuantan Port, Penang Port, Bintulu Port and Kemaman Port [3]. Majority of them are multipurpose ports where containerization is a main contributor of the business trade followed by bulk cargo. The privatization of port and the legislation Act in Malaysia had further elevated the competitiveness of some of the ports and had resulted towards a phenomenal growth of freight management in Malaysian ports. For example, according to the CEIC [4], in 2018, the total container throughput reported as at August reached 208,099.00 TEUs in Port Klang. It was also reported that dry bulk cargo throughput reached 10.624 ton mn in December 2017.

In spite of this, in Malaysia and many other seaports in the world, port operators use seaport throughput volume as a main indicator for their port performance. However, it does not provide a clear picture of the impact that it provides to the ancillary services surrounding the port area. This is due to the lack of seaport information relating to their operation activities. Furthermore, according to [5], it is targeted that by 2020, Malaysia can be the top 20 ranked globally in Logistics Performance Index (LPI). As such, there is an urgent call to the local ports in Malaysia to engage appropriate measurement tool in monitoring the port efficiency to enable them to achieve sustainability in a challenging logistics ecosystem.

Even though studies in seaports have been discussed extensively with great significance for container terminal operation, there is no direct measurement established so far to measure the efficiency of business for the dry bulk terminal. This is because the terminal operation does not know on how to operate the equipment, the infrastructure or facilities and the utilization of labours in dry bulk terminal which results in losing their competitive advantages. This resulted in customer dissatisfaction and the service level does not align with the logistics performances and LPI requirement.

This research seeks to address the potential conceptual measurement of dry bulk terminal performance based on port technical efficiency. Various studies have shown that the performance of any industries relies closely with the efficiency in utilizing the resources. Meanwhile, a comparable tool is necessary in order to achieve higher port performance.

2. Dry bulk terminal
Due to the importance with regards to the overall supply chain, the operational issues from seaport have attracted many scholars from logistics and transportation sector. As noted, the increase in seaborne trade has led the researchers to explore and investigate whether they are managed efficiently. The absence studies of dry bulk terminal are addressed by Balci et al. [6]. There are relatively few studies on dry bulk terminals and some studies on management performance [7], terminal capacity [8], stockyard size [9], berth scheduling [10] and port workers training [11]. However, no study has specifically focused on the efficiency and performance of dry bulk terminal. Therefore, this research warrant to prove the need of dry bulk terminal studies globally and in Malaysia specifically.
3. Data envelopment analysis (DEA)

Data envelopment analysis (DEA) is a multi-factor productivity analysis model used in measuring the relative efficiencies of a homogeneous set of decision making units (DMUs). It is a linear programming method developed by Charnes, Cooper and Rhodes [12] that computes the efficiency level within the numbers of organization or within the same organization. Unlike econometric models, non-parametric frontiers are the flexible techniques which allows for several alternative formulations. The non-parametric is used when the production process cannot be identified which does not require specific functional form.

3.1. Definition of technical efficiency and DEA

The initial technical efficiency measurement originally introduced in 1951 was by Koopmans [13]. He emphasized that the concept is technically efficient if and only if it is impossible to improve any input or output without worsening some other input or output. The concept was further refined by Debreu [14] and Shephard [15] which measures technical inefficiency as the radial distance of a producer from a frontier. Then, Farrell [16] extended their work by establishing the notion of relative efficiency in which the efficiency of a particular decision making unit (DMU) may be compared with another DMU. Technical efficiency is defined to the ability of a DMU to produce the maximum feasible output from a given number of inputs to produce a given level of output which previously referred to output-oriented technical efficiency. In order for DMU to be efficient, Farrell also proposed that the measurement should come from production function. Figure 1 illustrated the technical efficiency and dry bulk terminal performance measurement.

![Figure 1. Technical efficiency and dry bulk terminal performance measure.](image)

3.2. Previous studies in DEA

The DEA has been extensively used in evaluating efficiency for various industries and institutions. As shown in Table 1, the studies have covered various industries such as airports, ferry services, agriculture, hotels, hospitals, schools and banking sectors. From the studies denoted a positive result for each industry in improving their work performance.

