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Efficiency Measurement of Major Container Terminals in Asia

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Abstract : *Due to the growth of container traffic and port competition, ports have increasingly been under pressure to improve their efficiency in port operation and port management for competitive edge. The purpose of this study is to compare the technical efficiency among major container terminals in China, Korea and Singapore using Data Envelopment Analysis (DEA). This paper analyses the returns-to-scale using the output orientation of VRS and CRS model. The benefits of this study examining the relative performance of container terminals will enable container terminal operating companies or port policy makers in those countries to identify current slacks and to set up a proper port management and operation plan to improve their productivity.*

Key words : *DEA, Efficiency, Port Performance, VRS, CRS, Container Terminal*

1. Introduction

The container terminal is the interface between ocean and land to transfer and transport containers from one mode of transportation to another. 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(Tongzon, 1989; Chin and Tongzon, 1998).

As a methodology, the applications of standard Data Envelopment Analysis (DEA) models such as the CCR(Charnes et al., 1978) and BCC(Banker et al., 1984) have been applied to container port industry to measure the efficiency. This study tries to measure technical efficiency using output - oriented model of DEA as a proportional increase in output production of container terminals and compare the returns to scale models in DEA covering a selected sample of container terminals.

DEA uses multiple inputs and outputs simultaneously to derive efficiency ratings within a homogenous set of units (Charnes et al., 1978). DEA is one of the most important performance measurements which overcome most shortcomings of the parametric approach.

In this paper, 26 container terminals from China, Korea and Singapore are taken as a sample study based on the argument that container terminals are more suitable for one-to-one comparison than whole container ports(Wang et al., 2002). Data are obtained from sources like Containerization International Yearbook(2005) and various port authorities and terminal operators.

The rest of the paper is organized as follows; Section 2 gives a brief review of related studies which have used this technique in port efficiency measurement. Section 3 outlines DEA models and discusses the output and input measures used. Section 4 provides practical results for DEA applied to 26 container terminals in China, Korea and Singapore. Finally, section 5 concludes the main results in the paper.

2. Literature Review of Port Efficiency Measure Using DEA

Container terminals can be defined as places with facilities for shipping lines where equipments are available to handle ships and containers with operational efficiency. There are some literatures that have attempted to measure the productivity and efficiency of container terminals using DEA. In general, most studies have been concentrated on the CCR model. Roll and Hayuth(1993) relied on data commonly available from annual reports in ports and Tongzon(2001) covered 16 ports for which he obtained comparable data for 1996. The model preferences are evenly distributed between stochastic frontier and Data Envelopment Analysis.

Cullinane et al.(2001) used stochastic frontier model to analyse the administrative and ownership structures of

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major container port in Asia and Liu(1995) focused on production to calculate technical efficiency and compares the influence of public and private ownership in Britain. Roll and Hayuth(1993) showed how DEA can be useful in assessing the relative effectiveness of various ways of organizing port services when limited data is available.

Martinez, Diaz, Navarro and Ravelo(1999) relied on DEA to assess the relative efficiency of Spain's ports. Tongzon(2001) used DEA to make an international comparison of efficiency of 4 Australian and 12 other ports from around the world.

Furthermore, Song et al.(2003) applied DEA windows analysis, utilizing panel data, to a sample of the world's major container ports in order to deduce their relative efficiency. Their results show that panel data prevails over cross sectional data.

Ryoo(2005) conducted a comparative analysis of container terminal operation in Busan and Kwangyang port. His research showed that inefficient terminals need to fully utilise their terminal facilities and increase container throughput through effective marketing activities.

3. Data Envelopment Analysis

3.1 Basic Concept

DEA is a non-parametric productivity analysis model for measuring the relative efficiencies of a homogenous set of decision making units(DMUs). The efficiency score in presence of multiple input and output factors is defined as:

$$Efficiency = \frac{Weighted\ sum of\ outputs}{Weighted\ sum\ of\ inputs}$$

The DEA approach identifies a set of weights that individually maximizes each DMU's efficiency while requiring the corresponding weighted ratios 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 as compared to the 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 constant returns-to-scale(CRS).

