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Review Article

A SURVEY OF DATA ENVELOPMENT ANALYSIS IN CONTAINER TERMINALS

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ABSTRACT
In recent years, Data Envelopment Analysis (DEA) technique has been used quite frequently in determining container terminal efficiency. When the studies reviewed, conducted on the subject in the recent past, it is seen that the details such as the parameter on which the activity model focuses, sample selection, sample size and input-output selection have not yet been clarified enough, additionally, problems and confusion are encountered in practice. In this study, a critical analysis was carried out regarding the determinations in the use of the DEA technique, which is frequently used in the measurement of container terminal efficiency, and on which issues should be considered in order to establish the model better. In the consequences of the study, it was seen that data accessibility was an obstacle to reaching more robust results in efficiency analysis. It is very important to make evaluations between ports that are close to each other in terms of regional or infrastructure, demand and technological development in order to obtain more reliable and consistent results. Moreover, future studies should consider reliable inputs such as the number of equipment in the terminal that divided by two group, the terminal area, maximum depth, pier length.

Keywords: *Container Terminal, Productivity, Efficiency, DEA, Data Envelopment Analysis*

1. INTRODUCTION

Facilities where transportation modes can be changed between sea and land and / or rail, transfer between ship and ship or between ship and inland watercraft are called container terminal. Container terminals may be parts of their ports that are specially designed for container handling, or they can also be terminals established only for container handling. The goals of container terminal operations include maximization of the total handling amount on a yearly basis, obtaining more output with less handling equipment, labor or capital, more ship frequency and lower anchoring or drift periods and operational flexibility.

Since port management is about a country's gateways to other countries, it is an area that needs to be addressed, as well as complex and global. If ports want to be successful in global competitive conditions, they should perform performance analyzes in all aspects in order to pre-evaluate their opportunities and handicaps. (Mahmoudi *et al*., 2020). Therefore, especially container terminal efficiency and performance evaluation on terminal basis has attracted great attention. The number of articles published on this subject has also been increasing rapidly in recent years.

When the studies on efficiency analysis are examined, it is stated that the container terminal operators not only provide a strong management tool, but also are crucial for the development of terminal planning and operations (Notteboom and Verhoeven, 2010). Therefore, container port efficiency analysis is very important for competitiveness in the industry (Cullinane and Wang, 2006). So, the need for a more stable, consistent and good modeling of the technical activity, which is tried to be determined by different methods by establishing different models, shows the importance of the research.

2. AIM AND SCOPE OF THE RESEARCH

The Data Envelopment Analysis (DEA) is frequently used in the efficiency analysis of seaports and especially container terminals as in many areas. In this study, it is aimed to examine the sample, technique and input-output parameters used in the researches in the literature and to synthesize the theory and practice. The research question is whether the researchers choose the determinants of efficiency for container terminals properly or not. The results of the study are expected to shed light on future studies of efficiency analysis. This study demonstrates the value of such research for both academic knowledge and practitioners, as it will help to clear some confusion about the determinants of performance measurement.

When the studies of the researchers who use DEA in the efficiency measurement of the ports are reviewed, it is inferred that they have many limitations and hesitations especially about the input selection and output quantity. It is thought that this situation is mainly caused by the unique and complex structure of the terminal. As a matter of fact, DEA attracts attention as the most common method in container terminal efficiency measurement.

3. METHODOLOGY

In the study, Science Direct, Google Scholar, Scopus, Web of Knowledge databases were used in the search made by considering the articles published in international journals and published in English. Firstly, the primary articles list was created with the PRISMA flow chart (The Preferred Reporting Items for Systematic Reviews and Meta-Analyses) used in systematic screening and meta-analysis, and then the articles directly related to the subject were defined and filtered with the detailed evaluation.

In the study, a preliminary evaluation was made of 111 articles published in international refereed journals on the technical efficiency analysis of container terminals between 2009 and 2020, where DEA method was applied.

Subsequently, 26 articles were selected for detailed analysis. Inputs and outputs used to evaluate the efficiency of container terminals used in DEA are presented in Fig. 1.

Common features of the investigated studies are that it is related to container terminal efficiency and the use of DEA method. In the following sections of the study, it will be dwelled on which assumptions are accepted for container terminal efficiency analyzes including DEA method, which parameters are taken into the model as input, which parameters are used as output, and critical analysis will be made by making recommendations. Based on the study, limitations and contradictions will be addressed, taking into account the technological infrastructure of today's terminals and competition conditions.

4. PERFORMANCE MEASUREMENT

Although performance is a relative concept, it is defined as the degree of success in achieving specified goals (Devine and Ostrom, 1985). Performance can also be explained by the production function. Production processes transform specific inputs into specific outputs. The production function also explains the relationship between changes in the amount of input and the amount of output in this process. Nicholson (1995), by making the basic definition of the production function for a product, tried to determine the maximum amount of product that can be produced with alternative input combinations (frontier models) such as labor, capital, warehouse space.