At the same time, the DEA analysis also reveals the advantage of this approach to accommodate multiple input and output with regards to a specific source of efficiency. By doing so it identifies the amount of inefficiency factors that is required to be reduced or increased from inputs and outputs to become efficient. In fact, the dataset required does not have to be necessarily huge or voluminous as this prompts the DEA to be easily applicable and become a comparable toolkit.
Table 1. Summary of different studies with DEA.

| Industry   | Goal                                                                 | Reference                     |
|------------|----------------------------------------------------------------------|-------------------------------|
| Aviation   | Analysis of airport operational efficiency and performance           | Orkcü, H. Hasan et al. [17]   |
| Ferry      | Measures of cross efficiency and structural efficiency from subsidiary ferry to enhance the performance | Yu et al. [18]                |
| Agriculture| Evaluation and benchmarking of water use efficiency in agricultural production | Geng et al. [19]              |
| Tourism    | Resources measurement of 7 hotels and subsidiary in Taiwan between period 2011-2015 | Ang et al. [20]               |
| Hospital   | Assessing the health care resources spending and system               | Du et al. [21]                |
| School     | Improvement program for public funded school in financial, resources and decision making | López-Torres and Prior [22]   |
| Banking    | Identifying the source of inefficiency in banking system             | Wang et al. [23]              |

3.3. Current use of DEA in seaport

Port performance measurement is executed as a normal exercise in order to know the level of standing compared to competitors. Most of the research study is focused on efficiency of port operations as a measurement application. In 1976, the United Nations Conference on Trade and Development (UNCTAD) has developed port performance based on 18 indicators in which 7 indicators are from financial and 11 indicators as operational [24].

Although the DEA have been widely used in seaport studies, the exploration research should be extended in other contexts such as bulk, liquid as well as dry bulk terminal. Moreover, the development of DEA application for dry bulk terminal is relatively new and at infancy level.

In spite of the previous study of DEA in other sectors, DEA research also has been substantially done in container terminal sector [25, 7]. However, an important point that needs to be noted, there is no direct study conducted between DEA and dry bulk terminal in Malaysia. Furthermore, to the best of knowledge of the researchers, there is no attempt or studies have been initiated to relate all the possible factors of dry bulk terminal (e.g. equipment, infrastructure/facility and labour). As such, the study measuring dry bulk terminal with DEA application needs to be addressed for the achievement of competitive advantage of dry bulk terminal in Malaysia.

4. Conceptual framework of dry bulk terminal performance

4.1. Classical production theory

The efficiency and performance study is derived from the economic theory which is based on the idea of a production function. It represented the technological function for certain time period which indicates that the maximum output can be feasibly obtained from several set of the given factors. This shows a higher relationship between input and output factors towards the level of production. The concept will normally be interpreted as when the limit frontier being shifted, the changes towards production will be followed.

In this study, the proposed Production Function Theory has been applied because the input (e.g. terminal resources) has a significant impact towards output (e.g. cargo throughput). Without measuring the efficiency of resources used, the dry bulk terminal would be unable to measure their performances on particular aspect. Therefore, the reason to adopt this theory is due to the fact that it can estimate non
direct parameter that cannot be measured from accounts data. The concept can be simplified into a mathematical equation as follows:

\[ T = f [E, I/F, L] \]

where,
T is an output for throughput produced
f is a functional relationship
E is equipment
I/F is an infrastructure/facility
L is a labour

4.2. Common port terminal efficiency indicator

Apart from that, the fundamental operational management of 5Ms elements (e.g. man, material, machine, methods and money) is a useful concept for this study whereas three of them (machine, money and manpower) has a direct significant relationship towards the dry bulk terminal efficiency and performance. These three inputs are proposed as in Figure 2 to portray that they are the major indicator and will significantly implicate the dry bulk terminal operations.

Furthermore, with the advent of digitalization and internet of things (IoT), industries exposed to the pressure of international competition, and there is a valid reason for services supplied to their particular industry to be competitive. In fact, there are many context of port performance studies with regards to the seaport operations and ports measurement indicators described in Table 2. However, perceived to these studies, none of them studied the ports measurement indicators in relation to dry bulk terminal.

