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Application of DEA on the measurement of operating efficiencies for east-Asia major container terminals

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Abstract: As the competition among East Asia container terminals has become increasingly fierce, every terminal is striving to increase its investments constantly to maintain the competitive edge. The unreasoning behavior, however, has induced that substantial waste and inefficiency exists in production. From this perspective, data envelopment analysis provides a more appropriate benchmark. By applying three kinds of DEA models, this study acquires a variety of analytical results on operational efficiency of the 31 major container terminals. Firstly, this study finds the reason of inefficiency. It is followed by identification of the potential areas of improvement for inefficient terminals by applying slack variable method. Furthermore, return to scale approach is used to assess whether each terminal is in a state of increasing, decreasing, or constant return to scale. The results of this study can provide container terminal managers with insights into resource allocation and optimization of the operating efficiency.

Keywords: Efficiency, Container Terminal, Data Envelopment Analysis

1. Introduction

In recent years, with rapid expansion of global business and international trade, one distinctive feature of the current container terminal industry is that competition among container terminals is more intensive than previously.

Port markets used to be perceived as monopolistic due to the exclusive and immovable geographical location of the port and the unavoidable concentration of port traffic. However, the rapid development of international container and intermodal transportation has drastically changed the market structure from one of monopoly to one where fierce competition is prevalent in many parts of the world. Many container ports no longer enjoy the freedom yielded by a monopoly over the handling of cargoes from their hinterland. Instead, they have to compete for cargo with their neighboring ports (Cullinane, et al., 2006).

To maintain its competitiveness in such competitive condition, Kevin Cullinane et al. (2006) claimed that container terminals have to invest heavily in sophisticated equipment or in dredging channels to accommodate the most advanced and largest container ships in order to facilitate cost reductions for the container shipping industry.

It is important to note, however, that pure physical expansion is constrained by a limited supply of available land, especially for urban center terminals, and escalating environmental concerns. In addition, the excessive and inappropriate investment also can induce the phenomenon of inefficiency and wasting of resources. In this context, improving the productive efficiency of container terminal (Le-Griffin et al., 2006) appears to be the viable solution.

Realizing the facts, port authorities have shown great interest in efficient terminal management. Thus, they are continually searching for strategies to meet growing demands by utilizing their resources reasonably.

In this context, it is essential that how to rationally utilize the existing infrastructures in order to achieve a desired result that outputs have been maximized given the inputs, as well as find the potential areas which should be improved immediately for inefficiency terminals.

For a container terminal, productivity performance makes significant contribution to the prospects of survival and competitive advantage. It is also an important tool in informing port authorities and operators port planning. Traditionally, the productivity of container terminals has been variously evaluated by numerous attempts at calculating and seeking to improve or optimize the operational productivity of cargo-handling at berth and in the container yard.

If container terminals can conduct effective evaluation of their productivity performance to enhance the efficiency of productivity, it will provide more valuable information for terminal managements in their attempts to establish competitive strategies for the future and to improve their resource utilization for ongoing improvements in operational efficiency.

From this perspective, data envelopment analysis model provides a more appropriate benchmark for the container terminal. The aim of this study is assumed to be the minimization of the use of input(s) and maximization of the output(s), by applying with DEA-CCR, DEA-BCC, and DEA-Super- Efficiency, three models, to acquire a variety of analytical results about the productivity efficiency for the thirty-one Chinese and Korean major container terminals.

According to efficiency value analysis, this study firstly identifies efficient container terminals and ranks the sequence of them, then finds the reason of inefficiency ones. It is followed by identification of the potential areas of improvement for inefficient terminals by applying slack variable method. Return to scale approach is used to assess whether each terminal is in a state of increasing, decreasing, or constant return to scale. Finally, by comparing the efficiency scores between Chinese and Korean container terminals, the study can identify which input or output variables are more critical to the models, and would more impact the efficiency of terminals.

The paper is structured as follows: after the introductory section of Chapter 1, there will be followed by the description of three data envelopment analysis (DEA) models. In so doing, the four main approaches to applying DEA to analyze data are included in Chapter 2. The required definition of input/ output variables and the data collection have been described in Chapter 3. Estimates of the efficiency of a sample of container terminals are derived in Chapter 4. Finally, conclusions are drawn in Chapter 5.

2. Research Method

2.1. Data Envelopment Analysis (DEA)

DEA can be roughly defined as a nonparametric method of measuring the efficiency of a Decision Making Unit (DMU) with multiple inputs and/or multiple outputs. This is achieved by constructing a single ‘virtual’ output to a single ‘virtual’ input without pre-defining a production function. The term DEA and the CCR model were first coined in Charnes et al. (1978) and were followed by a phenomenal expansion of DEA in terms of its theory, methodology and application over the last few decades. The influence of the CCR paper is reflected in the fact that by 1999 it had been cited over 700 times.

