TOOLS USED TO BENCHMARK THE EFFICIENCY OF CONTAINER PORTS AND TERMINALS

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ABSTRACT

Container terminal is an important element in the contemporary global economy; on the international market it is very important to know who operates efficiency. In this paper the efficiency of container port or terminal is benchmarked by Data Envelopment Analysis, which is a non–parametric linear programming method; the method identifies efficient or inefficient DMUs and diagnoses the factors that differentiate the performance of inefficient DMUs. This paper presents a model of DEA and examines some recent studies about the container port production efficiency.

Keywords: Efficiency, Data Envelopment Analysis (DEA), Production, Container Terminal.

1. INTRODUCTION

Data Envelopment Analysis is a methodology based on linear programming and it was developed for performance measurement; this technique measures the performance efficiency or inefficiency of organizational units which are termed Decision-Making Units (DMU). The Decision making units (DMUs) can include: bank branches, hospitals, container port, universities, schools, tax offices, manufacturing units, department of glib organizations, police stations, prisons, defence bases.

DMU converts multiple inputs into multiple outputs and their performances are to be evaluated:

Productivity = \frac{output}{input}

Data envelopment analysis uses the concept of efficiency or productivity which is the ratio of total outputs to total inputs; the score of efficiencies estimated is relative, that is relative to the best DMU (or DMUs if there is more than one best).

Efficiency = \frac{VirtualOutput}{by.weight}{VirtualInput}{by.weight}

The basic model is proposed by Charnes, Cooper and Rhodes in 1978 [1]; for each DMU they formed a virtual input and output [2] (by weights) and tried to determine the optimal weights. They transform a fractional program to linear program.

2. THE MATHEMATICAL FORMULATION

There are many models of DEA [3] (linear programming); one of them is:

2.1. Input Oriented model (the envelopment model):

Min \theta - \varepsilon(\sum_{i=1}^{m} s_{i}^{-} + \sum_{r=1}^{s} s_{r}^{+}) \tag{1}

Subject to:

for CRS (Constant Return to Scale):

\sum_{j=1}^{n} \lambda_{j} \times x_{ij} + s_{i}^{-} = \theta \times x_{io} , i=1,2...m;

\sum_{j=1}^{n} \lambda_{j} \times y_{rj} - s_{r}^{+} = y_{ro} , r=1,2...s;

\lambda_{j} \geq 0 , j=1,2...n

for VRS (Variable Return to Scale), we add:

\sum_{j=1}^{n} \lambda_{j} = 1

for NIRS (Non-Increasing Return to Scale), we add:

\sum_{j=1}^{n} \lambda_{j} \leq 1

for NDRS (Non-Decreasing Return to Scale), we add:

\sum_{j=1}^{n} \lambda_{j} \geq 1

the efficient target is (optimal solution):

\left\{ \begin{array}{l}
  x_{io} = \theta^{*} \times x_{io} - s_{i}^{-}^{*} , i=1,2...m \\
  y_{ro} = y_{ro} + s_{r}^{+}^{*} , r=1,2...s
\end{array} \right.

2.2. Output Oriented model (the envelopment model):

Max \phi + \varepsilon(\sum_{i=1}^{m} s_{i}^{-} + \sum_{r=1}^{s} s_{r}^{+}) \tag{2}

Subject to:

\sum_{j=1}^{n} \lambda_{j} \times x_{ij} + s_{i}^{-} = x_{io} , i=1,2...m;

\sum_{j=1}^{n} \lambda_{j} \times y_{rj} - s_{r}^{+} = \phi y_{ro} , r=1,2...s;
\[ \lambda_j \geq 0, \ j=1,2\ldots n \]

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\[ \sum_{j=1}^{n} \lambda_j \geq 1 \]

the efficient target is (optimal solution):
\[
\begin{cases}
X_{io} = x_{io} - s_{i}^{+} \\
y_{ro} = \phi^{r} y_{ro} + s_{r}^{+}
\end{cases}, \ i=1,2\ldots m, \ r=1,2\ldots s;
\]

Where:
- \( N \) is the number of DMUs,
- \( x \) is input vectors (\( m \) inputs),
- \( y \) is output vectors (\( s \) outputs),
- \( s_{i}^{-}, s_{r}^{+} \) are slacks,
- \( \phi \) and \( \theta \) are weights,
- \( \varepsilon \) is non-Archimedean number,
- \( \lambda \) is a measure for benchmark (efficiency score).

3. SOFTWARE PACKAGE

The Efficiency Measurement System (EMS) \cite{4} is a useful tool which solves Data Envelopment Analysis problems. It was developed by Holger Scheel and is free for academic users; problems are optimized with BPMPD interior-point solver.

EMS computes Data Envelopment Analysis efficiency scores, accepts data in text format or MS Excel.

Other software packages \cite{5} are:
- DEAP;
- PIM-DEA;
- DEA Frontier;
- Konsi DEA Software;
- Banxia Software;
- DEA-Solver;
- Warwick DEA
- STATA
- AMPL
- Mathematica

4. INPUT(S) AND OUTPUT(S) DATA

One of the most important objectives of the application using Data Envelopment Analysis is the proper choice of input and output data.

Data input used in most of the application are:
- number of berths
- number of cranes
- number of tugs
- number of quay cranes
- number of quayside gantries
- number of yard cranes
- shipshore gantry cranes
- number of port authority employees
- number of reach stackers
- number of straddle carriers
- number of container terminal workers
- terminal area of ports
- total length of the terminal
- total quay length
- other expenditures

The output data used to benchmark container port and terminal are:
- revenue obtained from rental of port facilities
- throughput (teu)
- ship calls
- number of ships
- ship working rate
- total cargo handled (tons)
- container throughput (number of containers handled)
- ship working rate
- service level

5. SOME RECENT RESEARCH ABOUT MEASURING THE EFFICIENCIES OF CONTAINER PORTS

The DMU in this study is container port or container terminal, and the authors use Data Envelopment Analysis methodologies for comparing the efficiency of container terminals.

Benchmarking the operating efficiency of Asia container ports \cite{6} is a study published in the European Journal of Operational Research, 2010; this study employs DEA to measure scale efficiencies, technical efficiencies and determines the current returns to scale for Asian container ports, from China, Taiwan, Philippines, Malaysia, Thailand, Indonesia, South Korea, and Japan; The study published efficiency score of 31 Asia containers ports: only 26\% of the Asian
container ports are regarded as efficient and 74% of Asian container port need to reduce their inputs if they are to become efficient.

The input(s) data are: terminal area (m²), ship-shore container gantry (no.), container berth (no) and terminal length (m); the output data is container throughput (teu).

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Cullinane K and Song D. [7] evaluate the efficiency of the world’s 57 most important container ports and terminals using DEA; the output variable is: throughput (teu) and the input are: quay length (m), terminal area (ha), quayside gantries (no.), yard gantries (no.) and straddle carriers (no.).

The efficient terminals are: Hong Kong (Terminal 3), Los Angeles, Long Beach, Antwerp (Noordzee), Port Klang (Klang Container), Gioia Tauro Keelung and Colombo.

In International Journal of Logistics: Research and Applications [10], Cullinane K. analyses 69 Europe’s container terminal; with annual throughput over 10000 TEUs. The input data are: terminal length (m), terminal area (ha) and equipment (number); the output data is container throughput (teu).

6. REFERENCES


