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# DEA와 DEA/Window 분석을 이용한 중남미 항만의 운영 효율성 변화 분석에 관한 연구*

임 병 학**
(Leem, Byung-Hak)

<Abstract>

## Using DEA and DEA/Window Analysis to Analyze Operation Efficiency Variation of Middle and South America Seaports through Window

In this paper Data Envelopment Analysis (DEA) cross-section data and window analysis are used to determine the relative efficiency of leading 10 ports in the Middle and South Americans countries. The results of cross-section provide information for the overall time period. The panel data provide large details of performance analysis over a period of time. The cross-sectional data analysis shows that the average efficiency value increases from year 2000 to 2005, and the efficiency of four seaports is declined, while the other is rising from year 2004. On the other hand, panel data

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** Associate professor, Division of Business Administration, Pusan University of Foreign Studies
E-mail: bhleem@pufs.ac.kr

analysis explains that overall average efficiency of seaports from window 1 to window 3 is rising constantly except some ports. At the point of 2004, efficiency for most ports in window 4 is declining. This seems to imply that for increasing port efficiency, outputs should be encouraged to increase the scale of production; on the other hand, the inefficient ports with declining efficiency reduce their scale of operation to be efficient.

[Key Words: Middle and South America Seaports, Data Envelopment Analysis, Windows Analysis, Efficiency, Panel Data, Scale Efficiency]

## 1. Introduction

Global economies are rapidly changing. Also, they are shifting from the tripolar one that consisted of the North American, European and Asian economies to a multipolar system. As for Latin America, its economy is predominantly supported by Brazil and will be promoted by the implementation of the expansion plan of the Panama Canal. Additionally, abundant natural resources such as iron ore, copper and ethanol production are key factors to realize its growth potentiality as one of the world's most important logistics markets. Fig 1 shows the seaport locations of Middle and South America.

Fig. 1 Seaports Locations of Middle and South America

Logistics markets of Seaports in Middle and South America are divided into four regions. First of all, there is Middle America and Caribbean at North, which consist of transshipment seaports. Major ports of them are San Juan (Puerto Rico), Kingston (Jamaica), Puerto Manzannillo, Coco Solo (Panama), and Manzanillo (Mexico). The next is the western and pacific coast that Peru and Chile are located. Major ports are San Antonio (Chile) and Callao (Peru). The third region is eastern seaport. Santos seaport of Brazil plays a leading part as major hub ports. The final region is logistics market focused on Buenos Aires port (Argentina).

The container throughput of major countries of Middle and South America in 2005 is about 27,340, 000 TEU, which is 10% of the world's throughput. On the one hand transshipment throughput of Middle and South America seaports is 25.4%, compared with 27.1% of world average throughput.

Middle America and Caribbean of them are 41.2% and South America 9.1%. Middle America and Caribbean handles mainly transshipment freights, but South America does import and export freights. Indeed, it is meaningful to analyze whether these ports are operated efficiently or effectively (Yang, 2007).

Therefore, this paper is to analyze productivity of seaports over times using DEA and Window analysis and to provide operational efficiency and managerial insights. This paper is further organized as follows. The next section provides literature reviews and theoretical background. Later, research model, variable selection, and then an empirical analysis of measuring ports operational efficiency are provided. Finally, this study comes with a summary, limitations of this study and direction for further paper.

## 2. Literature Reviews

Since performance covers diverse purposes and types of organizations / levels, it is a multidimensional construct. A number of studies have been argued that a multi-factor performance measurement model may be used. The development of a multi-factor performance measure which reconciles diverse financial and operational performance measures is important because it may let policy makers to know how far a particular industry or company can be expected to increase its multiple outputs and decrease its inputs levels by simply improving its efficiency, without absorbing or wasting further resources (Zhu, 1996).