Among the models in the context of DEA, the two DEA models, named CCR (Charnes, et al., 1978) and BCC models (Banker, et al., 1984) have been widely applied. The CCR model assumes constant returns to scale so that all observed production combinations can be scaled up or down proportionally. The BCC model, on the other hand, allows for variable returns to scale and is graphically represented by a piecewise linear convex frontier.

Because the CCR model gives a value of 1 for all efficient DMUs, it is unable to establish any further distinctions among the efficient DMUs. Andersen, P. and Petersen, N. C., (1993), therefore, presented Super-efficiency model which removes an efficient DMU, and then estimates the production frontier again and provides a new efficiency value for the efficient DMU that had previously been removed. The new efficiency value can thus be greater than 1, and the efficiency values of inefficient DMUs do not change.

In recent years, DEA has been increasingly used to analyze seaport production. Compared with traditional approaches, DEA has the advantage that it can cater for multiple inputs and outputs from the production process. This accords with the characteristics of port production, so that there exists, therefore, the capability of providing an overall summary evaluation of container terminal performance (Kevin Cullinane et al, 2007). The DEA methodology has been applied to the evaluation of container terminal performance in the previous literature. For example, Barros and Athanassiou (2004) apply DEA to the estimation of the relative efficiency of a sample of Portuguese and Greek container terminals. Jin (2011) analyzed the relative efficiencies of the container terminal operation in the port of Busan and Gwangyang using BCC-DEA with data from 2002 to 2004. The results show that the container terminals of Gamman and Uam are found to be the most efficient terminals in 2002, 2003 and 2004. Husong (2011) apply both DEA and Stochastic Frontier Analysis (SFA) to the same set of container port data for the world's largest container ports and compare the results obtained. A high degree of correlation is found between the efficiency estimates derived from all the models applied, suggesting that results are relatively robust to the DEA models applied or the distributional assumptions under SFA. Lu (2011) measured the operational efficiency of container terminals in South Korea relative to prior periods and relative to their competitors. DEA was utilized in a study conducted by Cullinane et al. (2005) focusing on the relation between privatization and container port efficiency. There is also DEA based research concerning port performance of specified countries. Dong (2011) attempted in applying DEA to assess and rank the efficiencies of terminals. Their aim was to analyze the relative efficiency of operations in container terminals of the Mercosur between 2002 and 2004 using DEA-BCC.

However, most previous studies have adopted two basic models of DEA (CCR & BCC model) to obtain aggregate efficiency, technical efficiency and scale efficiency. In contrast, this study applies DEA-CCR, DEA-BCC, and DEA-Super Efficiency, three models, to acquire a variety of analytical results about the productivity efficiency of container terminals. Instead of domestic scale, this research is conducted in Chinese and Korean container terminals.

