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Analysis of Port Efficiency Assessment Methods, Development of a New Multidimensional Complex Model

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Abstract

The transport sectors are developing dynamically. The volume of conveyances is increasing not only in the interior of certain countries, but also in the international traffic. The global transport system encompasses all types of long-distance transport and international conveyances form the basis for the functioning of the global market. The increase in the turnover of international goods leads to relevant increase in freight traffic. The efficiency of port performance is an important requirement to survive in the fiercely competitive freight sector, where every port struggles to attract and handle as much freights as possible. The aim of this study is to improve the methodology for assessing the efficiency of port performance by identifying the positive aspects and weaknesses in the port performance efficiency assessment model, as well as to develop suggestions for improving the port performance efficiency assessment model. The following tasks are set to achieve the goal: based on selected literature, to explore port performance efficiency assessment models and calculation methods, as well as the latest scientific conclusions on the researched problem; to study the role of ports in the economic growth of the transport sector; to identify key performance indicators of the efficiency of ports that could be used to analyse the efficiency of ports; to develop options for improving the port performance efficiency model.

KEY WORDS: *Ports Efficiency, Stochastic Frontier Analysis, Data Envelopment Analysis*

1. Introduction

Assessment of the efficiency of port performance is particularly important in countries and regions, where the ports are the driving force of the economy, providing taxes to the state budget, inflow of investments, creation of new jobs, development of infrastructure, etc. All ports in the world are unique in their nature and the task of measuring and analysing their performance after a single standard is not a simple one. The difficulty of establishing common standards is created by the fact that there is no common approach to summarising all the key aspects of the efficiency of port performance. Assessment of performance results is a fundamental concept for any business. Does the company assess the achieved results in terms of the set goals, tasks or either by considering the competitors? The development of ports is directly influenced by the globalization processes in the world: the global economic crisis – the real estate and banking crisis, economic sanctions, fluctuations of energy prices worldwide, the development of the Eurasian Silk Road.

2. Materials and Methods

The theoretical and methodological basis of the study. When developing the study, research by S. Esmer, K. Bichou, W. C. Huang, J. Tongzon, P. Langen, M. were used. Also the results of the research carried out independently by the Author were used in the study, as well as information available on the Internet and in the international scientific databases. In order to successfully achieve the goal of the study and to meet the set goals, the Author uses Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) in the study.

3. Results and Discussion

Currently, there is no unified approach to assessing the performance results of ports in the world. In practice the performance of container terminals is analysed the most using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). In some studies and publications on the assessment of port performance efficiency, individual terminals are analysed, but this analysis does not demonstrate the overall efficiency of the port. Such studies are emerging increasingly due to the fact that the terminals in their essence are the basis for port performance and development.

Soner Esmer points out multiple reasons why ports and terminals must assess their efficiency:

1. Ports and terminals must know how efficiently they operate, in terms of the amounts of cargo and passengers processed etc.
2. It is important to know the amounts of resources available (workforce, equipment, land), in order to enable complex port activities.
3. Ports and terminals must compare their current output with past operation results, in order to determine whether their results have improved or deteriorated.
4. All businesses need goals, which is why it is necessary to compare the goals set with the operating results, and ascertain whether the goals set have been achieved within the period specified for them.

5. Comparison of business results with those of competitors.
6. Taking into account the current efficiency assessment, it is necessary to set new goals in order to boost efficiency in the future.
7. Continuous monitoring of customer satisfaction with the services and facilities offered.

In view of the above, it is important that the port management assess their operating results, set goals for assessing operating results and regularly evaluate their results relative to the goals set.

Analysing the efficiency of container terminals through DEA (Soner Esmer, 2008) points out that the biggest problem preventing the creation of a uniform methodology for assessing the operation of any port is the lack of agreement between different ports, international organisations, experts in relation to what indicators must be chosen, and how they should be defined and assessed [9].

Traditionally, ports have been assessing their operating results by using a simple approach, i.e. comparing their actual and optimal throughput, measuring them in tonnes or containers processed [14]. If the actual long-term throughput of the port is close to its optimal throughput, one can conclude that the performance of the port within the specific time period has improved, or otherwise [13].

At the time, no globally-accepted uniform approach for assessing the operating results of ports has been developed. DEA and SFA are the world’s most common models for analysing container terminal operating results. When considering the assessment of port operating efficiency, various studies and articles analyse individual terminals, without including the overall efficiency of their corresponding ports. Such studies are becoming more and more frequent, taking into account the fact that terminals, in essence, act as the basis for port operations and development. Kevin Cullinane highlights that ports and terminals must not be considered as separate units, and their performance must be assessed as a whole [5].