DEA models are also classified as radial input oriented,

Output-oriented CCR Primal (CCR_P-O)	Output-oriented CCR Dual (CCR_D-O)
max Zo = $\theta + \epsilon\ (1^T s^+ + 1^T s^-)$ s.t. (3.1.1a) $Y\lambda - \theta y_o - s^+ = 0$ $X\lambda + s^- = 0$ $\lambda, s^-, s^+ \geq 0$ $\varepsilon > 0$ (Non-Archimedean)	min Wo = $v^T x_o$ s.t. (3.1.1b) $\mu^T y_o = 1$ $-\mu^T Y + v^T X \geq 0^T$ $\mu, v \geq \varepsilon 1$ $\varepsilon > 0$
Output-oriented BCC Primal (BCC_P-O)	Output-oriented BCC Dual (BCC_D-O)
max Zo = $\theta + \epsilon\ (1^T s^+ + 1^T s^-)$ s.t. (3.1.2a) $Y\lambda - \theta y_o - s^+ = 0$ $X\lambda + s^- = 0$ $\lambda, s^-, s^+ \geq 0$ $\varepsilon > 0$	min Wo = $v^T x_o + u$ s.t. (3.1.1b) $\mu^T y_o = 1$ $-\mu^T Y + v^T X \geq 0^T$ $\mu, v \geq \varepsilon 1$ $\varepsilon > 0$

radial output oriented or additive based on the direction of projection of the inefficient unit into the frontier. Since we only utilise the radial output oriented models in this study, we only present the mathematical formulation for the VRS and CRS output oriented models. A complete mathematical presentation of the DEA output and input oriented models is provided in Charnes et al.(1984).

3.2 Mathematical formulation

The mathematical presentation of the models provided is based on Joro et al.(1999) and Arnold et al.(1997). Let us assume that there are n decision making units(DMUs) to be evaluated. Each DMU consumes varying amount of m different inputs to produce p different outputs. Specifically, DMUj consumes amounts Xj = {Xij} of inputs (i = 1,...., m) and produces amounts Yj = {Yrj} of outputs (r = 1,...., s). Xj and Yj are the observations obtained for each DMU and Xj > 0 and Yj > 0. Y is the s×n matrix of output measures and X is the m×n matrix of input measures.

The CCR and BCC models are the basic model types in DEA. The output oriented CCR and BCC models are given in (3.1.1a), (3.1.1b), (3.1.2a), (3.1.2b). Note that, following Charnes and Cooper, the original primal formulation is called the dual and vice versa.

In the economic efficiency literature two types of efficiency are usually distinguished. One is technical or production efficiency associated with the production frontier, which measures the firm's success in producing the maximum possible output from a given set of inputs. The second is allocative or price efficiency, which measures the firm's success in choosing an optimal set of inputs with a given set of market prices for inputs.

One useful feature of DEA is the power to identify the sources and amount of wastage in inputs, or shortfalls in outputs for each inefficient DMU. By identifying the slacks from the analysis managers can take corrective actions required to achieve efficient performance. Furthermore, the benchmarks for inefficient terminals are another source that enables the managers to make strategies for improvement of inefficient terminals.

3.3 Terminal Output / Input Data Set

Container terminal productivity deals with the efficient use of labour, equipment and land. Terminal productivity measurement is a means of quantifying the efficiency of the use of these three resources(Dowd and Leschine, 1990). Song et al.(2003) discuss that input and output variables should reflect the actual objectives and process of container port production as accurately as possible. The goal of a container terminal determines the definition of variables.

