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*Research Article*

## **Measuring the Efficiency of Automated Container Terminals in China and Korea**

Yunna XU <sup>a</sup>, Kazuhiko ISHIGURO <sup>b\*</sup>

<sup>a</sup> *Fairwind International Shipping Co., Ltd, Shanghai, China;*

*E-mail: annaxu218@gmail.com*

<sup>b</sup> *Graduate School of Maritime Sciences, Kobe University, Kobe, 658-0022, Japan;*

*E-mail: ishiguro@maritime.kobe-u.ac.jp*

**Abstract:** This study evaluates the efficiency of Chinese and South Korean container terminals, including four automated and twenty traditional terminals, using data envelopment analysis. The study considers the following six input variables: water depth, quay length, storage area, number of quay cranes, number of gantry cranes, and number of terminal transfer vehicles. Container throughput is considered as the output variable. The most efficient terminals, located in the East China, are: SYCT (Shanghai), SIPG (Shanghai), SMCT (Shanghai), SSICT (Shanghai), and LNOCT (Lianyungang). In terms of relative performance, other terminals located along the Chinese coastline are ranked in the middle, and the terminals of South Korea perform relatively less efficiently. Although the superiority of automated container terminals is not as distinct as expected, there is a clear efficiency contribution from the crane input variable, and there is reason to believe that a time-series DEA analysis would emphasize this feature more prominently.

**Keywords:** Data Envelopment Analysis, Automated Container Terminal, Traditional Container Terminal, Efficiency Evaluation

### **1. INTRODUCTION**

With the fierce global competition within the port industry, improving the efficiency of container ports has become a significant issue. Since the invention and application of the container concept in the 1960s, container ports, originally centered on Europe, have been developing. This development laid the foundation for the world's leading container ports of today. In recent decades, the increasing trade volume in Asia has attracted global attention. Driven by market demand, some container ports have chosen to automate their operations in order to manage the increasing volume of goods. The ability to decrease the cost of manpower has also become an important factor in high labor-cost countries. As a result, with the growing trend of container port automation, it has become important for port managers to evaluate whether a port should be converted into an automated operation. The merits of automated operations are mainly the reduction in labor cost and improvements in safety. However, automation requires more initial and operational costs. Automated operations may not always be the best solution to improve efficiency.

The objective of this research is to evaluate the operational efficiency of container

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\* Corresponding author.

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terminals, including both automated and traditional container terminals. We apply data envelopment analysis (DEA) and conduct a sensitivity analysis. Various capital and land quotas are considered as inputs, with the containers' throughput as the output. Evaluating port efficiency is the first priority in addressing this issue. Container throughput is affected by the industries of the hinterland, its geometric position, and other elements of the social and economic environment of each terminal. In this study, container throughput is given as demand for terminals. This research focuses on how terminals correspond and adjust to the demand by preparing capital and land factors.

DEA, developed by Charnes et al. (1978) as the CCR method and extended by Banker et al. (1984) under the BCC method is a linear programming procedure for a frontier analysis of input and output. Many studies evaluating efficiency have preferred DEA for two reasons. First, it is a nonparametric method, and differs from stochastic frontier analysis (SFA), which is a parametric methodology. When applied to same dataset, the SFA model's efficiency scores tend to be larger than those derived from the DEA model (Cullinane et al., 2006). Second, DEA can handle multiple outputs and inputs independent of a production function's specifications (Panayides et al., 2009; Park and De, 2004). This paper primarily posits that a comparison of automated and traditional terminals can reveal the factors that lead to inefficiency. The first step involves using the CCR and BCC models. In measuring the efficiency of decision making units, Charnes et al. (1978) laid the original foundation of the CCR model. Along with the BCC model, the CCR model was initially established for estimating technical and scale inefficiencies in DEA. The results of these two models will be discussed further to delineate efficient decision making units (DMUs). Due to data availability, the targets of this analysis are 4 automated and 20 traditional container terminals in China and Korea.

This paper defines an automated container terminal as a container terminal equipped with any automated guided vehicles (AGVs) or container cranes (yard and quay) controlled under the terminal management system.

## **2. LITERATURE REVIEW**

### **2.1 Data Envelopment Analysis**

Various studies have analyzed port efficiency using data envelopment analysis. Tongzon's (2001) research was an early attempt to compare port efficiency on an international scale. Prior to this work, the DEA approach was widely applied to efficiency comparisons among enterprises or firms. The results indicated that port inefficiencies primarily occurred due to lapses in container berths, the terminal area, and labor inputs. The author's constructive results consequently led to an upsurge in studies that compared port efficiencies using DEA. Cullinane et al. (2005) compared the DEA and SFA approaches when estimating container ports' efficiency and scale properties. This research revealed a high degree of correlation between these efficiency estimates and concluded that high technical efficiency was closely related to scale, the level of private sector participation, and whether it was a transshipment or gateway port. Yeo et al. (2008) applied DEA to evaluate the competitiveness of container ports in Korea and China. As neighboring countries, the ports fiercely competed for substantial state investments. The analysis revealed that factors such as port service, hinterland conditions, availability, convenience, and logistics cost factors were critical in these regions.

Nevertheless, using only the DEA-CCR model to evaluate DMUs' operational

efficiency limits the information that can be obtained. As the CCR model assumes a constant return to scale, it is difficult for researchers to study the effect of scale efficiency on DMUs' operational efficiency. Scale efficiency can be calculated using the ratio of efficiency scores obtained from the DEA-BCC model; these scores represent the DMUs' levels of technical efficiency. The scores obtained from the CCR model have convinced researchers to adopt the BCC model, in addition to the conventional CCR model, to more comprehensively analyze DMUs' pure operational efficiency. Barros and Athanassiou (2004) used the CCR and BCC models to compare ports' operational efficiency in Greece and Portugal and ranked six seaports in the two countries according to their total and pure technical efficiencies. Baran and Gorecka (2015) adopted BCC and CCR models to determine the overall operational, technical, and scale efficiency of international container ports by creating a seaport efficiency ranking system. Further, da Cruz and Ferreira's (2016) study discovered the sources of seaport inefficiency by dividing ports' operational efficiency into three parts: productivity, profitability, and overall efficiency. Meanwhile, they also adopted CCR and BCC models.