As with other businesses, evaluating port performance or measuring terminal efficiency is very important from an economic, functional and strategic perspective. The methods used for performance measurement vary according to the assumptions about the data, production technology, economic behavior of decision-making units, and the type of measures applied.

Although productivity and efficiency, which are concepts related to performance, are often used interchangeably in the literature, they are defined differently by many researchers. Productivity is defined as producing the output with the least cost or obtaining the optimum output with the resources available, while efficiency is defined as reaching the maximum output by utilizing the resources in the best possible way (Yükcü and Atağan, 2009). Productivity and efficiency are also different in terms of process. While the efficiency period is short, the productivity process is usually longer. For example, while the process of becoming more effective as a result of a manufacturer company using all inputs at the optimal level is short, the process of increased productivity by minimizing the residues of resources is generally longer (Çağlar and Oral, 2011).

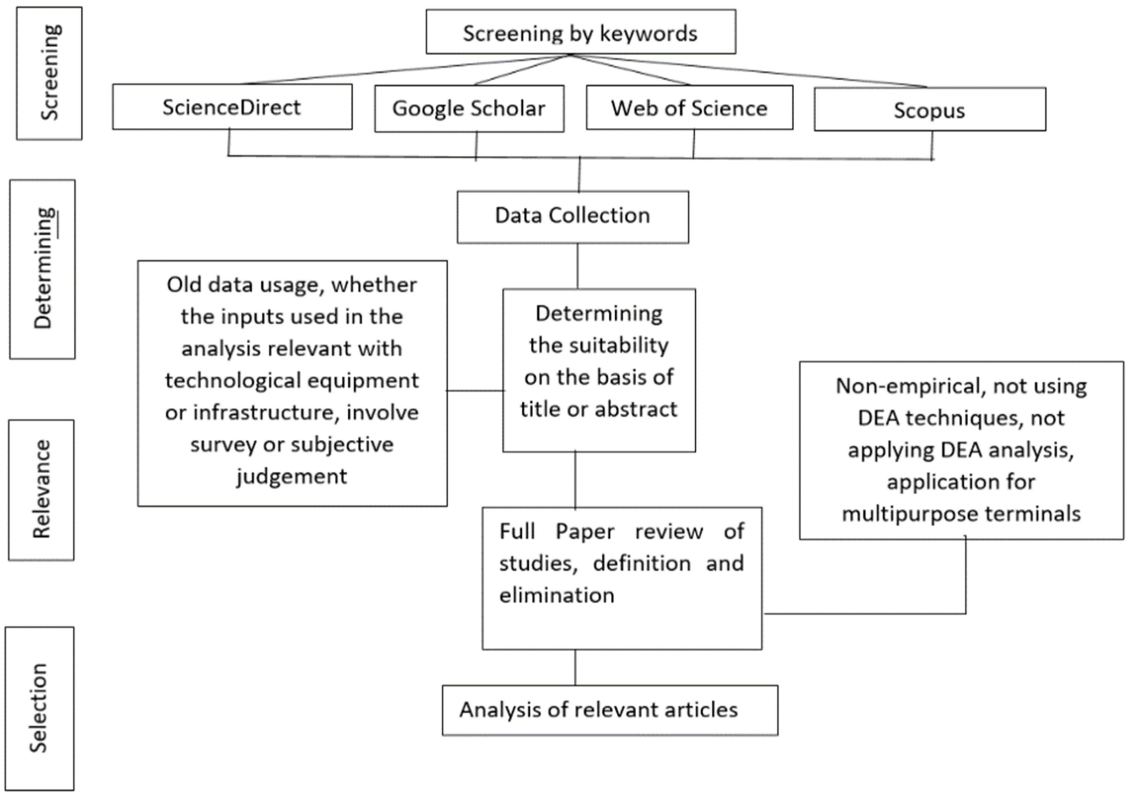

Fig. 1. Flowchart (PRISMA diagram) applied for article screening

The most common approach used to analyze the development of both efficiency and productivity over time is the Malmquist Productivity Index (MPI) (Malmquist, 1953; Caves *et al*., 1982; Fare *et al*., 1994; Cuccia, 2017). Malmquist (1953) and then Fare *et al*. (1994) first described MPI as a DEA-based method that measures the change in productivity over time. Measures of efficiency need to take into account multiple outputs and inputs together. One of the major disadvantage of DEA is that observation points can only measure their relative efficiency. To circumvent this disadvantage, researchers use DEA-Malmquist to evaluate changes in productivity over time in addition to predicting efficiency. (Wilmsmeier *et al*., 2013). The Malmquist index has some advantages that it does not require any input or output prices or any behavioral assumptions. This feature makes the Malmquist index very suitable for analyzing productivity changes in both public and other sectors. This index measures the “total factor productivity” changes between the DMU’s (Decision Making Units) by calculating the ratio of the distances of each DMU to a frontier or maximum output level.

