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Measuring transport systems efficiency under uncertainty by fuzzy sets theory based Data Envelopment Analysis

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Abstract

A crucial step in transportation planning process is the measure of systems efficiency. Many efforts have been made in this field in order to provide satisfactory answer to this problem. One of the most used methodologies is the Data Envelopment Analysis (DEA) that has been applied to a wide number of different situations where efficiency comparisons are required.
The DEA technique is a useful tool since the approach is non-parametric, and can handle many output and input at the same time.
In a lot of real applications, input and output data cannot be precisely measured. Imprecision (or approximation) may be originated from indirect measurements, model estimation, subjective interpretation, and expert judgment of available information. Therefore, methodologies that allow the analyst to explicitly deal with imprecise or approximate data are of great interest, especially in freight transport where available data as well as stakeholders' behavior often suffer from vagueness or ambiguity. This is particularly worrying when assessing efficiency with frontier-type models, such as Data Envelopment Analysis (DEA) models, since they are very sensitive to possible imprecision in the data set. The specification of the evaluation problem in the framework of the fuzzy set theory allows the analyst to extend the capability of the traditional "crisp" DEA to take into account and, thus, to represent the uncertainty embedded in real life problems. The existing fuzzy approaches are usually categorized in four categories: a) the tolerance approaches; b) the defuzzification approaches c) the α-level based approaches; d) the fuzzy ranking.
In this paper, we have explored the Fuzzy Theory-based DEA model, to assess efficiency measurement for transportation systems considering uncertainty in data, as well as in the evaluation result. In particular, the method is then applied to the evaluation of efficiency of container ports on the Mediterranean See with a sensitivity analysis in order to investigate the properties of the different approaches. The results are then compared with traditional DEA.

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Keywords: container ports; DEA; fuzzy DEA; fuzzy linear programming; ports efficiency.

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1. Introduction

In order to support trade oriented economic development, port authorities have increasingly been under pressure to improve port efficiency by ensuring that port services are provided on an internationally competitive basis. Ports form a vital link in the overall trading chain and, consequently, port efficiency is an important contributor to a nation's international competitiveness. Thus, monitoring and comparing one's port with other ports in terms of overall efficiency has become an essential part of many countries' microeconomic reform programmes.

This study hopes to contribute to this important task by applying an innovative approach to port efficiency ratings covering a selected sample of ports based on DEA model applied in fuzzy environment.

Over the past three decades Data Envelopment Analysis (DEA) has emerged as a useful tool for business entities and organizations to evaluate their activities. Mathematically, DEA is a linear programming-based methodology for evaluating the relative efficiency of a set of decision making units (DMUs) with multi-inputs and multi-outputs. DEA evaluates the efficiency of each DMU relative to an estimated production possibility frontier determined by all DMUs. The advantage of using DEA is that it does not require any assumption on the shape of the frontier surface and it makes no assumptions concerning the internal operations of a DMU.

There are some limitations of DEA that have to be considered. Because DEA is a methodology focused on frontiers, small changes in data can change efficient frontiers significantly. Therefore, to successfully apply DEA, we have to have accurate measurement of both the inputs and outputs. However, the observed values of the input and output data in real-world problems are sometimes imprecise or vague. Imprecise evaluations may be the result of unquantifiable, incomplete or spot information.

In recent years, fuzzy set theory has been proven to be useful tool for imprecise data in DEA models. Some researchers have proposed various fuzzy methods for dealing with this impreciseness and ambiguity in DEA (Lertworasirikul, 2002). However, there is no universally accepted approach for solving the fuzzy DEA model. In this paper we used an original approach to solve DEA with imprecise data.

We measure efficiency of sixteen international container ports considering six inputs (number of cranes, number of container berths, number of tugs, terminal area, delay time and labor units) and four outputs (TEUs handled, shipcalls, shiprate, crane prod.). Delay time is fuzzy input in developed model. Membership functions are of triangular shape. Applying this new approach we solve a Fuzzy Theory-based DEA model by FUZZY LOGIC TOOLBOX (collection of functions built on the MATLAB numeric computing environment to create and edit fuzzy inference systems and models).

The rest of the paper is organized as follows. Section 2 gives a brief review of related studies which have used DEA and Fuzzy DEA techniques. Section 3 introduces DEA model and develops the Fuzzy Theory-based DEA model built using MATLAB. Section 4 presents the results of empirical study conducted on 16 international container ports. Conclusions are reported in the final section.

2. Literature review on DEA and Fuzzy DEA

Many application of DEA can be found in literature. This method has been used in several contexts including education systems, health care units, agricultural production, and military logistics. DEA has also been applied in various transport systems. A briefly literature review on studies that have applied DEA method to analyze transport systems efficiency is proposed, with particular attention to port efficiency.

Chu et al. (1992) use DEA to measure efficiency of selected bus transit systems in the United States. Roll and Hayuth (1993) first tried to use DEA model in analyzing the efficiency of container ports. They evaluated the efficiency of 20 virtual ports through DEA with 3 inputs and 4 outputs. Martinez-Budria et al. (1999) classified 26 container ports in Spain into three groups according to the level of complexity based on data from 1993 to 1997 and then evaluated the efficiency of those ports through DEA-BCC model with 3 inputs and 1 outputs.