As DEA is an approach to compare firms' efficiency, finding factors of inefficiency has become a primary aim for most studies as the container shipping industry has progressed over the years. Researchers have also attempted to apply DEA in innovative ways. For example, Pjevecic et al. (2017) proposed a DEA-based decision-making approach to assess the efficiency of container-handling processes at a port container terminal. The authors applied the basic CCR model to reveal that only a specific number of AGVs could allow the container-handling process to reach optimum efficiency, as employing a smaller or a larger number of AGVs would decrease process efficiency.

Although the DEA approach has been widely used in evaluating port efficiency, the automated operation of container ports using DEA remains a new area of study. This is primarily because the automation of container terminals is still an evolving process. Thus, the data is difficult to quantify. For simplicity, this study calculates automated terminal facilities as its input variable, and estimates performance efficiency using annual data.

## **2.2 Output and Input Variables for Evaluating Port/Terminal Operations**

Roll and Hayuth (1993) established that input variables should include manpower, capital, and uniformity, and building on this, subsequent studies have used number of workers, number of personnel, and labor as manpower inputs and book value of assets and value of capital invested as capital inputs (e.g., García-Alonso and Martín-Bofarull, 2007; Barros, 2006; Rios and Maçada, 2006; Min and Park, 2005; Barros and Athanassiou, 2004). In addition to Roll and Hayuth (1993), Martinez-Budria (1999) applied expenditures and revenue as variables, focusing on the concept of profitability. This is similar to the work of Liu (2008), Wang and Cullinane (2006), and Park and De (2004), who also tried to analyze efficiency from a financial perspective. However, given the availability of data, these studies are relatively fewer in number. Following Tongzon's (2001) research, many scholars have applied similar input variables (e.g., Cullinane and Wang, 2007; So et al., 2007; Cullinane et al., 2006; Cullinane et al., 2005; Cullinane, 2004; Turner et al., 2004; Wang et al., 2003; Valentine and Gray, 2001).

With the evolution of operational facilities in the port industry, the facility inputs began to be defined more precisely around 2007, and they are closely related with each operation function (e.g., Cheon et al., 2010; Al-Eraqi et al., 2008; Liu et al., 2008; Wu et al., 2008; Lin et al., 2007). Several studies have applied a DEA-based Malmquist model to analyze port efficiency based on inputs and outputs similar to the DEA-CCR/BCC models (e.g., Song and Cui, 2014; Alejandro and Cesar, 2009; Liu et al., 2008; Estache et al., 2004). Aside from those

frequently chosen variables, Yuen (2013) presents an interesting study, adding the average age of employees as an input to study its influence on the throughput (TEU). The selection of input and output variables is crucial for the DEA model. Comparing the two studies released by Wu and Goh (2010) and Wu (2009), the pieces of equipment indicator has been applied differently as both an input variable and an output variable, leading to completely different results.

Most of the output variables in various studies are represented by the number of containers or total tonnage throughput. Other output variables include ship work rate, and Tongzon (2001) suggested ship operating speed, ship calls, user satisfaction, and number of ships as indicators. The most frequently used input variables are terminal area, total quay length, and number of cranes. Regarding an analysis of the factors between ports that have already attempted automated operations and those with traditional operations, it would be ideal to have access to the most recent data. However, as the automated container terminal market is still emerging, this paper does not further consider the maturity of the ports' automated operations.

### **3. DATA ENVELOPMENT ANALYSIS**

#### **3.1 Methodology**

DEA is commonly defined as a nonparametric method of measuring the efficiency of a DMU with multiple inputs and outputs. In statistics, a parametric model usually assumes that the population (random variable) obeys a certain distribution, which is determined by some parameters (such as the normal distribution determined by the mean and the variance). However a nonparametric model does not make any assumptions about the population distribution; it only knows that the population is a random variable whose distribution exists with an unknown form. While there may also be parameters in the distribution, the relevant parameters are usually unknown. Given a few samples, an inference could be made based on nonparametric statistics. In this paper, the variables of each DMU are not assumed to obey a certain distribution, nor is a prior determination of relationship assumed between them. Thus, compared with other analytical approaches, such as Free Disposal Hull (FDH) or SFA, DEA is the most appropriate approach.

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 input/output technical efficiency measure to multiple inputs and outputs by constructing a single “virtual” input to a single “virtual” output. The efficient frontier is then determined by selecting the DMUs that are the most efficient in producing the virtual output from the virtual input. As DMUs on the efficiency frontier have an efficiency score equal to one, inefficient DMUs are measured relative to efficient DMUs. The efficiency measure is also relative to other DMUs, and it is not possible to determine if DMUs judged as efficient are optimizing their inputs in producing outputs.

With the development of algorithms used to study data variations in one input or output for one DMU, this analytical approach makes it possible to analyze the sensitivity of results. The topic of sensitivity analysis, similar to stability or robustness, has taken a variety of forms in the DEA literature. One part of the relevant literature studies responses with given data when DMUs are deleted or added to the set being considered (e.g., Wilson, 1995). Another part of the literature deals with increases or decreases in the number of inputs and outputs to be treated.

### **3.2 Decision Making Units**

In total, 24 terminals are picked from the ports of Busan, Incheon, Lianyungang, Shanghai, Shenzhen, Tianjin, and Xiamen. The terminals are listed as follows.