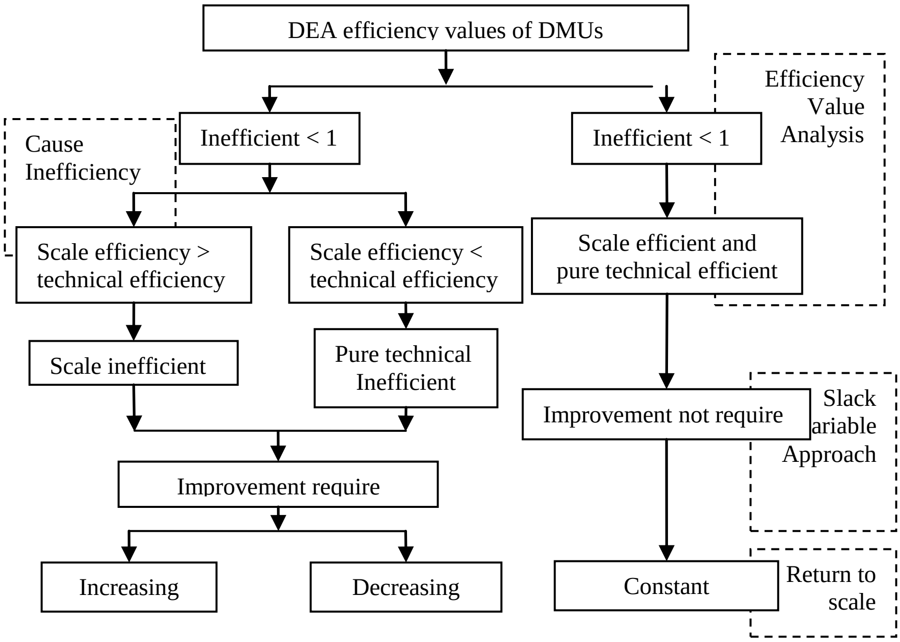

Fig. 1: Flow process of DEA analyses.
Source: Authors of the original source

In this study, the DEA model includes four types of analytical approaches. With respect to the efficiency value analysis, when technical efficiency is less than 1, that is technically inefficient, this means that the efficiency of the inputs and outputs being used are not appropriate, and that it is necessary to decrease inputs or increase outputs. However, when the scale efficiency is less than 1, that is scale inefficient, it means that the operational scale is not achieving an optimal value, and that the operational scale should be enlarged or reduced (based on the return to scale). In addition, it is possible to compare the technical efficiency value with the scale efficiency value, with the smaller value of the two indicating the major cause of inefficiency. Furthermore, the slack variable analysis handles the utilization rate of input and output variables. It does this by assessing how to improve the operational performance of inefficient DMUs by indicating how many inputs to decrease, and/or how many outputs to increase, so as to render the inefficient DMUs efficient. In summary, the flow process of multiple DEA analyses can be depicted as shown in figure 1.

2.2. Research Procedure

The research procedure of this study is summarized in figure 2. After the selection of container terminals, the output variable for the study should be selected firstly. Drawing on the literature review, site survey & interview, and Brainstorming to eliminate the duplication factors, the initial inputs/outputs variables can be chosen.

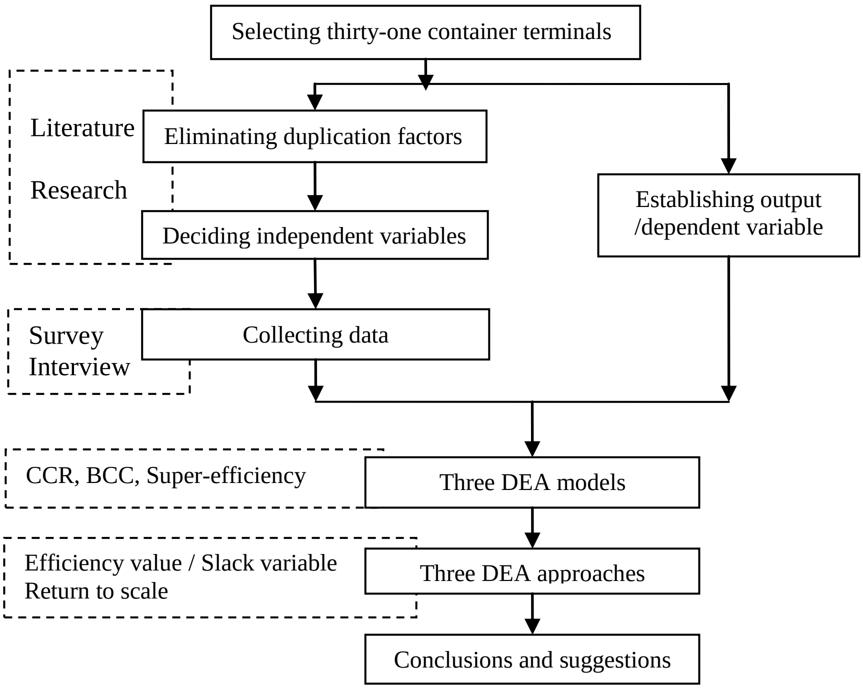

Fig. 2: Research procedure.
Source: Authors of the original source

Then, in order to provide a more comprehensive picture of research, and for the purpose of finding the operational efficiency value, an exploration composed of the CCR, BCC and Super-efficiency DEA models and four analytical approaches which include efficiency value analysis, slack variable method, return to scale approach and sensitivity analysis have been applied. After that, the evaluation results and suggestions will be given.

3. Result Analysis

3.1. Data Collection

Because it is difficult to acquire data on international container terminals, most of the previous documents have focused on the evaluation of container terminals within a single country. For doing a typical analysis, the data sample comprises the thirty-one Chinese and Korean major container terminals, including 14 Chinese major container terminals: Shanghai-Waigaoqiao, Yangshan; Hong Kong-COSCO, MTL, HIT, DPI and ACT; Shenzhen-Shekou, Chiwan, Yantian and Nansha; Ningbo-CS-4, NBCT and NBSCT; and 17 Korean major terminals: Busan-INTERGIS, HGCT, BICT, KBCT, HBCT, DPCT, UTC and Hanjin; Gwangyang-KX3-1, DBE2-1, HKTL, GICT1 and KIT2-2; Incheon-ICT, SGCT, Ulsan and JUCT; Pyeongtaek-PCTC. Thus, it has facilitated the acquisition of more reliable, on a comprehensive scale.

3.2. Standardization of Variables

In order to gain the accurate performance of container terminals, the value of input and output variables should be standardized.