The concept of efficiency, which is the subject of our study, is aimed at the goals and determines the realization levels of the goals by establishing a relationship with the results obtained by the firm (Erturan and Uysal, 2013; Rouyendegh, 2011). Efficiency is generally classified as technical efficiency, allocation efficiency and scale efficiency. Technical efficiency indicates whether the input is producing output as much as its capacity to produce. Thus, it reveals that outputs can be developed in proportion to the production limit. For example; while a container terminal is capable of handling 1000 units of 20-foot-length equal units (Twenty Foot Equivalent Unit (TEU) per unit time, but can handle 900 TEU, it is considered 10 percent ineffective or 90 percent efficient. Allocation efficiency refers to how low-cost a combination of input costs consists of producing the same amount of output. In terms of production, the unit of production that achieves higher output with equal or less input is more efficient. The unit of production that achieves equal or greater output with lower input values in terms of cost is more efficient. Scale efficiency determines an efficiency score based on this value by targeting the highest output values that can be obtained with available inputs. Calculating both scale efficiency and technical efficiency together enables the calculation of overall efficiency.

While emphasizing the efficiency, it should be known that the model presents from outputs and results. Getting the results is much more difficult to measure the results (Gülcü *et al*., 2004).

The techniques used in efficiency measurement can be classified as parametric and non-parametric methods, radial and non-radial methods, as well as deterministic and stochastic methods. Stochastic methods allow a random measurement error, unlike deterministic methods. While radial efficiency measurements predicted by using equally proportional reduction of outputs and inputs above the best practice limit (or frontier), non-radial efficiency measures were also developed (Panayides *et al*., 2009; Fare and Lovell, 1978). DEA, one of the nonparametric methods, is the leading technique used in container terminal activity.

4.1. Frontier Models

Farrell, (1957) first introduced frontier models in the analysis of economic efficiency. Farrell has created a widely accepted framework on this subject with his frontier models. There are some fundamental differences between the methods used to obtain the specification of the frontier model. The first difference; some are statistical and some are non-statistical methods. The first of the important differences is the statistical method assuming the data's stochastic property while non-statistical methods do not make any assumptions regarding this issue. Second important difference; is whether the frontier model is parametric. The non-parametric approach consists of a mathematical programming technique called DEA and different versions of this technique while the parametric approaches use econometric methods in which efficiency is measured according to the statistically estimated limit production function by putting a certain form (Cullinane and Gray, 2002). While the econometric approach comes to the forefront in the analysis of the efficiency of competing industrial organizations and public institutions, mathematical programming approaches are used more in managerial decisions (Aigner and Schmidt, 1977; Fare *et al*., 1994).

4.2. Data Envelopment Analysis

DEA is a nonparametric technique used in operations research and econometrics that can include more than one input and output variable and sequences observation points. (Ye *et al*, 2020). Charnes *et al.* first used DEA technique; they introduced it in 1978. Efficiency differences between businesses serving in the same sector can be calculated using this technique. With DEA, it becomes possible for decision-makers to control the production process at various levels, including daily operations, medium and long-term strategies, and make more effective decisions (Charnes *et al*., 1978). DEA uses the engineering approach, which is the ratio of the weighted sum of outputs to the weighted sum of inputs in efficiency evaluation. While calculating this ratio, it is not always possible to determine the input and output weights. Using the data set with DEA, different weights are determined for all decision units with linear programming. Thus, decision units are evaluated with weighting that will maximize their efficiency relative to other decision units.

The efficiency value obtained by DEA based on the fixed return to scale assumption represents the overall technical efficiency, which is the sum of pure technical efficiency and scale efficiency (Constant Returns to Scale-CRS). Banker, Charnes and Cooper introduced variable Returns to Scale-VRS (Variable Returns to Scale-VRS) technique, which is based on this handicap and thus enables the calculation of both efficiency values, in 1984. While fixed return to scale is taken as basis in CRS model, variable return to scale is used in VRS model. The VRS model assumes that scale differences may affect the overall efficiency of the decision-making unit and excludes the scale effect from the evaluation (Güner, 2015). DEA- Super Efficiency technique is; it was introduced by Charnes *et al.* to apply a rating method between units. This technique; It consists of a linear programming application that compares the same type of service units such as terminal, airport, school, drug store and puts them in hierarchical order. Solution indicators of the created model; some units are effective, less efficient or ineffective than some other units. For example; Cullinane and Wang (2006) were able to compare the technical efficiency of container terminals with DEA-Super efficiency and SFA (Stochastic Frontier Analysis methods, and they were able to rank the terminals with an equal and "1" efficiency score among themselves.

In addition, DEA is included in the literature as hybrid techniques for performance measurements, along with other multi-criteria decision making methods such as AHP or Fuzzy Ahp technique (Rouyendegh et al, 2019).