1. Shanghai Yidong Container Terminal (SYCT)
2. Shanghai International Port Group (SIPG)
3. Shanghai Mingdon International Terminal (SMCT)
4. Shanghai Shengdong International Container Terminal (SSICT)
5. New Oriental Container Terminal (LNOCT)
6. Nansha Port Ltd
7. Tianjin Port Container Terminal (TPCT)
8. Shanghai East Terminal (SECT)
9. Haicang xin hai da Container Terminal (XHDCT)
10. Pusan New Port Company (PNC)
11. Shanghai Pudong International Terminal (SPCT)
12. Pusan Newport International Terminal (PNIT)
13. Hyundai Pusan New-port Terminal (HPNT)
14. Guangzhou Container Terminal (GCT)
15. Jaseongdae Pier
16. Sinseondae Pier
17. Busan Newport Container Terminal Co. Ltd (BNCT)
18. E1CT (south port)
19. Singamman Pier
20. ICT (south port)
21. Gamman Pier
22. SNCT (new port)
23. HJIT (new port)
24. Uam Pier.

The automated container terminals are PNC and BNCT of the Port of Busan and SNCT and HJIT of the Port of Incheon.

### **3.3 Variables and Data Source**

The output variable is the annual container throughput of 2016. Among all the considerable output factors, container throughput (as measured in TEUs, the number of twenty feet container equivalent units handled) is the most important and widely used indicator, as it closely relates to the need for cargo facilities and services.

There are six input variables: water depth, quay length, storage area, number of quay cranes, number of gantry cranes, and number of terminal transfer vehicles. The quay length and storage area represent the land and capital factors, while the number of cranes and terminal transfer vehicles represent the equipment factors. For comparison purposes, it is necessary to compare traditional terminal transfer vehicles with AGVs based on their functions. Thus, this paper considers assets such as tractors, straddle carriers, forklifts, loaders, and empty handlers.

Data on the container throughput for each terminal are obtained from the China Port Development 2017–2019 report for Chinese terminals and data published by Busan Port Authority and Incheon Port Authority for Korean terminals. Data for input variables are mainly obtained from the Ports & Terminals Guide 2017–2018 and Guide to Port Entry 2017/2018. Additional data are obtained from SIPG's Zhendong Branch, Xiamen Ocean Gate

Container Terminal Co. Ltd., Busan Port Authority, and Incheon Port Authority.

## 4. RESULTS AND DISCUSSION

### 4.1 Efficiency Evaluation of Container Terminals

Table 1 shows the results of the efficiency evaluation of container terminals under a DEA approach. The results reveal that among 24 DMUs, 5 DMUs are judged to be efficient under a CCR model. They are SYCT, SIPG, SMCT, and SSICT from the Port of Shanghai and LNOCT from the Port of Lianyungang. All of these are located within the Yangtze River Delta area. Under the BCC model, 9 DMUs are identified as efficient. Besides the previously mentioned DMUs, XHDCT from the Port of Xiamen, GCT from the Port of Shenzhen, E1CT (south port) from the Port of Incheon, and Uam Pier from the Port of Busan also perform efficiently in terms of pure technical efficiency. Terminals such as SIPG, SMCT, and SSICT are relatively large in both scale and throughput, while a small terminal such as Uam Pier can also be found in the efficient group. This implies that a terminal's level of operational efficiency does not only depend on size or throughput.

Table 1. Results of CCR and BCC models

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale | Return |
|------|-------------|------------------|--------|--------|-------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000 | -      |
| 2    | Shanghai    | SIPG             | 1.000  | 1.000  | 1.000 | -      |
| 3    | Shanghai    | SMCT             | 1.000  | 1.000  | 1.000 | -      |
| 4    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000 | -      |
| 5    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000 | -      |
| 6    | Shenzhen    | Nansha port ltd  | 0.852  | 0.904  | 0.943 | drs    |
| 7    | Tianjin     | TPCT             | 0.844  | 0.884  | 0.954 | irs    |
| 8    | Shanghai    | SECT             | 0.836  | 0.907  | 0.921 | drs    |
| 9    | Xiamen      | XHDCT            | 0.730  | 1.000  | 0.730 | irs    |
| 10   | Busan       | PNC              | 0.656  | 0.839  | 0.783 | drs    |
| 11   | Shanghai    | SPCT             | 0.613  | 0.673  | 0.910 | drs    |
| 12   | Busan       | PNIT             | 0.451  | 0.554  | 0.814 | drs    |
| 13   | Busan       | HPNT             | 0.429  | 0.592  | 0.726 | drs    |
| 14   | Shenzhen    | GCT              | 0.387  | 1.000  | 0.387 | irs    |
| 15   | Busan       | Jaseongdae pier  | 0.357  | 0.456  | 0.784 | drs    |
| 16   | Busan       | Shinseondae pier | 0.324  | 0.382  | 0.848 | drs    |
| 17   | Busan       | BNCT             | 0.300  | 0.373  | 0.804 | drs    |
| 18   | Incheon     | E1CT(south port) | 0.269  | 1.000  | 0.269 | irs    |
| 19   | Busan       | Singamman pier   | 0.266  | 0.324  | 0.820 | drs    |
| 20   | Incheon     | ICT(south port)  | 0.235  | 0.242  | 0.970 | irs    |
| 21   | Busan       | Gamma Pier       | 0.228  | 0.279  | 0.820 | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.169  | 0.175  | 0.969 | drs    |
| 23   | Incheon     | HJIT(new port)   | 0.075  | 0.078  | 0.969 | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 1.000  | 0.001 | irs    |
|      | Mean        |                  | 0.543  | 0.694  | 0.809 |        |

\* CRS-TE = Technical Efficiency from the CRS-DEA; VRS-TE = Technical Efficiency from the VRS-DEA; Scale = Scale Efficiency = CRS-TE / VRS-TE; Return = Return to Scale; irs = increasing return to scale; drs = decreasing return to scale

To compare the pure technical efficiency value with the scale efficiency value, among the 19 inefficient terminals under the CCR model, 5 terminals are inefficient due to an inappropriate scale of production. They are XHDCT (Xiamen), PNC (Busan), GCT

(Shenzhen), E1CT (Incheon), and Uam Pier (Busan). For those terminals, to adapt their scale of production would be much more effective than changing the inputs or outputs. The remaining 14 terminals all utilize their input factors less efficiently. The pure technical efficiency values are much lower than the scale efficiency values, indicating that a decrease of input or increase of output would be worth considering for those terminals. In contrast to the results of the port efficiency analysis, the main reason for inefficiency is pure technical inefficiency. The more detail available with respect to the input (or output) factors, the more accurate the result is likely to be. In the following sub-sections, the influence of input factors will be discussed in more detail.

