EFFICIENCY EVALUATION OF AUTOMATED CONTAINER TERMINAL BY DEA

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Abstract: With the fierce competition among port industry all over the world, how to improve the efficiency of a container port has become a significant issue to whole industry. Recent decades, the increasing trade volume in Asia attracts the world's attention. Driven by the market demand, some container ports choose to convert into an automated operation to face the increasing goods. The objective of this paper is to conclude the characteristics of those ports and find out suitable ones to be automated.

By using an alternative DEA approach, the ratio of output and input could indicate the cause of efficiency or inefficiency of container terminals. On the basis of choose container terminals' various capital and land quotas as inputs, the containers' throughput as output, this paper values the performance of several container ports of China and Japan.

Keywords: *Port Efficiency, DEA, Automated Container Terminal, Japan, China*

1. INTRODUCTION

With the globalization of the world economy, transportation and logistics play an increasingly important role nowadays. Among the process, the efficiency of port industry is quite vital since port plays the function of connecting the waterways and land transportation. To promote operation efficiency of terminals and to save the cost of manpower, some container ports especially in the high-labor cost countries chose to convert into an automated operation during recent decades.

Automated container terminal in this paper is defined as container terminal which is equipped with any of Automated Guided Vehicles (AGVs) integrates yard-cranes and ship-cranes controlled under the terminal management system. For instance, the European Combined Terminal (ECT) in Rotterdam which is the first automated container terminal in the world, till 2017 has being applied with 265 AGVs and 136 automated stacking cranes (ASC).

As a result, with the trend of container port automation, it has been a great concern for the port's managers to measure a port whether and when it should be converted into automated operation.

To answer those questions, evaluating the ports' efficiency is the first priority. Data Envelopment Analysis (DEA), as developed by Charnes et al. (1978) and extended by Banker et al. (BCC)(1984) is a linear programming procedure for a frontier analysis of inputs and outputs. DEA has been preferred in many studies of evaluating the efficiency because of two facts. First fact is DEA is a nonparametric method. Different from another methodology called stochastic frontier analysis (SFA) which is a parametric method. When applied to same dataset, the efficiency scores derived from applying the SFA model tend to be larger than those derived from the DEA model (Kevin Cullinane et al. 2006).The other fact is its ability to handle multiple outputs and inputs, and its independence of the production function specification (Park and De 2004; Panayides et al. 2009).

In this paper the main idea is by comparing the automated terminals and traditional ones, to find out the factors that lead to inefficiency. First step is using CCR BCC model to find out the efficient DMUs and the return to scale. According to the return to scale, the DMUs which show increasing sign should keep expansion. According to this, the inefficient factor could be figure out. Thirdly, if the result shows some DMUs are inefficient mostly in facilities factors, it could conclude that converting into an automated operation might be a considerable method for those ports.

This paper is divided into five parts. The first part is introduction presenting the background, the concept of automated operation and method used in paper. The second part is literature review which summarizes and induces the literatures on evaluation of port efficiency by means of data envelopment analysis. The third part is methodology, inducing the model of DEA and quotas in it. The fourth part is results and discussion, which gives a discussion on the sense of outcome. The fifth part is conclusion for the former parts, gives strategy and reference for the traditional container ports.

2. LITERATURE REVIEW

Various studies have analyzed efficiency of ports using Data Envelopment Analysis. For example, a decision making approach based on DEA model was proposed by Danijela Pjevcevic et al. (2017) to assess the efficiency of container handling processes at a port container terminal. Danijela applied the basic DEA-CCR model, finding out that only by using a specific number of AGVs could the container handling process reach an efficient condition. Employing a smaller or a larger number of AGVs will both reduce the efficiency of the process. Nevertheless, by using only DEA-CCR model to evaluate DMUs' operational efficiency, the information we could know is limited. Since DEA-CCR model assumes constant return to scale, it is hard for researchers to study the effect of scale efficiency on operational efficiency of the DMU. As scale efficiency can be calculated by dividing efficiency scores obtained from DEA-BCC model, scores of which representative the technical efficiency of the DMU. By the scores obtained from CCR model, researchers begin to adopt DEA-BCC model with the conventional DEA-CCR model to analyze the pure operational efficiency of DMUs in a much more comprehensive way. Carlos Pestana Barros and Manolis Athanassiou (2004) used CCR and BCC models to compare the operational efficiency of Greece and Portugal, and ranked six seaports in the two countries according to their total efficiency and pure technical efficiency. Joanna Baran and Aleksandra Gorecka (2015) adopted BCC and CCR models to determine overall operational efficiency, technical efficiency and scale efficiency of international container ports, creating an efficiency ranking system of seaports. In order to find out the sources of inefficiency of seaports, Maria Rosa Pires da Cruz and Joao de Matos Ferreira (2016) divided ports' operational efficiency into three parts—productivity, profitability, and overall efficiency in their study. Meanwhile, they also adopted CCR and BCC models.