5. LITERATURE

Studies in which the most frequently used DEA among the efficiency measurements of container terminals in the literature is preferred are summarized in Table 1, chronologically, together with the data type, method used, input and output parameters. When the literature was reviewed, three reviews were found on the efficiency analysis of container terminals (Odeck and Bråthen, 2012; Panayides *et al*., 2009; Trujillo, 2009). Since the compilation studies were between 2009 and 2012, the empirical studies conducted between 2009 and 2020 were focused. The study of Odeck and Brathen (2013), which is detailed below, was in the form of meta-analysis. In this study, critical analysis will be made.

Panayides *et al*., (2009), examined the studies using DEA method in the efficiency analysis of ports after 1993 (The first terminal efficiency analysis was done by Roll and Hayuth (1993)). The study, which covers the articles published before 2009, focused on the suitability of inputs and outputs to technical efficiency analysis, sample selection, model and variable definition, alternative model suggestions, political effects and research gaps. In addition, the details of the studies were included and the findings of the effectiveness analyzes were examined in detail.

Trujillo, (2009) comprehensively evaluated parametric and non-parametric approaches to productivity analysis as applied to the port sector in their study. In addition, they examined the relationship between the event and whether the terminal is a private or public enterprise, port capacity, improvements and reform. As a general conclusion drawn from the 28 studies compiled, they stated that the efficiency analysis had positive effects on port performance. In addition, in terms of the method used, although it is known that the terminal creates multiple outputs, it is seen as a deficiency that many potential outputs are not included in the model, while the dynamic analyzes using panel data reach more consistent results than cross-sectional data, and they point out the importance of data accessibility. In operational and strategic terms, it was pointed out that technological equipment has a positive effect on efficiency and that the operation of port enterprises by the private sector increases the efficiency score.

Table 1: Details of articles using the DEA method

	Author/s	Year	Method	Type of data	Period	DMU	Port /Terminal	Input	Output
1	Jiang and Li	2009	Radial and Non-Radial DEA	Cross-sectional	2007	12	Port Level	Sum of Export/import, regional national income, pier length, cranes	Handled TEU
2	Cullinane and Wang	2010	DEA, Window Analysis.	Panel	1992-1999	25	Port Level	Shore cranes, yard cranes, straddles	Handled TEU, Terminal area, Pier Length
3	Wu and Goh	2010	DEA	Cross-sectional	2007	21	Port Level	Terminal area Pier Length Total equipment	Handled TEU
4	Hung *et al.*	2010	DEA	Cross-sectional	2006	31	Port Level	Pier length Terminal area Shore crane Pier quantity	Handled TEU
5	Cheon *et al.*	2010	DEA, Malmquist	Panel	1991-2004-2005	98	Port and Terminal Level	Pier length Terminal area Shore crane	Handled TEU
6	Bottasso *et al.*	2011	DEA	Panel	2001-2008	5	Terminal Level	Non-Labor expenditure Terminal area Shore crane Labor	Handled TEU
7	Wanke	2013	DEA, Regression analysis	Cross-sectional	2011	27	Port Level	Piers, Storage area, Terminal area	Handled TEU
8	Wilmsmeier *et al.*	2013	DEA	Panel	2005-2011	20	Terminal Level	Labor, Terminal area and Ship to Shore crane	Handled TEU
9	Schoyen and Odeck	2013	DEA	Panel	2002-2008	24	Terminal Level	Pier length Terminal area Yard crane Straddle carrier	Handled TEU Trucks
10	Polyzos and Niavis	2013	DEA-Super Efficiency, Tobit Regression	Cross-sectional	2008	30	Port Level	Pier length, Shore crane	Handled TEU
11	Yuen, *et al.*	2013	DEA-Malmquist	Panel	2003-2007	21	Terminal Level	Piers, Pier length, Terminal Area, Shore Crane, Yard Crane	Handled TEU
12	Munisamy and Jun	2013	DEA	Panel	2000-2008	30	Terminal Level	Pier length, Terminal area, Handling equipment, yard equipment, Truck	Handled TEU
13	Song and Cui	2014	DEA-Malmquist	Panel	2006-2011	26	Terminal Level	Labor, Shore crane, Pier length	Handled TEU
14	Tae-Won	2015	DEA, Total Factor Productivity	Panel	2003-2007	50	Port Level	Terminal area, pier, pier length, equipment, reefer capacity, cranes, CFS equipment	Handled TEU
15	Carine	2015	DEA-BCC, DEA-CCR and Super Efficiency	Cross-sectional	2012	16	Terminal Level	Handling equipment, Terminal area, Pier length	Handled TEU
16	Güner	2015	DEA	Cross-sectional	2010	13	Port Level	Terminal area, Pier length, Piers, Cranes, Tugs, Forklift, Labor	Handled cargo (mt), Ship Call
17	Baran and Górecka	2015	DEA-Malmquist	Cross-sectional	2012	18	Port Level	Piers, Terminal area, Storage capacity, Pier Length	Handled TEU