Therefore, this study defines the input and output of each container terminal at the level of per berth which is applied with the published data by inner report, except the berth length still keeping the actual values. The standardization formula can be summarized as:

$$\frac{Input/Output\ Variable}{Berth\ Number} = Input/Output\ Variables\ per\ berth \quad (1)$$

Formula 1: Variable standardization formula

Source: Authors of the original source

3.3. Definitions of variables

With respect to definitions of variables, a thorough discussion of the importance, difficulties and potential impact of variable definition can be found in (Song et al, 2003) and summarized as follows. Because of the most container terminals rely heavily upon sophisticated equipments and information technology, rather than being labor-intensive (Kevin Cullinane et al, 2005), the input and output variables should reflect the actual objectives and process of container terminal production as accurately as possible.

In the DEA analysis, the output variables measure various organizational objectives, such as productivity and customer response. In applying DEA analysis to container terminal, suitable productivity indicators that could be considered for evaluation of container terminal operations include: throughput, berth occupancy rate, berth occupancy, number of vessel arrivals and so on.

However, container throughput is the most important and widely accepted indicator of container terminal output. Almost all previous studies treat it as an output variable because it closely relates to the need for cargo-related facilities and services and is the primary basis on which container terminals are compared, especially in assessing their relative size, investment magnitude or activity levels. Most importantly, it also forms the basis for the revenue generation of a container terminal (Cullinane, et al., 2005). Another consideration is that container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a container terminal. Synthesizing the former research, in this study, the terminal productivity indicator is defined as the per berth handling capacity by dividing annual throughput by number of berth.

On the other hand, with respect to input variables, there are various general factors impacting terminal productivity, which can be distinguished from facilities, equipments, technology, business activities and working time. Figure 3 simply shows related factors which affect container terminal production.

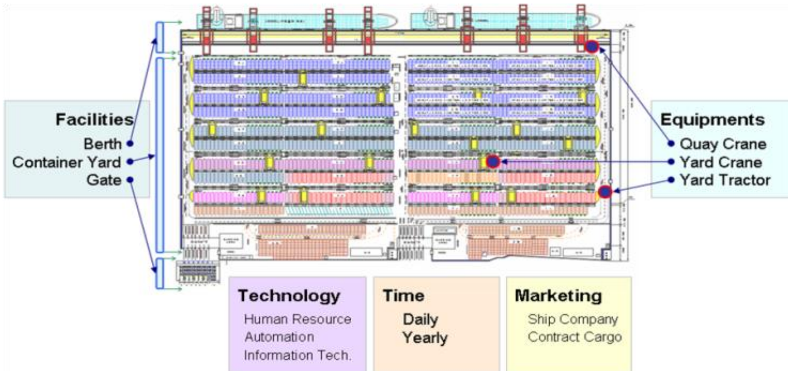

Fig. 3: The scope of variables.
Source: Authors of the original source

In order to determine the input variables, the used factors for variables in the study are discovered through an abundant literature review, discussion with experts working in container terminals for more than 20 years, and brainstorming, all factors that relevant to container terminal operation, are to be considered such as terminal facilities like yard area, number of berth, water depth, length of berth, gate, rail station etc.; container terminal equipments like Y/T, Q/C, RTGC, RMGC, reach stacker, top handler and folk lifter etc; human resource, information technical etc.

However, as far as the process of container terminal production is concerned, a container terminal depends crucially on the efficient use of infrastructures and facilities. On the basis of that, yard area per berth, the quantities of quay crane, yard crane, yard tractor per berth, water depth and berth length have been deemed to be the most suitable factors to be incorporated into the models as input variables. The discussion about the inputs has been summarized on the figure 4. Other input factors that possibly influence the efficiency estimates that may be derived from this analysis include aspects such as: crane operating hours, equipment age and maintenance, and port information etc. The selection of suitable variables for this study, however, depended on data availability, and the difficulties on acquiring data. Therefore, they have not been included in this study.

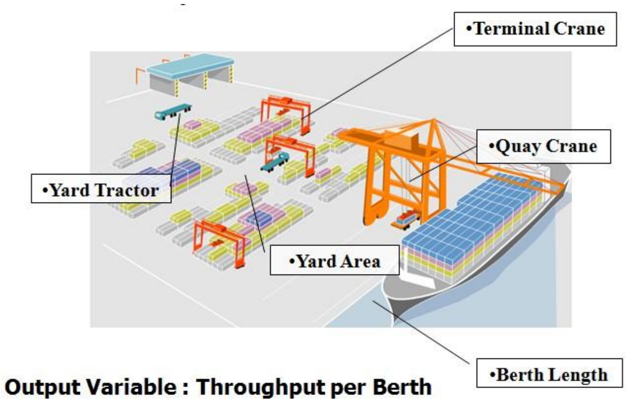

Fig. 4: Definition of input variables.
Source: Authors of the original source

Table 1: Data collection of Chinese major container terminals.
Source: First-hand data of 14 Chinese container terminals by author.