3. METHODOLOGY

(1) DEA

DEA is commonly defined as a nonparametric method of measuring the efficiency of a DMU (Decision Making Unite) with multiple outputs and inputs. The basic idea of DEA is that the efficiency of a DMU is determined by its ability to transform inputs into outputs. Such evaluations take a variety of forms in customary analyses. Examples include cost per unit, profit per unit, satisfaction per unit, and so on, which are measures stated in the form of a ration of aggregate outputs and aggregate inputs.

In this approach, efficiency is always less than or equal to unity as some energy loss will always occur during the transformation process. DEA generalizes this single output/input tec hnical efficiency measure to multiple outputs/inputs. This is achieved by constructing a single "virtual" output to a single "virtual" input. The efficient frontier is then determined by selecting DMUs which are most efficient in producing the virtual output from the virtual input. Because DMUs on the efficient frontier have an efficiency score equal to 1, inefficient DMUs are measured relative t the efficient DMUs. The efficiency measure is relative to other DMUs. It is not possible to determine if DMUs judged to be efficient are optimizing the use of inputs to produce outputs.

To understand the mathematic information of DEA more formally, consider *n* DMUs, when each DMU *j* ($j= 1,\ldots,n$) uses *m* inputs $X^j = (X_{1j}, X_{2j},\ldots X_{mj}) > 0$ for producing *s* outputs $Y_j = (Y_{1j}, Y_{2j},\ldots Y_{sj}) > 0$. The DEA efficiency score h_{jo} in CCR model can be obtained by solving the following fractional program:

$$\text{Maximize } h_{jo} = \sum_{r=1}^{s} u_r y_{rjo} \Big/ \sum_{i=1}^{m} v_i x_{ijo}$$

$$\text{Subject to} \sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij} \le 1, \mathrm{j} = 1 \ldots, n, \tag{1}$$

$$u_r, v_i \geq 0 \text{ for } r = 1, \ldots, s \text{ and } i = 1, \ldots, m.$$

Where y_{rj} = amount of output r from unit j, x_{ij} = amount of inout i from unit j, u_r = weight given r, v_i = weight given to input i, n= total number of outputs, m= total number of inputs.

The weights are all positive and the ratios are bounded by 100%. If a DMU reaches the max possible value of 100% it is considered efficient, otherwise it is inefficient. The formulation of (1) can be translated into a linear program, which can be solving relatively easily, and a DEA solves n linear program, one for each unit:

$$\text{Maximize } h_{jo} = \sum_{r=1}^{s} u_r y_{rjo}$$

$$\text{Subject to} \sum_{i=1}^{m} v_i x_{ijo} = 1 \qquad (2)$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \text{j} = 1 \ldots, \text{n},$$

$$u_r, v_i \geq \varepsilon \text{ for } r = 1, \ldots, s \text{ and } i = 1, \ldots, m.$$

Where is defined as an infinitesimal constant (a non-Archimedean quantity).

The BCC model can be defined by adding the constraint $z_{j0} = 1 - \sum_{r=1}^{m} v_i x_{ij0}$ as shown in model (3).

$$\text{Maximize } h_{jo} = \sum_{r=1}^{s} u_r y_{rjo} + z_{j0}$$

$$\text{Subject to} \sum_{i=1}^{m} v_i x_{ijo} + z_{j0}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + z_{j0} \leq 0, \text{j} = 1 \ldots, \text{n}, \qquad (3)$$

$$u_r, v_i \geq \varepsilon \text{ for } r = 1, \ldots, s \text{ and } i = 1, \ldots, m.$$

(2) Output and input variables

As to analyze the factor between ports which have already tried to take automated operation and ports with traditional operation, the data would better be as latest as possible. Because automated container terminal is still in an emerging market, in this paper the maturity of automated operation would not be further considered.

The output variable is annual container throughput during 2017 till 2018. Among all the considerable output factors, container throughput is the most important and widely used indicator because it relates the need for cargo-facilities and services very closely.

The input variables are number of berth, area of storage and number of cranes. Number of berth and area of storage stand for the land factor, while number of cranes represents the capital factor. In this paper the number of cranes includes a broad range of crane facilities. For example gantry cranes, rail-mounted cranes, Rubber tyred gantry cranes (RTG), crane barges, bridge cranes etc. For this reason, a direct observation could be gained between automated container terminals and traditional ones.

From the perspective of port manager, the input factors are usually more controllable than output factors. So an output-oriented model would be chosen.

(3) DMUs

In this paper, eleven container ports would be chosen.

Among those ports, six of them possesses automated container terminals: Shanghai, Hong Kong, Qingdao, Xiamen , Kawasaki and Nagoya port.

Traditional ports: Shenzhen, Guangzhou Harbor, Tianjin, Lianyungang and Kobe port.

The first reason of choosing these ports is the great demand of trade in this area. Secondly, the rapidly growing labor cost is weakening the competition towards against Southeast Asia.

4. RESULT AND DISCUSSION

As shown in table 1, the eleven DMUs are container ports which in the China and Japan. Among those ports, six ports--Shanghai, Hong Kong, Qingdao, Xiamen and Kawasaki port have already been adopted a measure of automated operation. While the other five ports have been maintaining traditional operation so far.