Considering average values, the average technical efficiency value is 0.543. If the worst performing DMU (Uam Pier) is removed, the average value would be 0.566. Thirteen DMUs fall below the average value. Most of the DMUs (12) are from South Korea—Port of Busan and Port of Incheon. The probable reason might be the output factor, which is determined by terminal container throughput.

## **4.2 Sensitivity Analysis**

### **4.2.1 Analysis of water depth input**

Table 2 shows the terminal efficiency results under a five-input model (without water depth). Those DMUs that perform more efficiently than in Table 1 show that the water depth input is a relative weakness. On the contrary, if DMUs perform less efficiently by removing the water depth input, it could reveal that this input does contribute to the level of efficiency. The number of efficient DMUs under the CCR model decreases to three terminals. SIPG (Shanghai) and SMCT (Shanghai) are no longer evaluated as efficient. To compare the rankings of Table 2 with Table 1, the most significant changes are that SIPG (Shanghai) dropped from 2<sup>nd</sup> to 7<sup>th</sup> place and Jaseongdae Pier (Busan) dropped from 15<sup>th</sup> to 19<sup>th</sup>. This change in ranking reveals that for those two terminals, the water depth input critically affects their performance.

This can also be seen from the change in efficiency values. The technical efficiency values of SMCT (Shanghai) and SIPG (Shanghai), both equal to 1.000 in Table 1, are reduced with the removal of the water depth input. SMCT is reduced to 0.924 as a result of a decrease in scale efficiency, and SIPG is reduced to 0.762 due to a decrease in both pure technical and scale efficiency. The Port of Shanghai consists of two parts, Waigaoqiao and Yangshan. Yangshan focuses more on serving European and American lines, and Waigaoqiao focuses on Southeast Asian lines. Since 2011, the Deep Water Channel Project in Waigaoqiao has helped promote its container handling capability, and that might explain why water depth input has been more efficiently utilized for SMCT and SIPG. SMCT operates Shanghai Waigaoqiao Phase-5, 6 Terminal, while SIPG runs the Waigaoqiao Phase-2, 3 Terminal.

GCT (Shenzhen) and Uam Pier (Busan) were efficient under the BCC model with six input variables; however, in Table 2, their pure technical efficiency values have dramatically decreased to 0.366 and 0.001, respectively. Their scale efficiency values have increased to 0.828 and 0.865. The return to scale for GCT has changed from increasing (irs) to decreasing (drs), indicating that the scale of production has become oversized at the five-input level. The return to scale for Uam Pier has also changed from irs to constant, implying that the removal of the water depth input restrains other input factors' effects.

For automated terminals PNC (Busan) and BNCT (Busan), both technical and scale efficiency have dropped slightly. PNC experienced decreases of 0.185 and 0.222, respectively, and BNCT decreased by 0.023 and 0.061. The other two automated terminals from the Port of

Incheon performed the same as in the six-input model. One possible reason for this is that the rankings of most of the automated terminals are significantly lower, and therefore, the effect of input variables may not be as noticeable. However, another reason is that for automated terminals, the water depth input does not influence productivity as significantly as other input variables. The impact of the water depth input pure technical efficiency performance seems to be weak. Only three DMUs are slightly affected. Compared with the average efficiency values, technical efficiency has dropped by 8%, pure technical efficiency by 10%, and scale efficiency by 0.7%. Based on the above, it could be concluded that the water depth input affects SMCT (Shanghai), SIPG (Shanghai), GCT (Shenzhen), and Uam Pier (Busan) the most.

Table 2. Terminal efficiency results (without water depth input)

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale  | Return |
|------|-------------|------------------|--------|--------|--------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000  | -      |
| 2    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000  | -      |
| 3    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000  | -      |
| 4    | Shanghai    | SMCT             | 0.924↓ | 1.000  | 0.924↓ | drs↓   |
| 5    | Tianjin     | TPCT             | 0.844  | 0.884  | 0.954  | irs    |
| 6    | Shenzhen    | Nansha port ltd  | 0.822↓ | 0.904  | 0.909↓ | drs    |
| 7    | Shanghai    | SIPG             | 0.762↓ | 0.936↓ | 0.814↓ | drs↓   |
| 8    | Xiamen      | XHDCT            | 0.730  | 1.000  | 0.730  | irs    |
| 9    | Shanghai    | SECT             | 0.685↓ | 0.907  | 0.755↓ | drs    |
| 10   | Shanghai    | SPCT             | 0.575↓ | 0.673  | 0.855↓ | drs    |
| 11   | Busan       | PNC              | 0.471↓ | 0.839  | 0.561↓ | drs    |
| 12   | Busan       | PNIT             | 0.412↓ | 0.554  | 0.744↓ | drs    |
| 13   | Busan       | HPNT             | 0.411↓ | 0.592  | 0.695↓ | drs    |
| 14   | Shenzhen    | GCT              | 0.303↓ | 0.366↓ | 0.828↑ | drs↓   |
| 15   | Busan       | BNCT             | 0.277↓ | 0.373  | 0.743↓ | drs    |
| 16   | Incheon     | E1CT(south port) | 0.269  | 1.000  | 0.269  | irs    |
| 17   | Busan       | Singamman pier   | 0.266  | 0.324  | 0.820  | drs    |
| 18   | Busan       | Shinseondae pier | 0.265↓ | 0.382  | 0.693↓ | drs    |
| 19   | Busan       | Jaseongdae pier  | 0.264↓ | 0.456  | 0.579↓ | drs    |
| 20   | Incheon     | ICT(south port)  | 0.235  | 0.242  | 0.970  | irs    |
| 21   | Busan       | Gamma Pier       | 0.174↓ | 0.279  | 0.625↓ | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.169  | 0.175  | 0.969  | drs    |
| 23   | Incheon     | HJIT(new port)   | 0.075  | 0.078  | 0.969  | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 0.001↓ | 0.865↑ | -      |
| Mean |             |                  | 0.497↓ | 0.624↓ | 0.803↓ |        |