Table 1: Details of articles using the DEA method – *Continue*

	Author/s	Year	Method	Type of data	Period	DMU	Port /Terminal	Input	Output
18	Almawsheki and Shah	2015	DEA	Cross-sectional	2012	19	Terminal Level	Terminal area, Pier length, Shore Crane, Yard equipment, Maximum Draught	Handled TEU
19	Jin and Ding	2015	DEA - Malmquist	Panel	2008-2012	21	Terminal Level	Pier length, Handling Equipment, Labor	Handled TEU
20	Acerand Timor	2017	DEA	Cross-sectional	2005-2009	20	Terminal Level	Labor, Pier Length, Yard + CFS equipment (RTG, RMG, LCH, CRS, SC, ECS, Forklift)	Handled TEU and Annual ship frequency
21	Wiegmans and Witte	2017	SFA, DEA	Cross-sectional	2016	127	Terminal Level	Working hours h/weekly, Terminal area, Storage capacity, Pier length, Draught, Shore crane, Stacker, Container Handling (TEU)	Handled TEU, Handling Capacity,
22	Kutin *et al.*	2017	DEA	Cross-sectional	2014	50	Port and Terminal Level	Maximum draught at Pier, Terminal area, Pier Length, Piers, RTG, YC(RMG+SC+RTG), Forklifts, Trucks	Handled TEU
23	Kammoun	2018	DEA, SFA	Panel	2007-2017	77	Port Level	Handling Equipment, Storage area, Labor	Handled TEU
24	Hlali	2018	DEA, SFA	Cross-sectional	2015	26	Port Level	Pier Length, Depth, Terminal area, Storage Capacity	Handled TEU
25	Kalgora*et al.*	2019	SFA, DEA-Window Analysis	Panel, Cross-sectional	2000-2005	22	Port Level	Pier length, Terminal area, Shore crane, stacker, Draft, Handling Capacity	Handled TEU
26	Birafane and Abdi	2019	DEA	Panel	2014-2017	8	Port Level	Pier Length, Terminal area, Equipment	Handled TEU

The studies of Odeck and Bråthen (2012), on the other hand, consist of meta-analysis of average technical efficiency changes obtained by examining 40 studies in peer-reviewed journals. In the conclusions of this meta-analysis, they tried to determine the parameters on which the differences of mean scores depend. These parameters; analysis method, port location, data type, number of observations and variables. In addition, in this study, they obtained very interesting results, especially with the random effects regression model. In recent studies, lower average efficiency scores compared to previous studies, higher average efficiency scores compared to SFA method in studies using non-parametric DEA method, panel data having cross-sectional data. The conclusions have been reached European ports have lower efficiency scores compared to other world ports. Apart from these review articles, some of the studies that include applications; Polyzos and Niavis (2013) followed a 2-stage DEA efficiency analysis, than; they examined the regional ports close to each other in terms of proximity to the main routes with Tobit regression analysis. Wilmsmeier *et al.* (2013) applied the DEA to analyze the level of technical efficiency in 20 container terminals in Latin America and Spain between 2005 and 2011. In addition, using the Malmquist Total Factor Productivity Index, they tried to evaluate the impact of the financial crisis on the efficiency and productivity of the difficulties experienced in responding effectively to the unexpected increase and sudden changes in demand.

Jin and Ding (2015) analyzed the efficiency scores of 21 small and medium-sized container terminals in China using DEA method. Then, they used the Malmquist Productivity index value, which they obtained by using the technical efficiency change index and technical efficiency score of each port, as the dependent variable in Tobit regression analysis. Although the dependent variable is continuous, in the case of constraint, the “ordinary least squares” (OLS) method calculates consistent estimates. On the other hand, Tobit regression models generally assumes “discrete normal distribution” instead of normal distribution and prefers to using “Maximum Likelihood estimation” (MLE) method. Since Malmquist Productivity Index scores have lower and upper limits, the least squares (OLS) regression model can be discrete. Therefore, using the Tobit regression model rather than the least squares model, they determined the

Malmquist Productivity Index by factors such as the number of workers, terminal setup capital, line affiliates as well as terminal operator and ship route number(Tobin, 1958). As a result of the empirical application of the model, it has been concluded that there is a positive relationship between route, number of workers, capital, line participation status, while there is a negative relationship between the number of terminal operators and efficiency. Having more than one cargo handling contractor in the same terminal may cause conflict of interest and lead to a decrease in efficiency. For this reason, as much as possible, one organization chart should prevail within the terminal.

Almawsheki and Shah (2015) analyzed the technical efficiency of 19 Middle East container terminals in geographically critical regions. In addition to preferring DEA as a method, they also has benefited from slack variable analysis to assess the inefficiency values and how terminals can improve themselves and better use of inputs. Among the inputs used in the study, the draft, that is, the highest water depth level of the dock draws attention. As it is known, in the traditional production function, worker, capital and facility constitute inputs. Therefore, if the dock length and terminal area are considered as capital, it is thought that it would be quite appropriate to include dredging and deepening studies as inputs in the model in case of increasing competitiveness.