The maximization of output verily relies on the operational and technical aspect of the terminal. When a ship arrives at the port, quay cranes(QCs) take the import containers off the ship's hold or off the deck. Next, the containers are transferred from the QCs to vehicles that travel between the ship and the stack. After a certain

Table 1 Input and Output Variables

Container Terminal	(I)No of berth	(I)Length(m)	(I)Total area(m²)	(I)G/C	(O)TEU in 2004
Zhang Hua Bang(China)	3	784	305,000	8	1,118,000
Jun Gong Lu	4	857	307,000	7	1,464,000
Bao Shan	3	640	218,000	5	1,078,000
WaiGaoQiao Ph 1	3	900	500,000	6	2,339,400
WaiGaoQiao Ph 2,3	5	1,550	1,600,000	15	4,300,000
WaiGaoQiao Ph 4	4	1,250	1,630,000	14	1,200,000
Busan Jasungdae(Korea)	5	1,474	647,000	13	1,826,280
Busan Shinsundae	4	1,200	1,039,000	12	1,982,306
Busan Gamman Hanjin	1	350	182,750	3	639,562
Busan Gamman Hutchison	1	350	182,750	4	721,493
Busan Gamman Global	1	350	182,750	3	568,702
Busan Gamman Korea Express	1	350	182,750	4	874,839
Busan Sin Gamman	3	826	308,000	7	972,786
Busan U-am	3	500	184,000	5	548,021
Busan Gamcheon Hanjin	2	600	148,000	4	547,766
Gwangyang Korea Express	1	350	210,000	3	396,211
Gwangyang Hutchison	1	350	210,000	2	141,584
Gwangyang Hanjin	1	350	210,000	2	270,386
Gwangyang Global	1	350	210,000	2	224,244
Gwangyang Dongbu	1	350	210,000	2	126,729
Gwangyang KIT	7	1,950	856,000	10	162,711
Jurong(Singapore)	5	1,300	33,438	13	600,000
Brani	9	2,629	790,000	29	5,204,520
Keppel	14	3,220	960,000	36	8,062,740
Pasir Panjang	6	2,319	840,000	38	3,455,460
Tanjong Pagar	8	2,307	800,000	29	4,607,280

period the containers are retrieved from the stack by cranes and transported by vehicles to transportation modes like barges, deep sea ships, trucks or trains. To load export containers onto a ship, these processes are executed in reverse order. Most of the terminals make use of manned equipments, like straddle carriers, reach stackers, cranes and multi-trailer-systems(Iris F.A. Vis & Koster, 1999).

Based on the processes of container terminal operation the number of berths, terminal area and quay length are the best input variables for 'land' factor and number of quay gantry cranes is best input variable for 'equipment' factor.

DEA may be applied to compare the relative efficiency of a single container terminal to a set of other container terminal where the common output may be defined in terms of an annual throughput measured in TEU. Container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a terminal or port as an output factor.

Efficiency begins to resemble the sum of weighted outputs over the sum of weighted inputs. As the method of weighting can be biased towards one particular outcome, the DEA technique allows for each weighted input/output to be seen in its most favourable light. The number of variables entered into the formula means the less emphasis there will be on any particular piece of data. Therefore Szczepura et al.(1992) argue that the number of variables should be kept to as low as possible. In general, the number of observations should be substantially grater than the total number of inputs and outputs.

4. Efficiency results using CCR & BCC Models

4.1 Results of Data Analysis

The sample consists of 26 container terminals from China, Korea and Singapore with technical variables or inputs like number of berths, length, total terminal area, number of gantry cranes, and container throughput as output.