#### 4.2.2 Analysis of quay length input

The next input factor to be observed is quay length. As shown in Table 3, it is the terminal efficiency results without the impact of the quay length input. The technically efficient DMUs are the same as in the six-input model. Four terminals from the Port of Shanghai and one terminal from the Port of Lianyungang are technically efficient. The number of pure technically efficient DMUs has decreased to seven terminals, and XHDCT (Xiamen) and Uam Pier (Busan) have been significantly influenced. The pure technical efficiency values of XHDCT and Uam Pier were 1.000 in the six-input model. However, in Table 3 the pure technical efficiency values for XHDCT have decreased by 47.3%, and the scale efficiency values have increased by 32%. Thus, the technical efficiency values have decreased by 37%. The return to scale remains the same. This indicates that the quay length input is being efficiently utilized in the case of XHDCT, so as to contribute to its efficiency.

For Uam Pier, the quay length input is as important as water depth input. The efficiency

values of Uam Pier have dropped to 0.001 (technical), 0.001 (pure technical), and 0.866 (scale) with a constant return to scale, which is almost equal to the efficiency values in Table 3. From Tables 1 and 3, it could be concluded that for Uam Pier, the water depth input and quay length inputs have the greatest impact. The ranking of the result has changed slightly—only TPCT (Tianjin) has dropped from 7<sup>th</sup> to 10<sup>th</sup> place. The efficiency values of TPCT (Tianjin) have decreased by 30%, and the return to scale has shifted from *irs* to *drs*. The trend of promoting efficiency by scaling up production has entirely changed as a result of the removal of the length input, indicating that the quay length input is already utilized efficiently.

Table 3. Terminal efficiency results (without quay length input)

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale  | Return |
|------|-------------|------------------|--------|--------|--------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000  | -      |
| 2    | Shanghai    | SIPG             | 1.000  | 1.000  | 1.000  | -      |
| 3    | Shanghai    | SMCT             | 1.000  | 1.000  | 1.000  | -      |
| 4    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000  | -      |
| 5    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000  | -      |
| 6    | Shanghai    | SECT             | 0.827↓ | 0.907  | 0.911↓ | drs    |
| 7    | Shenzhen    | Nansha port ltd  | 0.814↓ | 0.904  | 0.900↓ | drs    |
| 8    | Busan       | PNC              | 0.656  | 0.839  | 0.783  | drs    |
| 9    | Shanghai    | SPCT             | 0.611↓ | 0.673  | 0.908↓ | drs    |
| 10   | Tianjin     | TPCT             | 0.595↓ | 0.720↓ | 0.827↓ | drs↓   |
| 11   | Xiamen      | XHDCT            | 0.457↓ | 0.473↓ | 0.967↑ | irs    |
| 12   | Busan       | PNIT             | 0.450↓ | 0.554  | 0.812↓ | drs    |
| 13   | Busan       | HPNT             | 0.429  | 0.592  | 0.725↓ | drs    |
| 14   | Shenzhen    | GCT              | 0.387  | 1.000  | 0.387  | irs    |
| 15   | Busan       | Jaseongdae pier  | 0.357  | 0.456  | 0.784  | drs    |
| 16   | Busan       | Shinseondae pier | 0.324  | 0.382  | 0.847↓ | drs    |
| 17   | Busan       | BNCT             | 0.300  | 0.373  | 0.804  | drs    |
| 18   | Incheon     | E1CT(south port) | 0.261↓ | 1.000  | 0.261↓ | irs    |
| 19   | Busan       | Singamman pier   | 0.255↓ | 0.324  | 0.786↓ | drs    |
| 20   | Busan       | Gamma Pier       | 0.228  | 0.279  | 0.820  | drs    |
| 21   | Incheon     | ICT(south port)  | 0.210↓ | 0.217↓ | 0.967↓ | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.146↓ | 0.169↓ | 0.862↓ | drs↓   |
| 23   | Incheon     | HJIT(new port)   | 0.065↓ | 0.075↓ | 0.862↓ | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 0.001↓ | 0.866↑ | -      |
|      | Mean        |                  | 0.516↓ | 0.622↓ | 0.837↑ |        |

As automated terminals, this time, PNC (Busan) and BNCT (Busan) have not been influenced at all. SNCT (Incheon) and HJIT (Incheon) have both decreased dramatically in terms of efficiency performance. The technical, pure technical, and scale efficiency values of SNCT (Incheon) have decreased by 79%, 3%, and 11%, respectively; and those of HJIT (Incheon) by 13%, 34%, and 11%. The quay length input does affect the automated terminals from the Port of Incheon. Comparing the average efficiency values from the six-input model, the technical and pure technical efficiency values have dropped by 5% and 10%, respectively. However, it should be noted that the scale efficiency value increased by 3.5%.

#### 4.2.3 Analysis of storage area input

Table 4 shows the DEA results with the storage area input removed. The quantity of efficient DMUs remains the same as under the six-input model—five efficient DMUs under the CCR model, and nine efficient DMUs under the BCC model. From a rankings perspective, it is the first time that the ranked results are identical to Table 4, including the return to scale column. The removal of the storage area input has not affected the performance at all. Starting with

XHDCT (Xiamen), most of the subsequent DMUs have decreased slightly in pure technical efficiency values. This indicates that the influence of the storage area input does contribute to productivity, although to a lesser extent. The scale efficiency values also increased, which means the overall inefficiency in the CCR model would more likely be caused by inefficient operations rather than scale inefficiency when the storage area input is removed.