Sensitivity analysis is used to know how sensitive the solution values and efficiency scores of the DMUs are to the numerical observations. In order to know the robustness of the efficiency scores, we propose a new model for sensitivity analysis in the new slack model (NSM) of DEA (Agarwal S, 2011) by changing the reference set of the inefficient DMUs [1].

Data envelopment analysis (DEA) is a well-established methodology for the assessment of performance of a homogeneous set of decision making units (DMUs), e.g. economies, bank branches, schools or hospitals, which are described by their input and output quantities. DEA shows a high potential regarding the aggregation problem mentioned before, as DEA does not require explicit weights. The main problem when using DEA in the ecological context is the fundamental assumption that for a DMU, to achieve efficiency, ceteris paribus larger quantities of outputs and smaller quantities of inputs are preferable [7].

Having reviewed various academic sources [12], the author has concluded that, in practice, three data processing methods are largely used to assess port and terminal operation results and efficiency:

1. using DEA;
2. using SFA;
3. using port capacity indicators.

In view of the fact that the DEA and SFA methods are largely used to assess terminal operating results, the author has emphasised the essence of these methods in her study.

DEA, which does not include the functional forms of production, is one of the main efficiency analysis methods. In essence, it encompasses the use of linear programming methods for establishing parameters. DEA is the main linear programming model for efficiency analysis. Meanwhile, SFA is an econometric method, which is most frequently used between parametric methods.

SFA is a production margin function, which can be described as an ‘extension of a known regression model, based on the microeconomic assumption that the production function is an ideal value, maximum output that can be achieved taking into account the entirety of raw materials available.’ In recent studies, the difference between the estimated production margin and the observed one is calculated to determine the level of efficiency of a company/organisation. Before this analysis, the researchers developed various approaches to measure efficiency in an econometric way. On a fundamental level, SFA determines the minimum costs at a certain output level, and the costs of raw materials based on the current production technology. This method can be successfully integrated in assessing the efficiency of ports, assessing investments into the development and maintenance of port infrastructure, relative to the amounts and types of cargo processed. This method makes it possible to determine the level of efficiency of a specific entity, in relation to the inefficient use of raw materials, within a certain cost function.

This is why the efficiency of a decision-making unit (DMU) (Fig. 1), which can belong not only to a bank, hospital or university, but also to a port, is calculated relative to the ‘best-practising’ market participant. Furthermore, in order to determine statistical error and to separate it from the concept of efficiency, introduced two-way deviations, and an additional ‘possibility-limited’ efficiency analysis was integrated in DEA models [8]. Ultimately, this efficiency assessment method is used in a large number of different fields, including management, operational research and economics.

In order to demonstrate the basic DEA model mathematically, we will assume that every decision-making unit uses m inputs to get n outputs at a certain level of technology. This mathematical representation can be explained by finding appropriate values m and n, which increase the level of efficiency of the unit, which all efficiency indicators are related to.

The popularity of the DEA method in assessing the efficiency of ports is growing, and it is increasingly used to assess the capacity of individual terminals. The author proposes that the non-parametric, deterministic DEA method be combined with the parametric SFA method, which is used more as a method for assessing technical efficiency. In the opinion of the author, combining these two methods in assessing port operations can yield more complete port efficiency assessment data. It should be highlighted that DEA models have been only recently adapted to consider the network of internal production processes taking place within a DMU [3, 17]. Chien-Ming (2009) argued that if these dynamic effects are not accounted for, then the measure of efficiency obtained would be biased and provide misleading information to the decision-makers [3].

DEA and SFA non-parametric and parametric statistical methods are used by port researchers mostly to assess container terminal operating results, evaluating the performance of decision-making units to create a basis for such an assessment [4]. Multiple similar input data converted in multiple similar output data are taken as the basis. Although, DEA is the most popular non-parametric method to assess port efficiency, it is not exempt from criticism [11]. Container terminal production may be best modelled as a network of interrelated sub-processes [2] or with multiple outputs [15].

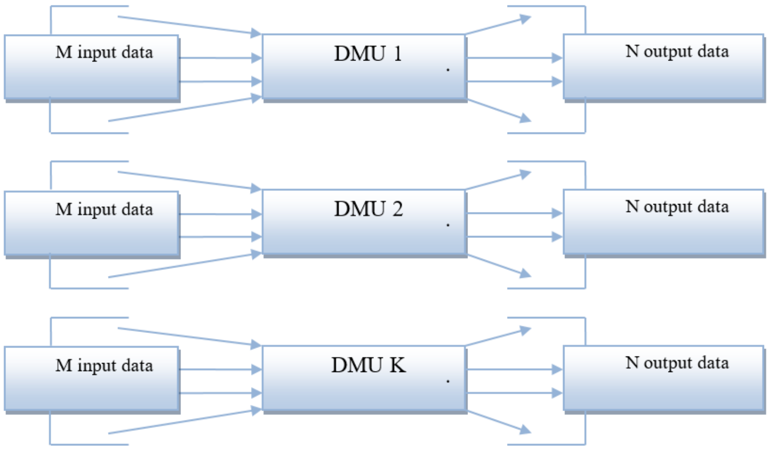

Fig. 1 DMU and homogeneous units [16]

The author of the study has developed a table that includes the most common input data, which, if processed using DEA and SFA, produce their corresponding output data (see Table).