Table 2 Ralative Efficiency Measures Using BCC and CCR DEA Models

1. DEA CCR-Output			2. DEA BCC-Output	
DMU (Container Terminal)	Score		DMU (Container Terminal)	Score
Zhang Hua Bang (China)	0.5705		Zhang Hua Bang (China)	0.5984
Jun Gong Lu	0.7624		Jun Gong Lu	0.8399
Bao Shan	0.7881		Bao Shan	0.9448
WaiGaoQiao Phase 1	1		WaiGaoQiao Phase 1	1
WaiGaoQiao Phase 2,3	1		WaiGaoQiao Phase 2,3	1
WaiGaoQiao Phase 4	0.3484		WaiGaoQiao Phase 4	0.3484
Busan Jasungdae (Korea)	0.5118		Busan Jasungdae (Korea)	0.5313
Busan Shinsundae	0.6088		Busan Shinsundae	0.6091
Busan Gamman Hanjin	0.7713		Busan Gamman Hanjin	1
Busan Gamman Hutchison	0.8247		Busan Gamman Hutchison	0.8247
Busan Gamman Global	0.6859		Busan Gamman Global	0.8892
Busan Gamman Korea Express	1		Busan Gamman Korea Express	1
Busan Sin Gamman	0.5058		Busan Sin Gamman	0.5569
Busan U-am	0.4332		Busan U-am	0.5734
Busan Gamcheon Hanjin	0.5386		Busan Gamcheon Hanjin	1
Gwangyang Korea Express	0.4743		Gwangyang Korea Express	0.6195
Gwangyang Hutchison	0.1815		Gwangyang Hutchison	0.5236
Gwangyang Hanjin	0.3467		Gwangyang Hanjin	1
Gwangyang Global	0.2875		Gwangyang Global	0.8293
Gwangyang Dongbu	0.1625		Gwangyang Dongbu	0.4686
Gwangyang KIT	0.0417		Gwangyang KIT	0.0512
Jurong (Singapore)	1		Jurong (Singapore)	1
Brani	0.9234		Brani	0.9468
Keppel	1		Keppel	1
Pasir Panjang	0.7548		Pasir Panjang	0.8439
Tanjong Pagar	0.8749		Tanjong Pagar	0.9171

The efficiency rankings calculated using the two approaches DEA VRS and CRS models are given in Table 2. Comparing these results reveal that the BCC or VRS model identifies more efficient terminals than CCR or CRS model.

On the basis of results presented in Table 2, the terminals WaiGaoQiao Phase 1, WaiGaoQiao Phase 2, 3, Busan Gamman Korea Express, Jurong and Keppel terminals are identified as efficient in the CRS model whereas container terminals identified as efficient in VRS model are WaiGaoQiao Phase 1, WaiGaoQiao Phase 2, 3, Busan Gamman Hanjin, Busan Gamcheon Hanjin, Gwqngyang Hanjin, Jurong and Keppel terminals. The excess length of 25.8 meters is identified as slack for Busan Gamman Hanjin terminal and an excess length of 198 meters and minor slack in area with only 50% of efficiency score is identified for Busan Gamcheon Hanjin by the CRS model whereas the VRS model identifies no slacks in both these container terminals(see Appendix).

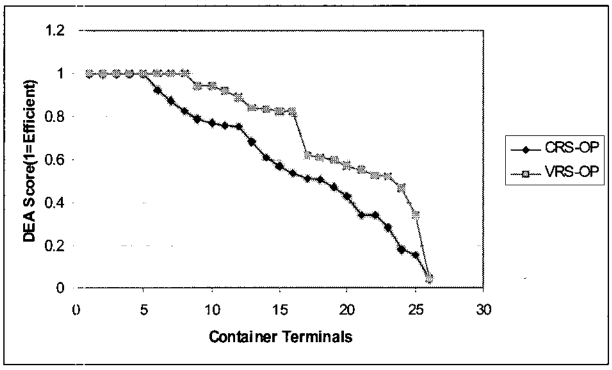

Fig. 1 Comparison between CRS and VRS Score

In the graphical representation of VRS and CRS score we can observe that the efficiency score tends to be consistently higher for all the container terminals in VRS, and the number of efficient terminals are more than that observed in CRS model.