Table 4. Terminal efficiency results (without storage area input)

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale  | Return |
|------|-------------|------------------|--------|--------|--------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000  | -      |
| 2    | Shanghai    | SIPG             | 1.000  | 1.000  | 1.000  | -      |
| 3    | Shanghai    | SMCT             | 1.000  | 1.000  | 1.000  | -      |
| 4    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000  | -      |
| 5    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000  | -      |
| 6    | Shenzhen    | Nansha port ltd  | 0.852  | 0.904  | 0.943  | drs    |
| 7    | Tianjin     | TPCT             | 0.844  | 0.884  | 0.954  | irs    |
| 8    | Shanghai    | SECT             | 0.836  | 0.907  | 0.921  | drs    |
| 9    | Xiamen      | XHDCT            | 0.715↓ | 1.000  | 0.715↓ | irs    |
| 10   | Busan       | PNC              | 0.613↓ | 0.718↓ | 0.853↑ | drs    |
| 11   | Shanghai    | SPCT             | 0.570↓ | 0.580↓ | 0.984↑ | drs    |
| 12   | Busan       | PNIT             | 0.451  | 0.517↓ | 0.873↑ | drs    |
| 13   | Busan       | HPNT             | 0.411↓ | 0.452↓ | 0.908↑ | drs    |
| 14   | Shenzhen    | GCT              | 0.338↓ | 1.000  | 0.338↓ | irs    |
| 15   | Busan       | Jaseongdae pier  | 0.331↓ | 0.365↓ | 0.908↑ | drs    |
| 16   | Busan       | Shinseondae pier | 0.319↓ | 0.355↓ | 0.900↑ | drs    |
| 17   | Busan       | BNCT             | 0.300  | 0.353↓ | 0.850↑ | drs    |
| 18   | Incheon     | E1CT(south port) | 0.269  | 1.000  | 0.269  | irs    |
| 19   | Busan       | Singamman pier   | 0.266  | 0.296↓ | 0.898↑ | drs    |
| 20   | Incheon     | ICT(south port)  | 0.235  | 0.242  | 0.970  | irs    |
| 21   | Busan       | Gamma Pier       | 0.223↓ | 0.248↓ | 0.901↑ | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.169  | 0.175  | 0.969  | drs    |
| 23   | Incheon     | HJIT(new port)   | 0.075  | 0.078  | 0.969  | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 1.000  | 0.001  | irs    |
|      | Mean        |                  | 0.534↓ | 0.670↓ | 0.838↑ |        |

As technical efficiency consists of pure technical efficiency and scale efficiency, a change in technical efficiency values could reveal which alteration is more noticeable. As shown in Table 4, the technical efficiency values have decreased, which reveals the alteration of pure technical efficiency values is stronger. Not including the five technically efficient DMUs, there are seven DMUs that have not been affected by removing the storage area input: Nansha Port Ltd (Shenzhen), TPCT (Tianjin), SECT (Shanghai), E1CT (Incheon), SNCT (Incheon), HJIT (Incheon), and Uam Pier (Busan). This means that for those terminals, there is little disparity in storage area investment. Among those terminals, two are automated container terminals. As relatively smaller terminals, the fact that the values for SNCT (Incheon) and HJIT (Incheon) were not affected is unexpected. A reasonable explanation for this is that the facet DMU numbers and lambda weight remain the same: for SNCT (Incheon) and HJIT (Incheon), the lambda weight of SYCT (Shanghai) is 0.716, the same as in the six-input model. As the results of SYCT (Shanghai) did not change, for these two automated terminals, the efficiency measures did not materially change.

As for the other automated terminals, PNC (Busan) and BNCT (Busan), the efficiency values have changed. The technical efficiency and pure technical efficiency values of PNC (Busan) have dropped by 7% and 14%, respectively. The pure technical efficiency value of BNCT (Busan) has dropped by 5%. The alteration of the average technical, pure technical, and scale efficiency values is 1.7% (decreasing), 3.5% (decreasing) and 3.6% (increasing).

Thus, comparing the alteration of the automated terminals' values with average values, it could be concluded that the storage area input contributes to the efficiency levels of PNC (Busan) and BNCT (Busan). However, from the average values it also could be summarized that the influence of storage area input is not as potentially significant as the influence of capital factors (i.e., water depth input and quay length input).

#### 4.2.4 Analysis of quay crane input

Prior to the analysis, it was assumed that the equipment variables would most affect the productivity of the automated container terminals. The results shown in Table 5 have verified this assumption. The technically and pure technically efficient DMUs in Table 5 are the same as those in the six-input model. The entire return to scale column also remains the same.

Table 5. Terminal efficiency results (without quay crane input)

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale  | Return |
|------|-------------|------------------|--------|--------|--------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000  | -      |
| 2    | Shanghai    | SIPG             | 1.000  | 1.000  | 1.000  | -      |
| 3    | Shanghai    | SMCT             | 1.000  | 1.000  | 1.000  | -      |
| 4    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000  | -      |
| 5    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000  | -      |
| 6    | Shenzhen    | Nansha port ltd  | 0.852  | 0.904  | 0.943  | drs    |
| 7    | Tianjin     | TPCT             | 0.844  | 0.884  | 0.954  | irs    |
| 8    | Shanghai    | SECT             | 0.836  | 0.907  | 0.921  | drs    |
| 9    | Xiamen      | XHDCT            | 0.730  | 1.000  | 0.730  | irs    |
| 10   | Busan       | PNC              | 0.656  | 0.839  | 0.783  | drs    |
| 11   | Shanghai    | SPCT             | 0.613  | 0.673  | 0.910  | drs    |
| 12   | Busan       | PNIT             | 0.451  | 0.554  | 0.814  | drs    |
| 13   | Busan       | HPNT             | 0.429  | 0.592  | 0.726  | drs    |
| 14   | Shenzhen    | GCT              | 0.387  | 1.000  | 0.387  | irs    |
| 15   | Busan       | Jaseongdae pier  | 0.357  | 0.456  | 0.784  | drs    |
| 16   | Busan       | Shinseondae pier | 0.324  | 0.382  | 0.848  | drs    |
| 17   | Busan       | BNCT             | 0.271↓ | 0.361↓ | 0.752↓ | drs    |
| 18   | Busan       | Singamman pier   | 0.266  | 0.324  | 0.820  | drs    |
| 19   | Incheon     | E1CT(south port) | 0.266↓ | 1.000  | 0.266↓ | irs    |
| 20   | Incheon     | ICT(south port)  | 0.235  | 0.242  | 0.970  | irs    |
| 21   | Busan       | Gamma Pier       | 0.228  | 0.279  | 0.820  | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.165↓ | 0.174↓ | 0.950↓ | drs    |
| 23   | Incheon     | HJIT(new port)   | 0.073↓ | 0.077↓ | 0.950↓ | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 1.000  | 0.001  | irs    |
|      | Mean        |                  | 0.541↓ | 0.694  | 0.805↓ |        |