Song and Cui (2014), in their study where the Chinese government examined the results of the improvements related to container terminals in recent years, using the DEA-Malmquist Productivity Index with the data of 2006-2011. The increase in productivity is due to technological developments rather than the increase in technical efficiency and the development of technical efficiency is the main they concluded that the source was the increase in scale efficiency. Apart from that, the relationship of productivity changes with geographical location, using the number of cranes, the number of workers and the length of the dock as inputs and ownership has been examined. It was concluded that there was no positive, significant and strong relationship between the terminal ownership and the efficiency in the study using the total amount of cargo handled per TEU as output.

Acer and Timor (2017), the working port in Turkey using DEA and Clustering Analysis of operational efficiency analysis, they sort out the most efficient ports. The number of workers, the length of the dock and the number of equipment were chosen as input variables, and the annual amount of cargo handled (throughput) and the number of ship calls on TEU basis as output. The terminal area, maximum depth, theoretical handling capacity, the number of in-port transfer vehicles and the number of dock cranes were removed from the DEA model by applying the canonical correlation statistics test.

Kammoun (2018) used Stochastic Frontier Analysis including Cobb-Douglas production function and traditional DEA (CCR and BCC) techniques in a comparative study in which seven container terminals located on the coast of Tunisia were evaluated. The conclusion reached in the study generally consists of determining the most efficient port that has achieved the best score with all three techniques.

Hlali (2018) conducted a comparative efficiency analysis using the cross-sectional data of 2015 of 26 large container terminals around the world and using SFA and DEA techniques. While the inputs used were draught, berth length, storage capacity, the annual total amount of cargo handled on TEU basis was preferred as output. Study results are in the form of a comparative presentation of efficiency scores.

6. DISCUSSION

6.1. Sample Selection

The size, geographical location and hinterland accessibility of the selected terminals should be close to each other. Otherwise, the efficiency analysis will not give healthy results. This is because each container terminal has its own unique character. When the literature on the dimensions of the amount of cargo handled and competitiveness was examined, terminal efficiency was seen as one of the five dimensions explained (Tongzon and Heng, 2005). Other dimensions; ship call frequency, economic activity, location, terminal fees. In this case, it can be inferred that the increase in terminal efficiency has a positive effect on the amount of cargo handled. Assuming that terminal efficiency is inversely proportional to competitiveness, we can conclude that competitiveness negatively affects the amount of container handling. The number of samples used in the studies are shown in Fig. 2 as below.

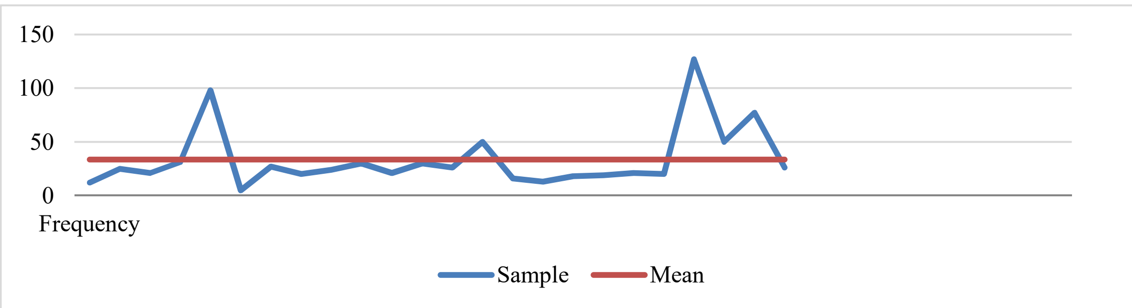

Fig. 2. Sample numbers of studies in the literature

6.2. Input Variables

When we consider the general structure of the container terminals, it is seen that it can be matched with a production facility consisting of inputs such as capital, labor, and facility. Under the title of facilities; apron, dock and / or pier, container yard, container freight station, gates, under the technology title; under the heading of human resources, automation, information technologies, equipment; Dock crane, mobile crane, field crane (rubber wheel, rail), field carriers (stacker, empty container handler) and trailer can be collected. Apart from these, time and sales / marketing can also be considered as other inputs.

All the inputs mentioned above, regardless of whether they are included in the model or not, are realized through a financial investment. In this case, it is thought that the right thing is to include all inputs in the model somehow. In general, as seen in Fig. 3, the number of equipment, the length of the dock, and the terminal area constitute the majority of the inputs preferred in the efficiency model.