Variables / Terminals	Inputs						Output
	Yard area per berth	QC per berth	TC per berth	YT per berth	Berth length	Water depth	Throughput per berth
Hong Kong							
COSCO	150,000	4.0	16.0	37.5	320	14.5	877,000
MTL	132,300	4.3	15.1	27.7	347	15.5	817,143
HIT	92,500	4.1	11.8	23.3	307	14.9	692,083
DPI	167,000	4.0	8.0	50.0	305	14.0	589,000
ACT	142,700	4.0	10.0	30.0	370	15.5	588,000
Shen Zhen							
Shekou	173,300	4.1	10.5	23.3	281	16.0	700,000
Chiwan	138,400	4.1	12.0	23.3	380	15.3	655,556
Yantian	168,000	4.9	14.0	30.7	406	16.0	640,000
Nansha	371,700	3.0	8.0	15.0	350	15.5	333,333
Ning Bo							
CS-4	200,000	3.6	11.2	20.4	350	17.0	700,000
NBCT	252,300	3.3	10.7	16.7	300	14.5	600,000
NBSCT	175,000	4.0	14.5	27.5	315	14.5	600,000
Shang Hai							
WQ-2	334,000	5.0	15.6	33.0	313	13.2	1,058,000
YS-1&2	278,900	3.8	13.3	24.4	333	16.0	633,333
Average	198,293	4.0	12.2	27.3	334	15.2	677,389

Table 2: Data collection of Korean major container terminals.
Source: First-hand data of 17 Korean container terminals by author.

Variables / Terminals	Inputs						Output
	Yard area per berth	QC per berth	TC per berth	YT per berth	Berth length	Water depth	Throughput per berth
Busan							
INTERGIS	162,750	4.0	19.0	24.0	350.0	15.0	768,459
HGCT	149,000	4.0	13.0	23.0	350.0	15.0	650,570
BICT	148,768	3.5	16.0	17.0	350.0	15.0	632,997
KBCT	228,918	2.8	9.2	14.6	300.0	15.0	468,353
HBCT	129,400	2.8	6.8	12.6	289.4	12.5	420,594
DPCT	123,200	2.8	10.8	14.4	330.4	15.0	409,165
UTC	123,333	3.3	10.0	16.0	333.3	11.0	284,868
Hanjin	74,000	2.5	6.5	11.5	300.0	13.4	279,569
Gwangyang							
KX3-1	210,000	3.0	8.0	12.0	350.0	15.0	403,603
DBE2-1	206,984	2.0	5.0	15.0	350.0	16.0	166,371
HKTL	210,000	2.0	6.0	15.0	350.0	16.0	124,590
GICT1	210,000	2.5	8.5	11.5	350.0	15.0	76,120
KIT2-2	175,600	2.0	3.8	4.0	390.0	15.5	51,638
Incheon							
ICT	68,886	3.0	6.5	7.0	300.0	14.0	172,448
SGCT	122,273	1.5	3.5	4.0	203.5	11.0	14,772
Ulsan							
JUCT	84,275	3.0	7.0	7.0	220.0	13.0	169,952
Pyeongtaek							
PCTC	96,000	2.0	6.0	10.0	240.0	11.0	355,991
Average	148,435	2.7	8.6	12.9	315.1	14.0	320,592

4. Efficiency Analysis and Implication

4.1. Efficiency Results Derived from DEA Models

As with using the data of thirty-one Chinese and Korean major container terminals by applying with DEA approaches, for proving the production function of container terminals exhibits either constant or variable returns to scale, the DEA-CCR and DEA-BCC models are chosen from among several DEA models to analyze terminal efficiency. However, conventional DEA model which distinguishes between efficient and inefficient DMUs in a homogeneous group does not provide more information about efficient units (Amirteimoori, et al., 2010). To discriminate between these efficient DMUs, DEA-Super-Efficiency, as a reinforcement of DEA-CCR, is adopted to rank the performance of efficient terminals according to their super-efficiency scores.

The efficiency analytical results for container terminals are summarized in table 3, and the following observations can be made. The column and row totals represent, respectively, the efficiency value of each port and the condition of return to scale in 2008 year.

It is clear from table 3 that, the DEA-CCR model yields lower average efficiency estimates than the DEA-BCC model, with respective average values of 0.783 and 0.939, where an index value of 1.000 equates to perfect (or maximum) efficiency. This result is reasonable since a DEA model with an assumption of constant returns to scale provides information on pure technical and scale efficiency taken together, while a DEA model with the assumption of variable returns to scale identifies technical efficiency alone. DEA-Super-Efficiency model which removes an efficient DMU, and then estimates the production frontier again and provides a new efficiency value that can be greater than 1. Therefore, the average efficiency value of Super-Efficiency model, 0.815 is greater than CCR model.