From a rankings perspective, only Singamman Pier (Busan) (18<sup>th</sup>) and E1CT (Incheon) (19<sup>th</sup>) have exchanged places. Only three of the automated container terminals, BNCT (Busan), SNCT (Incheon), and HJIT (Incheon), experienced a decrease in pure technical efficiency, as shown in Table 5. The technical efficiency value of BNCT decreased by 9.7%; that of SNCT and HJIT decreased by 2.4% and 2.7%, respectively. Though the effects could be considered as slight, these results prove that the contribution to efficiency of the quay crane input is remarkable. However, this is not reflected in the efficiency performance of the other automated terminal, PNC (Busan). This is because PNC possesses the largest number of quay cranes among all the terminals of South Korea, and although automated terminals have an advantage in their high capability facilities, there is no advantage derived from the quantity. Thus, to control the variables, we have to make a scatter diagram to observe the relationship between the quantity of quay cranes and the quay length.

#### 4.2.5 Analysis of gantry crane input

The result of removing the gantry crane input differs from the expected outcome. Only five terminals have been influenced by this change, and none of them are automated terminals. The technically efficient and pure technically efficient DMUs remain the same. As the efficiency values of the efficient DMUs have not changed, there is hardly any change in the efficiency values of the inefficient DMUs, which are determined mostly by the efficient DMUs. The five most influenced DMUs are Nansha Port Ltd. (Shenzhen), TPCT (Tianjin), PNIT (Busan), Shinseondae Pier (Busan), and Gamma Pier (Busan). The decrease in the technical efficiency value is around 4%, which is relatively low.

Table 6. Terminal efficiency results (without gantry crane input)

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale  | Return |
|------|-------------|------------------|--------|--------|--------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000  | -      |
| 2    | Shanghai    | SIPG             | 1.000  | 1.000  | 1.000  | -      |
| 3    | Shanghai    | SMCT             | 1.000  | 1.000  | 1.000  | -      |
| 4    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000  | -      |
| 5    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000  | -      |
| 6    | Shenzhen    | Nansha port ltd  | 0.848↓ | 0.887↓ | 0.956↑ | drs    |
| 7    | Shanghai    | SECT             | 0.836  | 0.907  | 0.921  | drs    |
| 8    | Tianjin     | TPCT             | 0.812↓ | 0.831↓ | 0.978↑ | irs    |
| 9    | Xiamen      | XHDCT            | 0.730  | 1.000  | 0.730  | irs    |
| 10   | Busan       | PNC              | 0.656  | 0.839  | 0.783  | drs    |
| 11   | Shanghai    | SPCT             | 0.613  | 0.673  | 0.910  | drs    |
| 12   | Busan       | PNIT             | 0.433↓ | 0.541↓ | 0.800↓ | drs    |
| 13   | Busan       | HPNT             | 0.429  | 0.592  | 0.726  | drs    |
| 14   | Shenzhen    | GCT              | 0.387  | 1.000  | 0.387  | irs    |
| 15   | Busan       | Jaseongdae pier  | 0.357  | 0.456  | 0.784  | drs    |
| 16   | Busan       | Shinseondae pier | 0.310↓ | 0.372↓ | 0.833↓ | drs    |
| 17   | Busan       | BNCT             | 0.300  | 0.373  | 0.804  | drs    |
| 18   | Incheon     | E1CT(south port) | 0.269  | 1.000  | 0.269  | irs    |
| 19   | Busan       | Singamman pier   | 0.266  | 0.324  | 0.820  | drs    |
| 20   | Incheon     | ICT(south port)  | 0.235  | 0.242  | 0.969↓ | irs    |
| 21   | Busan       | Gamma Pier       | 0.221↓ | 0.273↓ | 0.811↓ | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.169  | 0.175  | 0.969  | drs    |
| 23   | Incheon     | HJIT(new port)   | 0.075  | 0.078  | 0.969  | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 1.000  | 0.001  | irs    |
|      | Mean        |                  | 0.540↓ | 0.690  | 0.809  |        |

#### 4.2.6 Analysis of terminal transfer vehicle input

Table 7 shows the efficiency results from removing the terminal transfer vehicle input and they were completely unexpected. The vehicle (namely the terminal transfer vehicle) input stands for the investment in the horizontal transportation facilities. As the quantity and type of these facilities vary significantly, depending on the terminal, it was expected that the result would change materially. However, only one DMU has been influenced. The efficient DMUs remain the same as those in Table 6, and the rank of the only influenced DMU, SECT (Shanghai), has dropped from 8<sup>th</sup> to 10<sup>th</sup> place. The technical efficiency and pure technical efficiency values of SECT (Shanghai) have both decreased, reaching 0.636 and 0.658, respectively. This represents a decrease of 24% in technical efficiency and 27% in pure technical efficiency. The scale efficiency value has increased by 5%. SECT (Shanghai) is in charge of the Shanghai Waigaoqiao Phase-4 Terminal. The company started operations in February 2003, and it continues to perform well in gateway operations using a “smart”

gateway, which combines a recognition system for seal numbers, RFID scanning techniques, and EDI techniques. Though the efficiency of gateway operations has not been taken into consideration in this model, a smart gateway would help promote the efficiency of horizontal transportation operations. This may explain the alternation of SECT (Shanghai).