The number of input and output data values does not have to be the same, e.g. two input data values may generate 3, 4, 5...n output data values. The author has observed that in most cases, these methods do not involve more than 9−10 data values per position.

Table

Common input and output data used with DEA and SFA [author's construction]

DEA		**SFA**	
Input data	Output data	Input data	Output data
• berth capacity • cargo handling capacity	• tonnes of cargo transhipped • number of vessels • revenue • customer satisfaction	• length of berth • terminal area • number of gantry cranes • number of employees	transhipped TEUs
• berth dimensions • area of terminals • number of cranes	transhipped TEUs	• labor force • capital	turnover
• number of employees • value of assets	• number of vessels • tonnes of cargo transhipped • transhipped TEUs	total cost	• labor force • capital • intermediate costs
• labor costs • depreciation costs • other expenses	• tonnes of cargo transhipped • port fee revenue	• labor force • capital	turnover

Following an exposition of the DEA methodology, the many previous applications of the technique to the port industry are reviewed and assessed. The DEA technique is illustrated through a detailed example application using sample data relating to the world's leading container ports. The different DEA models give significantly different absolute results when based on cross-sectional data. However, efficiency rankings are rather similar. The efficiency estimated by alternative approaches, therefore, exhibits the same pattern of efficiency distribution, albeit with significantly different means. An analysis of panel data reveals that container port efficiency fluctuates over time, suggesting that the results obtained from an analysis of cross-sectional data may be misleading. Overall, the results reveal that substantial waste exists in container port production. It is also found that the sample ports exhibit a mix of decreasing, increasing and constant returns to scale. The chapter concludes that the optimum efficiency levels indicated by DEA results might not be achievable in reality, because each individual port has its own specific and unique context. Consequently, more singular aspects of individual ports should be investigated to determine the reasons that explain estimated efficiency levels [5].

The basic information derived from the above three DEA models, i.e. the DEA-CCR model, the DEA-BCC model and the Additive model, is whether or not a firm can improve its performance relative to the set of firms to which it is being compared. A different set of firms is likely to provide different efficiency results because of the possible movement of the production frontier [6].

The economic impact of a port is largely measured using result indicators and resources related to them: cargo turnover, employment. (Talley, 2006) Believes that one of the options for achieving set economic goals is increasing the turnover of cargo at the port. Ports are classified based on the amount of cargo they process, and these data are published on the websites of port administrations, in statistical databases etc. It is commonly thought that increasing the turnover of cargo suggests that the efficiency of the port is improving, although one should keep two limitations of this indicator in mind. The author agrees with the opinion of (Langen, 2007) [10] in that increases in turnover are largely contingent on the flow of international trade, and not on the rising efficiency of the port in question. The aforementioned researchers also note that the amount of cargo processed does not say anything about its economic effect on the port.

Even though academic sources often praise the flexibility of DEA, its structure can be troublesome if the weights assigned to the input/output sets have unrealistic properties. Because of this, researchers can create more realistic models, to improve model discrimination, using limitations on the weight of input and/or output bundles. The upper and lower limits are set for the weight of the input and output sets, after which they are included in the linear programming system (output limitations), (input limitations). The main problem of WR models is the possibility of reaching an unacceptable limit, which only depends on the judgement of the researcher.

4. Conclusions

A comparison of SFA and DEA based on selected data shows that for simple basic technologies, the performance of stochastic frontier models (relative to DEA) depends on the choice of functional forms. Furthermore, with SFA, incorrect input data can lead to a certain level of inefficiency correlation, making DEA more attractive. All of the above arguments make it patently clear that choosing one of the two methods can yield different results, and even if the input and output data are similar, they are not equal, and there will always be certain cost alternatives. It is impossible to recommend one method or the other, because they both have their advantages and disadvantages; in this context, the best approach is to combine them to reduce the efficiency error. The main difference between stochastic and deterministic models is that stochastic analysis includes the concept of error, which enables it to separate the effect of inefficiency from statistical deviation. Should both of these methods be implemented in port economics, one will be able to obtain reliable efficiency assessment results by choosing appropriate input and output indicators that can be expressed numerically and can be calculated.

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