By using of efficiency value analysis, slack variable approach, return to scale method and sensitivity analysis, the analytical results can be summarized as:

Firstly, the aggregate efficiency value acquired from the CCR model of Waigaoqian phase-2, HIT, COSCO, BICT, DPI, MTL, Shekou, PCTC, NBCT, CS-4 and INTERGIS terminals were all equal to 1 in 2008 year. The efficiency values of other terminals in that year were less than 1, which indicated that they were relatively inefficient terminals. The 'pure technical efficiency value' obtained from the BCC model represented the efficiency in terms of the usage of input resources. If a terminal has an efficiency value equal to 1 in the CCR model, the value of its pure technical efficiency would also be equal to 1. However, if the efficiency value on the CCR model is less than 1, a comparison could be made between the pure technical efficiency value and the scale efficiency value, thus allowing a judgment to be made about whether the inefficiency is caused by an inefficient application of input resources or an inappropriate production scale.

All of the pure technical efficiency values of the Waigaoqiao phase-2, HIT, COSCO, DPI, MTL, Shekou, PCTC, NBCT, CS-4, INTERGIS, HBCT, KX3-1, KBCT, Hanjin, ICT, JUCT, UTC, KIT2-2 and SGCT terminals were equal to 1 in 2008 year. The technical efficiency values of other terminals were less than 1, thus indicating that they would need to improve their usage of resources. Among these, GICT phase-1 terminal had the least pure technical efficiency value in 2008 year.

Then, the DEA-Super-efficiency model is utilized to reinforce the discriminatory power of the CCR model. Waigaoqian phase-2 has the best performance among these thirty-one container terminals in 2008 year. HIT and

COSCO terminals ranked as the second and third best in this model, respectively and the score of the two terminals are more than 1.100. Moreover, the scores of BICT, DPI, MTL, Shekou, PCTC, NBCT, CS-4 and INTERGIS also exceed 1.000. However, Incheon SGCT terminal has the lowest score which was 0.100.

The slack variable analysis, showed that HIT, COSCO, MTL, DPI, Shekou, NBCT, CS-4, Waigaoqian phase-2, INTERGIS, BICT and PCTC terminals had been relatively efficient in the 2008 year; their ratios of input variables to output variable were appropriate, and they were capable of applying their input resources effectively to achieve enhanced efficiency. In contrast, the terminals of ACT, Yantian, Chiwan, Nansha, NBSCT, YS-1&2, HGCT and GICT 1 terminals were relatively inefficient as a result of inappropriate application of input resources. KBCT, HBCT, Hanjin, DPCT, UTC, KIT2-2, KX3-1, HKTL, DBE2-1, ICT, SGCT and JUCT terminals were also relatively inefficient; however, in these cases, an inappropriate production scale was the cause of the inefficiency. The results indicated that Nansha, YS-1&2, KBCT, KIT2-2, KX3-1, HKTL, GICT1, DBE2-1, ICT, SGCT and JUCT terminals should have adjusted their yard area of container base in 2008 year. Nansha, HBCT, UTC, KIT2-2, KX3-1, ICT and JUCT terminals have adjusted their number of quay crane in 2008 year. YS-1&2 and JUCT terminals have adjusted their number of terminal crane in 2008 year. Yantian and HKTL terminals should have adjusted their number of yard tractor in 2008 year. ACT, Yantian, Chiwan, Nansha, YS-1&2, HBCT, Hanjin, DPCT, UTC, KIT2-2, KX3-1, HKTL, DBE2-1, ICT and JUCT terminals should have adjusted the length of their container berth in 2008 year. Nansha, YS-1&2, KBCT, HBCT, Hanjin, DPCT, KIT2-2, KX3-1, HKTL, DBE2-1, ICT and JUCT should have adjusted the deep-water of piers. In addition to adjusting and improving the input variables, each inefficient terminal should have increased their loading/unloading volumes if they were to reach a relatively efficient state.

After finding out the inefficient reasons, the inefficient terminal should make an adjustment to reach efficient performance. With respect to the return to scale analysis, Waigaoqiao phase-2, HIT, COSCO, DPI, MTL, Shekou, NBCT, CS-4, INTERGIS and Chiwan terminals were relatively efficient terminals in 2008 year and had constant return to scale. Apart from constant return to scale, all of other container terminals exhibited increasing returns to scale.

Table 3: Efficiency under three DEA Models.

