



Performance based stratification and clustering for benchmarking of container terminals

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ABSTRACT

Benchmarking of container terminals is an important issue facing port management. Data envelopment analysis (DEA), which is a multi-factor productivity measurement tool is generally used in assessing the relative efficiency of homogenous units and setting benchmark for inefficient units. Evaluation of container terminals by DEA produces limited set of efficient units which are reference to inefficient units irrespective of their differences in efficiency scores. DEA projects the lowest efficient units to highest efficient units but in reality, the reference set may be very different in size, environment and operating practices. Every container terminal is characterized by some physical values that represent relevant properties of the terminal. DEA, if employed alone, to measure the efficiency and set benchmark for inefficient terminals to improve efficiency may give biased result because all container terminals vary in their capacity. In order to overcome this shortcoming, in this paper, data mining and DEA are fused to provide a diagnostic tool to effectively measure the efficiency of inefficient terminals and prescribe a step-wise projection to reach the frontier in accordance with their maximum capacity and similar input properties which otherwise is not possible with DEA alone.

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1. Introduction

The container terminal is the physical link between ocean and land modes of transport and a major component of containerization system (Dowd & Leschine, 1990). 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 increasingly 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 (Chin & Tongzon, 1998; Tongzon, 1989). There are various papers based on efficiency measurement of container port industry in relation to productive activities. In particular, non-parametric frontier methods data envelopment analysis (DEA) has been developed with application across a wide range of sectors. The applications of standard DEA models such as the Charnes, Cooper and Rhodes (CCR) (Charnes, Cooper, & Rhodes, 1978) and Banker, Charnes and Rhodes (BCC) (Banker, Charnes, &

Cooper, 1984) have been applied to container port industry to measure the efficiency. Other methods that have been used in efficiency measurement of ports are DEA windows analysis, stochastic cost frontier (SCF) and stochastic production frontier method (SPF).

Although benchmarking in DEA allows for the identification of targets for improvements, it has certain limitations. A drawback in benchmarking is that inefficient DMUs are projected to the efficient frontier ignoring the differences in the efficiency score. Another drawback regarding the use of DEA model is that an inefficient DMU and its benchmarks may not be inherently similar in the operating practices (Doyle & Green, 1994). This paper enhances the capability of DEA by using DEA recursive analysis to provide reference set to inefficient units in accordance with their maximum capacity to improve efficiency to their optimal level in contrast to an unrealistic level. Next clustering is carried out using unsupervised clustering tool Kohonen's self-organizing map (KSOM) (Kohonen, 1982) to cluster units with similar input properties so as to make appropriate benchmarking at the respective stratified efficiency levels obtained by using DEA recursive analysis.

The rest of the paper is organized as follows: In Section 2 there is a review of literature on DEA and efficiency measures in port sector. Section 3 deals with the limitations of DEA and proposes a methodology to overcome these shortcomings. Section 4 deals with the practical application, the results of which are displayed

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in the tables accordingly. The final section discusses the conclusion and future research issues.

2. Data envelopment analysis: the concept

DEA is a multi-factor productivity analysis model for measuring the relative efficiencies of a homogenous set of decision making units (DMUs). The DEA approach identifies a set of weights (all weights must be positive) that individually maximizes each DMU's efficiency while requiring the corresponding weighted ratios (i.e., using the same weights for all DMUs) of the other DMUs to be less than or equal to one. A DMU is considered relatively inefficient if its efficiency rating is less than one (i.e. $E < 1$). The degree of inefficiency for a DMU is measured relative to a set of more efficient DMUs. However, a DMU identified as being efficient (i.e. $E = 1$) does not necessarily imply absolute efficiency. It is only relatively efficient to other DMUs that are being considered.

DEA models are classified with respect to the type of envelopment surface, the efficiency measurement and the orientation (input or output). There are two basic types of envelopment surfaces in DEA known as constant returns-to-scale (CRS) and variable returns-to-scale (VRS) surfaces. Each model makes implicit assumptions concerning returns-to-scale associated with each type of surface. Charnes et al. (1978) introduced the CCR or CRS model that assumes that the increase of outputs is proportional to the increase of inputs at any scale of operation. Banker et al. (1984) introduced the BCC or VRS model allowing the production technology to exhibit increasing returns-to-scale (IRS) and decreasing returns-to-scale (DRS) as well as CRS. DEA models are also classified as radial input oriented, radial output oriented or additive (both inputs and outputs are optimized) based on the direction of projection of the inefficient unit into the frontier. Since we only utilize the radial output oriented models in our study of container terminals, for the convenience of the reader, we provide a summary consisting of Charnes–Cooper transformation model and the corresponding to it linear programming (LP) dual model (sometime referred to as the 'Farrell Model') in the 'relaxed' form in Table 1.