Table 2. Summary of different ports measurement indicators.

| Author          | Data          | Significant indicators                                                                 | Method       |
|-----------------|---------------|----------------------------------------------------------------------------------------|--------------|
| UNCTAD          | N/A           | Financial (e.g. tonnage worked, berth occupancy revenue per ton, cargo handling revenue per ton, labour expenditure, capital equipment expenditure per ton), Operational (e.g. arrival time, waiting time, service time, turnaround time, tonnage per ship, fraction of time berth per ship per shift, tons per ship-hour in port, tons per ship-hour at berth) | N/A          |
| Tongzon [26]    | Annual report | Cargo throughput, ship working rate, land, labour, capital, number of berths, cranes, tugs, stevedoring, terminal area | DEA          |
| Bichou [27]     | Report 2004-2010 | Terminal area, maximum draft, length of quay crane, crane move per hour, yard stacking index, no. of trucks & vehicles, gate cut-off time | DEA          |
| De Oliveira et al. [28] | Report 2008-2011 | Total length (m) of the berths, no. of cranes, port storage area (m2) | DEA & Order-α frontier SPF |
| Perez et al. [29] | Report 2000-2010 | Quay crane, storage capacity, no. of cranes | SPF          |
Based on Table 2, majority of the seaport studies are relying on the operational and technical factor in measuring the port performance. This is due to the visibility factors that are available physically rather than obtaining a total economic efficiency. Since this study has adopting the Production Function Theory and employed three elements from 5Ms in operation management, Here, in Figure 2 below is the proposed framework associated with dry bulk port terminal where the technical efficiency are categorized into three variables according to existing literature known as equipment, infrastructure/facility and labour.

| Study                          | Year       | Data collected                              | Method(s)  |
|-------------------------------|------------|---------------------------------------------|------------|
| Serebrisky et al. [30]        | 1999-2009  | Cranes, berth length, terminal area         | SFA        |
| Suárez-Alemán, Sarriera, Serebrisky, & Trujillo [31] | 2000-2010  | Total terminal area, total length of berths, no. of mobile cranes and capacity, no. of ship-to-shore cranes | DEA & SFA  |
| Sun et al. [32]               | 2013       | Number of staff, operational costs, fixed assets | DEA        |
| Wiegmans and Witte [33]       | Terminal company websites | Design efficiency (e.g. terminal infrastructure), operational characteristics (e.g. labour, land, equipment) | SFA & DEA |
| López-Bermúdez et al. [34]    | 2008-2017  | Frequency of calls, no. of cranes, draft (e.g. vessel sizes, location, port cluster, port infrastructure) | SFA        |

Figure 2. Proposed framework of port performance measurement.

The port terminal operation is a main aspect to be evaluated because it constitutes the largest component of total vessel turnaround time of loading and unloading activity. Generally, there are three approaches in measuring the performance according to economist including indexing, production function and input-output approach. In supporting, most of the researcher’s, for example [35, 36] suggested ports performance measurement should employ DEA which is on an input-output basis.

Generally, in port operations, four categories of cargoes that are managed include bulk, dry bulk, liquids and containerized shipments. However, in order to define the determinant of efficiency for dry bulk terminal, the micro performance indicators are usually related to time variables been accessed, for example, cargo handling speed and moves of crane per hour. This may draw an important operational efficiency measures about a detailed picture of port performance. In order to measure the performance of port terminal, several categories may be useful to assess in terms of physical, productivity, financial, resource utilization as well as service level. This is to enable a particular efficiency or parameter to be measured as time, number of equipment available and productivity of work that need to be considered.
5. Conclusion
The main insight of this research is to highlight the major technical efficiency of dry bulk terminal operations in Malaysia. This will eventually benefit various decision making strategies at various management level specifically in dry bulk terminal. At managerial level, port efficiency may indicate the current port procedure and labour proficiency which helps to identify the suitability for improvement or providing training. As for strategic level, this study may be useful for port infrastructure development in optimizing their operations whether resources are fully utilized or underutilized. Last but not least at operational level, it may assist the daily operations to monitor and control the output schedule and cost.

A conceptual framework of efficiency for dry bulk terminal has been proposed based on the existing literature research. The input being part of the resources i.e. equipment, infrastructure/facility, labour and output of cargo throughput is identified. The DEA model is developed to evaluate the efficiency score based on the assumption of CCR approach to address the problem of inefficiency of dry bulk terminal. The proposed conceptual framework can be used to implement as a new performance measurement for dry bulk terminal. However, further studies are required to prove the visibility and accuracy of this method. Future studies will be conducted for the implementation of the proposed framework.

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