4.2 Efficiency Results with RTS

Table 3 shows the efficiency results of RTS. The RTS efficiency score is calculated as the ratio of a CCR efficiency score to a BCC efficiency score. If the ratio is equal to one (1) a container terminal is considered to be efficient. Decreasing returns-to-scale (DRS) shows diseconomies of scale and a need for improvement. CCR inefficient terminals show either DRS or IRS and BCC inefficient terminals show either DRS or IRS.

From Table 3 the number of CRS, DRS and IRS container terminals are 7, 8 and 11 respectively. The number of efficient container terminals that have been identified in CRS and VRS model for Shanghai are 2 and the number of DRS, IRS and CRS identified are 1, 2 and 3 respectively.

The number of efficient terminals in case of Busan and Gwangyang shown by CRS model are 1 and that by VRS model are 3. Now considering the Returns-to-scale (RTS) we can see that the two extra container terminals as shown by VRS exhibit decreasing returns to scale (DRS) in port production and should be improved to enhance the efficiency level. CCR inefficient terminals show DRS or IRS. BCC inefficient terminals show DRS or IRS.

The number of DRS, IRS and CRS for Busan and Gwangyang are 7, 6 and 2 out of which the number of DRS is higher for Gwangyang terminals showing considerable diseconomies of scale. Also the number of inefficient terminals is higher for Gwangyang terminals with considerable slack in length and terminal area.

Gwangyang KIT container terminal shows under utilization of berth both in CRS and VRS model but with IRS. In case of Singapore container terminals out of 5 the number of efficient terminals in both CRS and VRS model is found to be 2 with two of its terminals namely Pasir Panjang and Tanjong Pagar showing enormous slack in gantry cranes.

Table 3 Returns-to-scale (RTS)

	Container Terminals / Country	RTS
1	Zhang Hua Bang (China)	IRS
2	Jun Gong Lu	IRS
3	Bao Shan	DRS
4	WaiGaoQiao Phase 1	CRS
5	WaiGaoQiao Phase 2, 3	CRS
6	WaiGaoQiao Phase 4	CRS
7	Busan Jasungdae (Korea)	IRS
8	Busan Shinsundae	IRS
9	Busan Gamman Hanjin	DRS
10	Busan Gamman Hutchison	CRS
11	Busan Gamman Global	DRS
12	Busan Gamman Korea Express	CRS
13	Busan Sin Gamman	IRS
14	Busan U-am	IRS
15	Busan Gamcheon Hanjin	DRS
16	Gwangyang Korea Express	IRS
17	Gwangyang Hutchison	DRS
18	Gwangyang Hanjin	DRS
19	Gwangyang Global	DRS
20	Gwangyang Dongbu	DRS
21	Gwangyang KIT	IRS
22	Jurong (Singapore)	IRS
23	Brani	CRS
24	Keppel	IRS
25	Pasir Panjang	CRS
26	Tanjong Pagar	IRS

There are 3 IRS and 2 CRS without any DRS signifying absence of any diseconomies of scale. In terms of DRS out of the evaluated sample Gwangyang container terminals of Korea are ranked higher with 4 terminals showing DRS. Therefore, it is recommended that improvement of productivity of Gwangyang container terminals of Korea should be given priority in order to gain competitive advantage over the neighbouring terminals. The terminals of Singapore are identified as most efficient by both BCC and CCR model with higher score of IRS and absence of DRS.

4.3 Reference Set

In addition to providing efficiency measures, DEA also provides other information relevant for the inefficient DMUs. In particular, DEA identifies efficient facet being used for comparison as well as a combination of the inputs which are being inefficiently utilized and the derivation of specific outputs from the efficient level. Because efficient DMUs do not have any slack, this information is only of interest of inefficient DMUs. Table 4 provides the BCC and CCR model reference results for the inefficient terminals.

For every inefficient terminal the peer group consists of efficient units and a set of targets for the inefficient unit is provided at the frontier. These targets are obtained by a pro rata increase in the outputs of the inefficient terminal. Based on the result presented in Table 4 the reference set for Bao Shan container terminal are WaiGaoQiao Phase 1, Busan Gamman Korea Express and Keppel terminal in BCC model and WaiGaoQiao Phase 1 and Keppel Terminal in CCR model identified by linear combination of units in the set while maintaining the same output level.