It could be shown that four ports among the list were considered the most efficiency. They are Shanghai, Shenzhen, Hong Kong and Guangzhou Harbor port. Their aggregate efficiency values acquired from DEA-CCR model were all equal to 1. Thus also indicating that their pure technical efficiency also is 1 which could be obtained from DEA-BCC model.

Contrarily, the other seven ports—Qingdao, Tianjin, Xiamen, Lianyungang, Kawasaki, Kobe and Nagoya port are less efficient. Among the seven ports, Nagoya port is the least efficient port.

All of the pure technical efficiency values of

Table 1 Efficiency Summary

Port	firm	crste	vrste	scale	
Shanghai	1	1.000	1.000	1.000	-
Shenzhen	2	1.000	1.000	1.000	-
Hong Kong	3	1.000	1.000	1.000	-
Qingdao	4	0.795	0.906	0.877	irs
Guangzhou Harbor	5	1.000	1.000	1.000	-
Tianjin	6	0.622	0.694	0.896	drs
Xiamen	7	0.738	0.828	0.891	irs
Lianyungang	8	0.845	1.000	0.845	irs
Kawasaki	9	0.060	1.000	0.060	irs
Kobe	10	0.767	1.000	0.767	irs
Nagoya	11	0.526	0.609	0.864	irs
mean		0.759	0.912	0.836	

* crste = technical efficiency from CRS DEA vrste = technical efficiency from VRS DEA scale = scale efficiency = crste/vrste

Lianyungang, Kawasaki and Kobe were equal to 1, while the scale efficiency values were less than 1, thus indicating that for these three ports reduction on input or increase on output is not necessary. Comparing the pure technical efficiency value and the scale efficiency value, it could be concluded that an inappropriate production scale is the main cause of the inefficiency of the Qingdao, Lianyungang, Kawasaki and Kobe port. And the return to scale showed that all the ports should expand the scale of production. Furthermore, Kawasaki and Kobe port had the less scale efficiency values than average scale efficiency values.

All the scale efficiency values of Tianjin, Xiamen and Nagoya port are less than pure technical efficiency values. Though both of scale efficiency and pure technical efficiency cause the inefficiency of Tianjin, Xiamen and Nagoya port, technical improvements are more critical. As output factor is hard to control as port managers, the reduction on input factors should be considered.

Among the automated container ports, only Shanghai and Hong Kong port is relatively efficient; Kawasaki port is technical efficient. Only Tianjin, Xiamen and Nagoya have the potential on reducing input factors.

5. CONCLUSION

This paper contributes to extant research in DEA approach have been applied to automated container terminal for the first time. Analysis of the port efficiency shows that Tianjin, Xiamen and Nagoya port could reduce the input factors to keep competition in the future market. Since land input factors—number of berth and storage area are not flexible to be changed, reduction on number of cranes seems more considerable for port managers. In this paper, automated container terminals, for example are using super post-Panamax gantry cranes, ZMPC gantry cranes etc. to improve the operation efficiency. The potential of automated container terminal is even great than ever.

However, for the reason of data availability, this paper still has many limitation. Firstly, lacking of manpower input factors. Secondly, the disparities of container terminal is very wide. If more data were available in the future, research on efficiency of automated container terminal could be more thoroughly expored.

APPENDIX A

Container terminals of DMUs

Shanghai	Bao Shan Container Terminal (BSCT) Jun Gong Lu Terminal (JCT) Shanghai East Terminal (SECT) Shanghai Mingdon International Terminal (SMCT) Shanghai Pudong International Terminal (SPCT) Shanghai Waigaoqiao Container Terminal (PSCWT) Zhang Hua Bang Container Terminal (ZCT)
Shenzhen	Chiwan Container Terminal Da Chan Bay Container Terminal Shekou Container Terminal (SCT)
Hong Kong	Asia Container Terminals (ACT) Asia Port Services APS COSCO-HIT Terminal DP World Terminal Euroasia Dockyard HIT Terminals Modern Terminals River Trade Terminal (RTT) Yuen Fat Wharf
Qingdao	QPCT QQCT QQCTU
Guangzhou Harbor	Dongguan International Wharf Dong Jiang Cang Container Terminal DWICT

	Fangcun Terminal GPSAL Henan Terminal PSA DGCT Terminal Xingang Container Terminal Xinsha Container Terminal
Tianjin	Shenhua Tianjin Coal Terminal (STCT) Tianjin Bulk Terminal (TBT) Tianjin Huaneng Port/Coal Terminal (TPHCT) Tianjin Port Coke Terminal (TPPCT) Tianjin Port Coke Terminal (TPPCT) Tianjin Yuanhang Ore Terminal (TYOT)
Xiamen	Hairun Terminal Haitian Port Terminal New World Xiangyu Terminal Xiamen International Container Terminal Xiamen Ocean Gate Terminal (XOCT) Xiamen Songyu Container Terminal (XSCT)
Lianyungang	New Oriental Container Terminal LYG-PSA
Kawasaki	Kawasaki Container Terminal
Kobe	Kobe Port Terminal Corporation (KPTC)
Nagoya	Nabeta Pier Container Terminal Nagoya Container Berth Terminal (NCB)

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