Models / Terminals	Efficiency			Reasons of inefficiency		Return to scale
	Score					
	CCR efficiency	Super efficiency	Rank	BCC efficiency	Scale efficiency	
WQ-2(C)	1.000	1.343	1	1.000	1.000	Constant
HIT(C)	1.000	1.211	2	1.000	1.000	Constant
COSCO(C)	1.000	1.130	3	1.000	1.000	Constant
BICT(K)	1.000	1.091	4	1.000	1.000	Constant
DPI(C)	1.000	1.088	5	1.000	1.000	Constant
MTL(C)	1.000	1.031	6	1.000	1.000	Constant
Shekou(C)	1.000	1.030	7	1.000	1.000	Constant
PCTC(K)	1.000	1.028	8	1.000	1.000	Constant
NBCT(C)	1.000	1.027	9	1.000	1.000	Constant
CS-4(C)	1.000	1.012	10	1.000	1.000	Constant
INTERGIS(K)	1.000	1.005	11	1.000	1.000	Constant
HBCT(K)	0.981	0.981	12	1.000	0.981	Increasing
KX3-1(K)	0.933	0.933	13	0.936	0.997	Increasing
Chiwan(C)	0.907	0.907	14	0.908	1.000	Increasing
KBCT(K)	0.903	0.903	15	0.909	0.994	Increasing
ACT(C)	0.901	0.901	16	0.915	0.985	Increasing
HGCT(K)	0.893	0.893	17	0.901	0.992	Increasing
DPCT(K)	0.805	0.802	18	0.819	0.979	Increasing
YS-1&2(C)	0.800	0.799	19	0.831	0.962	Increasing
Hanjin(K)	0.759	0.750	20	1.000	0.750	Increasing
NBSCT(C)	0.746	0.746	21	0.860	0.867	Increasing
Yantian(C)	0.743	0.743	22	0.800	0.929	Increasing
ICT(K)	0.663	0.663	23	1.000	0.663	Increasing
Nansha(C)	0.656	0.657	24	0.729	0.900	Increasing
JUCT(K)	0.652	0.652	25	1.000	0.652	Increasing
UTC(K)	0.538	0.538	26	1.000	0.538	Increasing
DBE2-1(K)	0.482	0.482	27	0.922	0.522	Increasing
KIT2-2(K)	0.347	0.347	28	1.000	0.347	Increasing
HKTL(K)	0.304	0.304	29	0.830	0.366	Increasing
GICT1(K)	0.182	0.182	30	0.733	0.248	Increasing
SGCT(K)	0.100	0.100	31	1.000	0.100	Increasing
Average	0.783	0.815		0.939	0.831	

4.2. Implication of Efficiency Value Analysis

4.2.1. Implication by Throughput

For making a concrete analysis for the integral empirical results, table 3 reports the efficiency estimates for three DEA models, an estimate of the scale efficiency and, based on this, the returns to scale classification of each container terminal.

11 out of the 31 terminals included in the analysis are identified as efficient when the DEA-CCR model is applied.

Table 3 also reports the scale properties of port production yielded by DEA models. Of the 31 terminals, 12 exhibit constant returns to scale, and 19 exhibit increasing returns to scale. Among those large terminals (classified as having annual container throughput per berth of more than 0.5 million TEU), 11 of 16 show constant return to scale, other large terminals show increasing return to scale. On the other hand, all of the small terminals, except PCTC terminal, having annual container throughput of less than 0.5 million TEU, exhibit an increasing returns to scale.

Although a rather arbitrary dichotomous classification of the sample has been made between large and small terminals on the basis of a cut-off throughput of 0.5 million TEU per annum, these results do suggest an association between large terminals and constant returns to scale and between small terminals and increasing returns to scale. On the other hand, the terminals that exhibit constant returns to scale are only large terminals.

These findings can be found in (Cullinane K., 2005) and probably explained by a combination of the abundant nature of container terminal investment, the consequent commercial risks involved and the level of competition in the market. The sample of large terminals will probably have evolved as the result of successfully pursuing strategies aimed at attaining container hub status. In order to attract more container ships to anchor their terminals and enhance the technical efficiency of their operations, this would inevitably mean that these terminals have, over the years, invested heavily in expensive and ever more advanced equipments. Having achieved a certain level of operational scale, large terminals are eventually faced with potential limits to their further growth. There may even be physical constraints such as the unavailability of land to facilitate any further expansion. At the very least, the decision to opt for further investment in throughput capacity is deferred until such point that all potential sources of improved technical efficiency have been utilized. At the other end of the scale, terminals with lower throughput levels are also likely to have the objective of attaining or maintaining hub status. As implied above, this requires a certain minimum scale of operation, however, whereby network connectivity between mainline and feeder services can be facilitated. Meanwhile, small terminals need not necessarily face any greater difficulty than large terminals in gaining access to the requisite capital resources to make major investments in infrastructure. Hence, the risks associated with such investments are concomitantly less, even though they bring about significant proportionate growth in design capacity.

4.2.2. Implication by China and Korea

To analyze efficiency as the divisional criterion by countries, there is an important phenomenon should be paid attention to the efficiency scores of container terminals.

With respect to the analytical results of the aggregate efficiency value acquired from the CCR model, besides Busan BICT terminal, the five best efficient container terminals are all from China. From the angle of aggregate efficiency, the results about the status of efficient and inefficient in thirty-one container terminals have been summarized by the figure 5, except the three efficient terminals (BICT, PCTC and INTERGIS), most Korean terminals are relative inefficient. On the contrary, the numbers of efficient Chinese terminals are similar with the inefficient Chinese terminals.