For container terminals like Gwangyang Hutchison, Gwangyang Global, Gwangyang Dongbu the pro rata increase leads to the set of targets of Gwangyang Hanjin for BCC model and WaiGaoQiao Phase 1 for CCR model. However, Gwangyang Hutchison, Gwangyang Global and Gwangyang Dongbu are clearly dominated by Gwangyang Hanjin in BCC and WaiGaoQiao Phase 1 in CCR model respectively. Returning to BaoShan container terminals the set of targets have been obtained from a weighted average of peer units WaiGaoQiao Phase 1, Busan Gamman Korea Express and Keppel terminal. Similarly, the reference sets for rest of the inefficient terminals are determined.

The difference in the number of reference set for inefficient terminals with respect to CCR and BCC model is in the projection path to the efficient frontier for an inefficient DMU. The CCR model results in a constant returns-to-scale, piece-wise linear envelopment surface with both input and output orientations for projection path. The BCC model provides a variable returns to scale, piece-wise linear envelopment surface, similar orientation with CCR model.

Table 4 Reference Set

DMUs (Inefficient)	BCC reference set	CCR reference set
Zhang Hua Bang	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	Busan Gamman Korea Express	WaiGaoQiao Phase 2,3
	Keppel Terminal	Keppel
Jun Gong Lu	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	Busan Gamman Korea Express	Keppel
	Keppel Terminal	
Bao Shan	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	Busan Gamman Korea Express	Keppel
	Keppel Terminal	
WaiGaoQiao Phase 4	WaiGaoQiao Phase 2,3	WaiGaoQiao Phase 2,3
	Busan Gamman Korea Express	Busan Gamman Korea Express
Busan Jasungdae	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	WaiGaoQiao Phase 2,3	Busan Gamman Korea Express
	Keppel Terminal	Keppel
Busan Shinsundae	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	WaiGaoQiao Phase 2,3	WaiGaoQiao Phase 2,3
	Busan Gamman Korea Express	
Busan Gamman Hanjin	No reference set	WaiGaoQiao Phase 1
		WaiGaoQiao Phase 2,3
		Busan Gamman Korea Express
Busan Gamman Hutchison	Busan Gamman Koera Express	No reference set
Busan Gamman Global	Busan Gamman Hanjin	WaiGaoQiao Phase 1
		WaiGaoQiao Phase 2,3
		Busan Gamman Korea Express
Busan Sin Gamman	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	Busan Gamman Korea Express	Keppel
	Keppel Terminal	
Busan U-am	Busan Gamman Korea Express	WaiGaoQiao Phase 1
	Jurong	Keppel
	Keppel	

Gwangyang Gamcheon Hanjin	No reference set	WaiGaoQiao Phase 1
		Keppel
Gwangyang Korea Express	Busan Gamman Hanjin	WaiGaoQiao Phase 1
		WaiGaoQiao Phase 2,3
		Busan Gamman Korea Express
Gwangyang Hutchison	Gwangyang Hanjin	WaiGaoQiao Phase 1
Gwangyang Global	Gwangyang Hanjin	WaiGaoQiao Phase 1
Gwangyang Dongbu	Gwangyang Hanjin	WaiGaoQiao Phase 1
Gwangyang KIT	WaiGaoQiao Phase 1	WaiGaoQiao Phase 1
	WaiGaoQiao Phase 2,3	
	Keppel	
Brani	WaiGaoQiao Phase 1	Busan Gamman Korea Express
	WaiGaoQiao Phase 2,3	Keppel
	Keppel	
Pasir Panjang	WaiGaoQiao Phase 1	Busan Gamman Korea Express
	WaiGaoQiao Phase 2,3	Keppel
	Keppel	
Tanjong Pagar	WaiGaoQiao Phase 1	Busan Gamman Korea Express
	WaiGaoQiao Phase 2,3	Keppel
	Keppel	

5. Conclusion

In this paper an attempt is made to evaluate the efficiency of container terminals in China, Korea and Singapore by applying DEA analysis. The efficiency results are obtained depending on the output orientation of container terminals and the envelopment surface. The two basic types of envelopment surfaces in DEA are 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. The benchmarks for inefficient terminals are another source in DEA that enables the managers to make strategies for improvement of inefficient terminals.