Ship cranes are still used in undeveloped country ports. Therefore, it should be close to each other in terms of development level in efficiency analysis. For example, it would be more accurate to evaluate two terminals with similar numbers of dock cranes. Otherwise, it should be ensured that the terminal, which has much less cranes, does not receive support from ship cranes and ship personnel. Sarriera and Briceño-garmendía (2013), in their study where they conducted technical efficiency analysis of Latin American and Caribbean ports, took into account that ship cranes were used based on the annual maximum capacities of shore gantry cranes and mobile cranes.

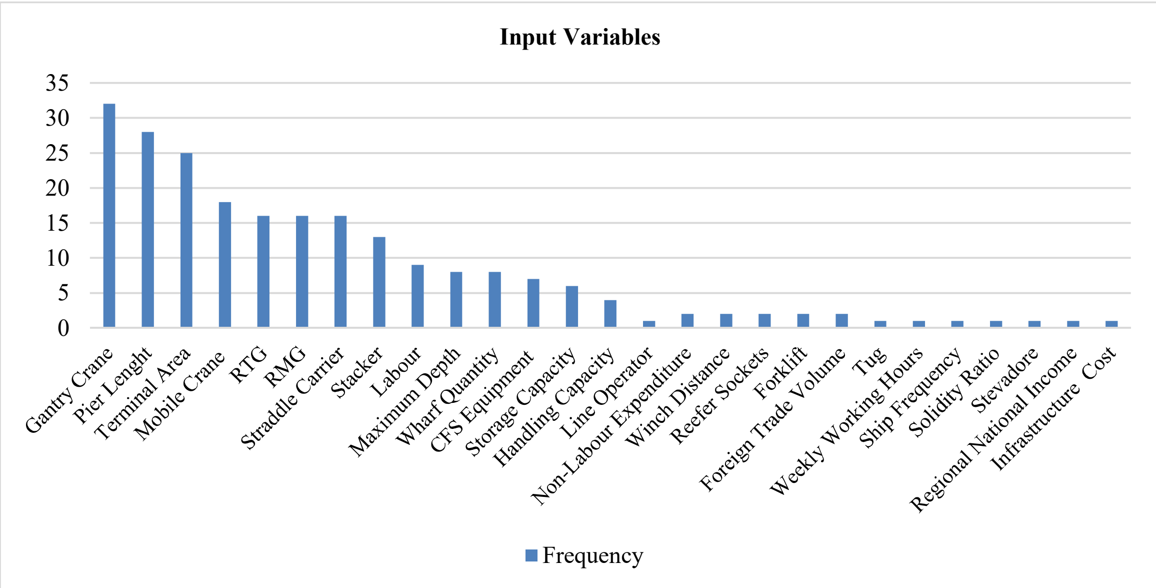

Fig. 3. Input variables used in studies

Shore gantry crane is one of most important elements of the theoretical handling capacity at the container terminal. Therefore, it draws attention as the most common input used in efficiency analysis in the literature. In the terminal design, the number of moves of the gantry crane in the expected 1-hour period is calculated. The optimum number of cranes is determined together with other parameters such as vessel's hatchcover moves, gang change and annual expected handling amount. As mentioned above, the number of moves per hour varies according to the crane size, as the increase in the dimensions of the shore gantry crane will increase the average distance of the "spreader".

It is observed in the studies that gantry cranes and mobile cranes are separated from each other and create two different inputs. When these two equipment safety factors are taken into consideration, they have the same handling capability in the hourly period. Therefore, it may be more correct to create an input in the form of "total number of cranes handling ships".

Especially the yard equipment systems used in container terminals also present some differences. For example; Such as "straddle carrier system", "rubber tyred or rail mounted system" or "forklift" system. These systems are used interchangeably, not together. Therefore, considering the number of equipment, it can be said that it is not correct to use interchangeable equipment, which have some advantages and disadvantages compared to each other, as inputs by considering them as identical to each other. Therefore, the efficiency model should be created using the equipment costs input will give healthier results such as Malmquist DEA technique. In this context, while creating the inputs, taking three different input values into the model in three categories such as ship handling equipment, terminal-handling equipment, and trailer in the terminals using the same field handling system can give better results.

In an activity model where handling equipment creates input, it may be more appropriate to include the handling capacity as output instead of input. As in Hu *et al.* (2010); Kutin *et al.* (2017), it can be grouped according to the size of the dock crane to see whether there is a statistically significant difference between the efficiency scores of the group.

6.3. Output Variables

In the efficiency analysis in the literature, the output variable is generally considered as annual container handling amount on TEU basis. However, the annual total handled TEU value, in other words, when the output amount is considered as the number of each container, it will decrease approximately between 0,4 to 0,6 times depending on the port-to-port and cargo potential. It should be evaluated whether the acceptance of this assumption, which is considered as a constraint in the literature.

Cullinane and Song (2006) regarding the need for data sources to be complete, accurate and reliable, has a significant effect on efficiency scores. Since the total handling amount is actually the sum of the containers loaded, discharged and relocated, if the annual cargo handled will constitute the output value, the best choice should be taken as total handling, i.e. loading, unloading and shifting, on the basis of pieces, instead of TEU, depending on data availability. Output variables used in studies are shown in Fig. 4 as below.