2.1. Mathematical formulation

Charnes, Cooper and Rhodes (CCR) model allows representing multiple inputs and outputs of each DMU and can be represented as a ratio of the abstract input to abstract output, and the resulting efficiency value can then be used for comparison with other DMU in the set.

Mathematically, this ratio can be expressed as the following objective function:

$$\max h_o(u, v_i) = \frac{\sum_r (u_r y_{ro})}{\sum_i (v_i x_{io})}$$

where u_r is the variable representing the output value; v_i is the variable representing the observed input value; y_{ro} is the observed amount y of output r produced by DMU_o from the input x_{io} ; x_{io} is the observed amount of input i consumed in order to produce y amount of output r by the DMU_o (the DMU to be evaluated).

Adding the normalizing constraint, according to which ratio of virtual input to virtual output for each DMU must be less than one, the following LP problem can be formulated:

$$\begin{aligned} \max \quad & h_o(u, v) = \frac{\sum_r (u_r y_{ro})}{\sum_i (v_i x_{io})} \\ \text{subject to} \quad & \frac{\sum_r (u_r y_{rj})}{\sum_i (v_i x_{ij})} \leq 1 \quad \text{for } j = 1, \dots, n, \\ & u_r, v_i \geq 0 \quad \text{for all } i \text{ and } r, \end{aligned}$$

where in the case of fully rigorous development $u_r, v_i \geq 0$ would be replaced with the constraint including a non-Archimedean element ϵ such as $\frac{u_r}{\sum_{i=1}^m v_i x_{io}}, \frac{u_r}{\sum_{i=1}^m v_i x_{io}} \geq \epsilon > 0$, and ϵ is smaller than any positive real number (Cooper, Seiford, & Zhu, 2004).

A relative efficiency of a DMU can be characterized as being strong or weak. Strong or weak efficiency depends on the absence or presence of slacks. For example, a DMU is considered to be strongly or fully efficient if $\theta^* = 1$ and all slacks are equal to zeroes. On the other hand a DMU could be weakly efficient if it obtained the same score $\theta^* = 1$, but some slacks are not equal to zero. As it is shown above, the type of relative efficiency of a given

Table 1
DEA model types (Cooper et al., 2004)

Charnes–Cooper transformation	LP dual ('Farrell model')	LP dual solution (score)
<i>Input-oriented DEA model</i>		
$\begin{aligned} \max \quad & z = \sum_{r=1}^s \mu_r u_{ro} \\ \text{subject to} \quad & \sum_{r=1}^s \mu_r y_{ro} - \sum_{i=1}^m v_i x_{ij} \leq 0 \\ & \sum_{i=1}^m v_i x_{ij} = 1 \\ & \mu_r, v_i \geq 0 \end{aligned}$	$\begin{aligned} \theta^* = \min \quad & \theta \\ \text{subject to} \quad & \sum_{j=1}^n x_{ij} \lambda_j \leq \theta x_{io}, \quad i = 1, 2, \dots, m; \\ & \sum_{j=1}^n y_{rj} \lambda_j \geq y_{ro}, \quad r = 1, 2, \dots, s; \\ & \lambda_j \geq 0, \quad j = 1, 2, \dots, n; \end{aligned}$	Solution: $\theta^* \leq 1$ Score: If $\theta^* < 1$, DMU is inefficient If $\theta^* = 1$, DMU is efficient
<i>Output-oriented DEA model</i>		
$\begin{aligned} \min \quad & q = \sum_{i=1}^m v_i x_{io} \\ \text{subject to} \quad & \sum_{r=1}^s v_r x_{ij} - \sum_{r=1}^s \mu_r y_{rj} \geq 0 \\ & \sum_{r=1}^s \mu_r y_{ro} = 1 \\ & \mu_r, v_i \geq \epsilon \end{aligned}$	$\begin{aligned} \theta^* = \max \quad & \theta \\ \text{subject to} \quad & \sum_{j=1}^J z_j x_{jn} \geq \theta u_{jn}, \quad m = 1, 2, \dots, M; \\ & \sum_{j=1}^J z_j x_{jn} \leq x_{jn}, \quad n = 1, 2, \dots, N; \\ & z_g \leq 0, \quad j = 1, 2, \dots, J; \end{aligned}$	Solution: $\theta^* \leq 1$ Score: If $\theta^* < 1$, DMU is inefficient If $\theta^* = 1$, DMU is efficient

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