The numbers of efficient container terminals that are identified by VRS model are more than that of CRS model and the efficiency score is also consistently higher in the VRS model due to variation in returns-to-scale because CCR fits linear production technology and BCC features variable returns-to-scale. The number of DRS, IRS and CRS for Busan and Gwangyang are 7, 6 and 2 out of which the number of DRS is higher for Gwangyang terminals showing considerable diseconomies of scale.

The Singapore container terminals are found to be most efficient terminals among the sample of terminals evaluated with 3 IRS and 2 CRS without any DRS signifying absence of any diseconomies of scale. It is recommended that improvement of productivity of Gwangyang container terminals of Korea should be given priority in order to gain competitive advantage over the neighbouring terminals.

This paper has checked the efficiency measurement of China, Korea and Singapore container terminals using BCC and CCR model but realignment of additional model is recommended where elimination of input or output factors can provide some interesting results in the efficiency of container terminal productivity.

Simple radial measure used in this research may produce some bias results upon which cross sectional or panel data can be used to get a comprehensive picture on technical efficiency. Further research concentrating on data quality and environmental factors might give some interesting results.

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Appendix

Results of Slack

No.	DMU	Score	Excess No of berth S-(1)	Excess Length(m) S-(2)	Excess Total area(m^2) S-(3)	Excess G/C S-(4)	Excess TEU in 2004 S+(1)
1	Zhang Hua Bang	0.59845094	0.2640884	40.6339052	0	0	0
2	Jun Gong Lu	0.83998824	1.55414365	167.056412	0	0	0
3	Bao Shan	0.94488255	1.54530387	185.192207	0	0	0
4	WaiGaoQiao Ph 1	1	0	0	0	0	0
5	WaiGaoQiao Ph 2, 3	1	0	0	0	0	0
6	WaiGaoQiao Ph 4	0.34846142	0	0	384312.5	1.75	0
7	Busan Jasungdae Container	0.53130266	0	137.956172	0	1.3244186	0
8	Busan Shinsundae	0.60915068	9.26E-02	0	0	1.55960255	0
9	Busan Gamman Hanjin	1	0	0	0	0	0
10	Busan Gamman Hutchison	0.82471518	0	0	0	0	0
11	Busan Gamman Global	0.88920542	0	0	0	0	0
12	Busan Gamman Korea Express	1	0	0	0	0	0
13	Busan Sin Gamman	0.55694049	0.54972376	134.676941	0	0	0
14	Busan U-am Container	0.57345001	1.57222408	51.3694589	0	0	0
15	Busan Gamcheon Hanjin	1	0	0	0	0	0
16	Gwangyan Korea Express	0.61950366	0	0	27250	0	0
17	Gwangyang Hutchison	0.52363658	0	0	0	0	0
18	Gwangyang Hanjin	1	0	0	0	0	0
19	Gwangyang Global	0.82934767	0	0	0	0	0
20	Gwangyang Dongbu	0.4686966	0	0	0	0	0
21	Gwangyang KIT	5.12E-02	2.93153153	754.756757	0	0	0
22	Jurong	1	0	0	0	0	0
23	Brani Terminal	0.94686064	0	454.769231	0	6.5	0
24	Keppel Terminal	1	0	0	0	0	0
25	Pasir Panjang Terminal	0.84392448	0	738.105546	0	23.0697674	0
26	Tanjong Pagar Terminal	0.91719885	0	332.044723	0	9.04651163	0