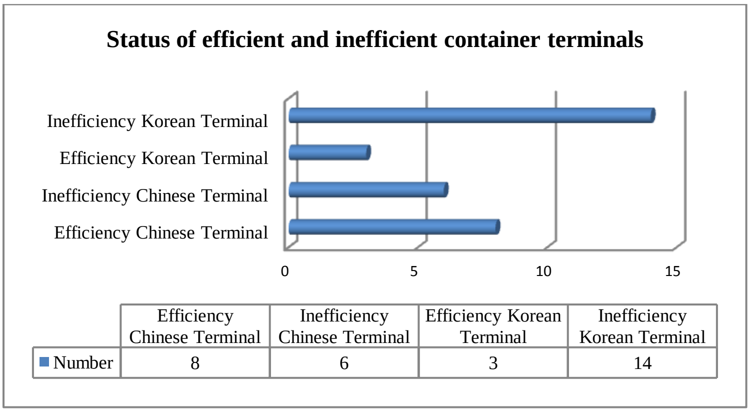

Fig. 5: Status of efficient and inefficient container terminals.

In addition, this study goes on to compare the three kinds values of DEA models between Chinese terminals and Korean terminals respectively. With respect to DEA-CCR model, the aggregate efficiency values of Chinese terminals are higher than Korean terminals obviously. With regard to pure technical efficiency, the performance of Korean terminals is better than Chinese terminals, and the reason can be summarized by:

During the first decade of the twenty-first century, international trade has increased rapidly for the expanding industrial economies of China. An overwhelming majority of this increasing international trade is conducted by sea transportation; therefore, the huge investments of equipments have been put into the container terminals production. In addition, taking geographic advantage of huge area and respective cheap cost, and the rapid development of international container and intermodal transportation of Chinese container terminal production has drastically changed the market structure, and then attracted more customers and the cargo. The enough quantities of equipments, quay crane, yard crane etc. and optimal scale of berth length, yard area etc. has strongly impacted on the productivity of container terminals. Therefore, the efficiency of Chinese container terminals is relatively higher than that of Korean container terminals in 2008.

5. Conclusions

For the container terminals in the competitive circumstances, efficiency is an important concept and concerned with how to use limited resources more economically for any sort of production. As a benchmarking approach to study efficiency, DEA enables a terminal to evaluate its performance from each other in DMUs. By doing this, the possible waste of resources and the industry best practice can be identified.

This study has investigated the fundamentals of DEA and demonstrated how DEA can be applied to measure the efficiency of container terminals. The most frequently used DEA models, including DEA-CCR, DEA-BCC and DEA-Super efficiency models that respectively correspond to the assumptions of constant returns to scale and variable returns to scale of port production, are applied to analyze both Chinese and Korean data related to port production.

By using the range of DEA models, this study has evaluated the thirty-one container terminals of China and Korea, and in the process has acquired varied and complementary conclusion from the different models. The study has made efficiency value analysis, and has established a return to scale to compare the technical efficiency value with the scale efficiency value, with the lesser of the two indicating the major cause of inefficiency for each terminal. Moreover, using slack variable analysis, the study has provided useful information that indicates how relatively inefficient container terminal can improve their efficiency.

According to efficiency analysis of container terminals, empirical results reveal that substantial waste exists in the production process of the container terminals in the sample. For instance, the average efficiency of container terminals using the DEA-CCR model amounts to 0.783. This indicates that, on average, the terminals under this study can dramatically increase the level of their outputs by 1.28 times as much as their current level while using the same inputs. Empirical results also reveal that the terminals in the study were found to exhibit a mix of increasing and constant returns to scale at current levels of output. Such information is particularly useful for terminals managers or policy makers to decide on the scale of production.

Moreover, the reason why aggregate efficiency values of Chinese terminals are higher than Korean terminals can be summarized that the huge investments of equipments have been put into the Chinese container terminals production, geographic advantage of huge area and respective cheap cost.

However, the pure technical efficiency values of Korean terminals are more than Chinese terminals, thus indicating that the most Korean terminals handle application of input resources better.

In final conclusion, it is important to note that to estimate the efficiency of a container terminal is the beginning and not the end of any analysis. It is undoubtedly the case that each individual container terminal has its own specific and unique context within which it operates and which will contribute to its level of efficiency. Put differently, although DEA results provide important information on the port industry, they should be carefully interpreted as the ideal efficiency indicated by DEA results might not be achievable in reality for the terminals under study. It will then be useful to explore the more subtle reasons behind the degree to which each individual container terminal is (in) efficient. Moreover, DEA results also might be achievable by building the individual terminals simulation model such as using arena software, according to change the ways of inputs and output, which will be made in the future study.

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