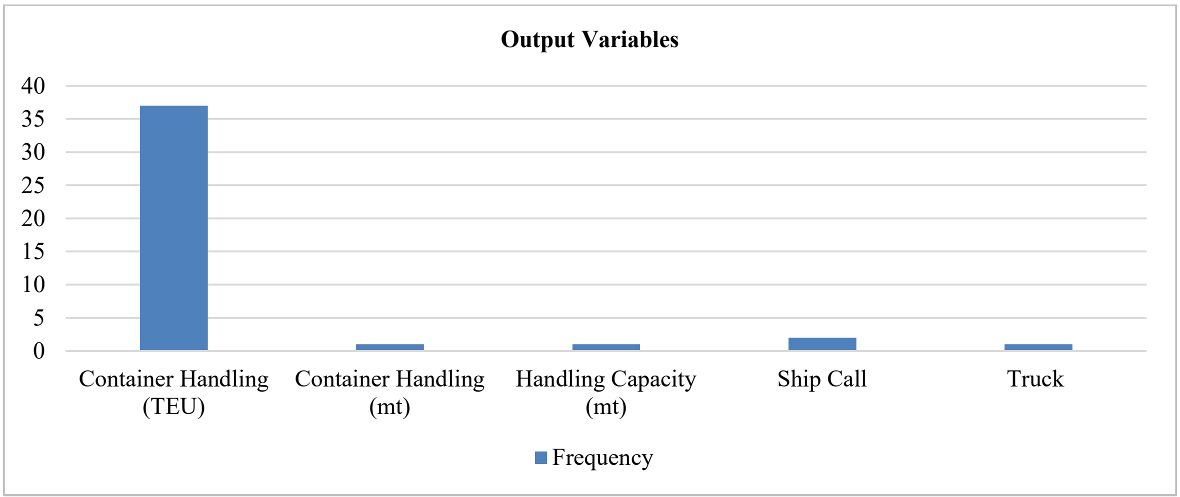

Fig. 4. Output variables used in studies

7. CONCLUSION

Although DEA is frequently used in container terminal efficiency measurement (Odeck and Brathen, 2012; Almawhseki and Shah, 2013), it has never been adopted as the sole efficiency measurement method. When the studies using the DEA technique, which is the subject of our study, are reviewed, it is seen that the same authors in different studies frequently change the inputs and outputs that form the activity model. The confusion experienced ends with the work done and the determination of efficiency scores and the reasons for ineffectiveness cannot be examined well enough. It is thought that this situation will adversely affect the course of the future studies. Although most of the studies reviewed recognize the multi-output nature of container terminal operations, they do not reflect this bundle of output to their performance evaluations. This is due to data availability. Authors tend to use primary data, preferring to stay in the safe haven. Obtaining data from secondary sources due to accessibility problems is another matter of discussion. Especially in studies, using panel data, the amount of containers (TEU) handled annually is clearly recorded, while it is very difficult to access data of input values by years from primary sources, and it is not encountered in secondary sources. For example; while the maximum berth depth increases by 2 meters with the scanning process, this increase may be valid for only one berth of the terminal. Alternatively, the number of equipment or workers in the container freight station may vary even within the same year. Trucks used for transporting containers may leave their places to mobsters. The post count can be increased or decreased. These or other similar possible situations are inherent to terminal operation. Moreover, it should not be ignored. Therefore, it is thought that using cross-sectional data and evaluating the current situation in container terminal efficiency analysis will give results that are more reliable. In case the data are obtained in a healthy way, of course, as Kumbhakar *et al.* (2000) stated in their studies, the use of panel data provides a better interpretation of efficiency scores that change over the years. Cullinane and Song (2006) investigated the technical efficiency of the ports in their study using the SFA method. In their study using Cross-Sectional data, they determined the difference in efficiency between private sector terminal enterprises and state ports. This situation can be examined more carefully, since the use of cross-sectional data may cause a temporary inefficiency immediately after new investments are made in ports (Cullinane *et al.*, 2004). In another study on this issue (Wang and Cullinane, 2015), it is mentioned that container terminal applications of DEA in the literature are largely limited by standard DEA models using cross-sectional data. Panel data for container port production conducted a medium to long-term efficiency analysis for 25 container terminals, confirming the necessity of using panel data and revealing that significant waste is involved in trying to reach the maximum number of container handling. It is understandable that past studies are carried out with reliable inputs such as the number of equipment in the terminal, the terminal area or the number of workers. However, in order to obtain more reliable and consistent results, it is very important to make evaluations between ports close to each other in terms of regional or infrastructure, demand and technological development. Especially the practical recommendations of this study show the novelty. In future studies, researchers consider mentioned issues while determining the variables in order to design efficiency model.

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