The alternation of the average efficiency values appears to be influenced by SECT (Shanghai), reflecting a 1.7% decrease in technical efficiency value and a 1.4% decrease in pure technical efficiency value. With only a 0.2% increase in scale efficiency value, we consider the influence of vehicle input to be limited.

Table 7. Terminal efficiency results (without transfer vehicle input)

| Rank | Port        | Terminal         | CRS-TE | VRS-TE | Scale  | Return |
|------|-------------|------------------|--------|--------|--------|--------|
| 1    | Shanghai    | SYCT             | 1.000  | 1.000  | 1.000  | -      |
| 2    | Shanghai    | SIPG             | 1.000  | 1.000  | 1.000  | -      |
| 3    | Shanghai    | SMCT             | 1.000  | 1.000  | 1.000  | -      |
| 4    | Shanghai    | SSICT            | 1.000  | 1.000  | 1.000  | -      |
| 5    | Lianyungang | LNOCT            | 1.000  | 1.000  | 1.000  | -      |
| 6    | Shenzhen    | Nansha port ltd  | 0.852  | 0.904  | 0.943  | drs    |
| 7    | Tianjin     | TPCT             | 0.844  | 0.884  | 0.954  | irs    |
| 8    | Xiamen      | XHDCT            | 0.730  | 1.000  | 0.730  | irs    |
| 9    | Busan       | PNC              | 0.656  | 0.839  | 0.783  | drs    |
| 10   | Shanghai    | SECT             | 0.636↓ | 0.658↓ | 0.967↑ | drs    |
| 11   | Shanghai    | SPCT             | 0.613  | 0.673  | 0.910  | drs    |
| 12   | Busan       | PNIT             | 0.451  | 0.554  | 0.814  | drs    |
| 13   | Busan       | HPNT             | 0.429  | 0.592  | 0.726  | drs    |
| 14   | Shenzhen    | GCT              | 0.387  | 1.000  | 0.387  | irs    |
| 15   | Busan       | Jaseongdae pier  | 0.357  | 0.456  | 0.784  | drs    |
| 16   | Busan       | Shinseondae pier | 0.324  | 0.382  | 0.848  | drs    |
| 17   | Busan       | BNCT             | 0.300  | 0.373  | 0.804  | drs    |
| 18   | Incheon     | E1CT(south port) | 0.269  | 1.000  | 0.269  | irs    |
| 19   | Busan       | Singamman pier   | 0.266  | 0.324  | 0.820  | drs    |
| 20   | Incheon     | ICT(south port)  | 0.235  | 0.242  | 0.970  | irs    |
| 21   | Busan       | Gamma Pier       | 0.228  | 0.279  | 0.820  | drs    |
| 22   | Incheon     | SNCT(new port)   | 0.169  | 0.175  | 0.969  | drs    |
| 23   | Incheon     | HJIT(new port)   | 0.075  | 0.078  | 0.969  | drs    |
| 24   | Busan       | Uam pier         | 0.001  | 1.000  | 0.001  | irs    |
|      | Mean        |                  | 0.534↓ | 0.684↓ | 0.811↑ |        |

## 5. CONCLUSION

This study describes the efficiency performance of automated container terminals in China and Korea through DEA analysis. From the results of the analysis, the most efficient terminals are SYCT (Shanghai), SIPG (Shanghai), SMCT (Shanghai), SSICT (Shanghai), and LNOCT (Lianyungang). The Yangtze River Delta area ports perform more efficiently relative to their counterparts elsewhere. The terminals located along the Chinese coastline are ranked in the middle, and the terminals of South Korea perform relatively less efficiently.

The automated container terminals—PNC and BNCT from the Port of Busan and SNCT and HJIT from the Port of Incheon—demonstrate less than satisfactory levels of operational efficiency; only PNC is slightly above the average efficiency values. It is important to note that for these terminals, port construction was in process during the research period, so the hysteric nature likely impacted the results. Although, the superiority of automated container terminals is not as distinct as might be expected, the contribution to efficiency caused by the quay crane input variable could be clearly observed. There is reason to believe that a

time-series DEA analysis would highlight this feature more prominently.

This study contributes to the extant research on the DEA approach by being the first to apply DEA to a comparison between automated and traditional container ports. This paper does not suggest any theory or formulation, but rather an approach to find meaningful practical information by conducting sensitivity analyses. Through these analyses, this study has also identified input factors that are not always strongly correlated each other. While substantial research has analyzed the port industry using the DEA approach, the limited availability of terminal data has caused many challenges. This study distinguishes between automated and traditional container ports by accounting for their terminal facilities, such as gantry cranes and AGVs. Thus, a direct observation could be obtained through the DEA model's results.

However, this study has several limitations. First, in considering DEA as a method for identifying best practices among peer DMUs, its ability to analyze inefficient objects is sub-optimal. In addition, due to limited data availability, this study used panel data, and changes in technical efficiency and technology are difficult to analyze using only one year of data. Second, the factors influencing port performance far surpass what this paper has considered. The manpower factor, including the number of employees and management factors, such as the proportion of private-sector participation, would also impact port efficiency. Third, wide disparities exist among container terminals; whether a port is a transshipment or gateway port also significantly affects output factors. A disadvantage of the DEA method is that the boundaries of the production functions it measures are deterministic. Therefore, all random interference terms are considered to be efficiency factors. At the same time, the evaluation of this method is susceptible to extremes. Therefore, research on automated container terminals' efficiency could be more thoroughly explored if more container terminal data became available in the future.

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