Data Envelopment Analysis (DEA) has applied to a wide diversity of business fields and in particular to container terminals to measure financial and operational efficiency. Ahmed Salem Al-Eraqi, et al. (2008) analyzed 22 seaports in the Middle East and East African region for 6 years (2000 - 2005) with Berth Length (m), Storage Area (m2), and Handling Equipment as inputs, and Ship Calls (Units), Throughput (Tons) as outputs. Carvalho (2007) analyzed forty one ports from eleven European countries using DEA models, using as inputs Operational Expenses (OPEX) and Capital Expenses (CAPEX); and as outputs conventional general cargo, containerized cargo, roll on-roll off cargo, dry bulk cargo, liquid bulk cargo and passengers. The study concluded that all the Portuguese ports had very low efficiency scores except Lisbon which was deemed as efficient due to a very high volume of passenger traffic. Wang & Cullinane (2006) focused on measuring the efficiency of container terminals in Europe. They proposed DEA with CCR and BCC models to evaluate efficiency. They concluded that management skills are crucial and emerge as a core in terms of business competence. Cullinane, et al. (2005) used DEA to highlight the major objective of port privatization to improve the efficiency of this sector, with data of the container throughput as output and area and length terminal, quay crane, yard crane, straddle as inputs. These authors concluded that public and private/public ports perform better than public/private and private ports. Barros (2006) evaluated the performance of 24 Italian seaports for the 2002 -2003 period using multiple efficiency models, such as DEA CCR, BCC, Cross efficiency DEA and DEA Super efficiency, whereas previously published articles were limited to one or two analysis models. Because of

this, the general conclusion emerged that the Italian companies display relatively high management skills, with most of them being Variable Return to Scale (VRS) efficient. This study also provides benchmarks to improve the functioning of the port in terms of efficiency. Lee, et al. (2005) analyzed and compared efficiency by RDEA and DEA method for 16 ports in Asia Pacific region, using as inputs No. of Cranes, No. of Container berths, No. of tugs, Terminal area (m2), Delay time (h) and Labor (units), and as outputs TEUs handled and Ship rate. Cullinane, et al. (2004) applied window analysis in order to evaluate the efficiency score of the world's major container ports over time by using panel data and cross-section data for 2003. They concluded that the cross-section method is poor because it does not provide details of port performance, whereas the panel data with window analysis reflect a variation of the absolute performance of a port over time, and the relative performance of that port in comparison to the others at the same time. Barros & Manolis (2004) compared the efficiency of ports of two European countries, Greece and Portugal. They took data from several ports of each of these countries during the 1998-2000 periods. Their paper is intended to evaluate the efficiency of major seaports in two small European countries using the CCR and BCC models.

As seen in the above studies, it is difficult to find researches which evaluated a dynamic efficiency of Middle and South America seaports. Therefore, the purpose of this research is to measure the efficiencies with DEA and DEA/Window and then show the desirable improvement direction of key indices to improve efficiencies with benchmarking strategies, especially for the inefficient seaports.

Table 1. Summary of literature reviews

| Researcher(year) | Analysis Areas (year) | Inputs | Outputs |
|---|---|---|---|
| Cullinane et al. (2004) | the world's major 30 container ports for 2003 | Quay length(m)<br>Terminal Area(ha)<br>Quayside Gantry (number)<br>Yard Gantry (number)<br>Straddle Carrier (number) | Throughput (TEU) |
| Barros & Manolis (2004) | Ports of two European countries, Greece and Portugal during the 1998–2000 periods | number of employees<br>book value of assets | number of ships<br>tons of freight moved<br>tons of cargo handled<br>tons of containers handled |
| Lee, et al. (2005) | 16 Ports in Asia Pacific Region (1996) | No. of Cranes, No. of Container berths, No. of tugs, Terminal area (m2), *Delay* time (h) and *Labor* (units). | TEUs handled,<br>Ship rate |
| Cullinane et al. (2005) | | area and length terminal, quay crane, yard crane, straddle | container throughput |
| Wang & Cullinane (2006) | 104 European container Terminals (2003) | total berth length<br>terminal area<br>equipment costs | TEUs handled |
| Barros (2006) | Italian 24 seaports for the 2002–2003 period | number of employees<br>investment<br>operating costs | liquid bulk<br>dry bulk<br>number of ships<br>number of passengers<br>number of containers with TEU<br>number of container with no TEU<br>total sales |

| | | | |
|---|---|---|---|
| Carvalho (2007) | 41 ports from eleven European countries (2003-2005) | Operational expenses<br>Capital expenses | Conventional general cargos<br>Containerized cargos<br>Ro-ro cargo<br>Dry bulk cargo<br>Liquid bulk cargo<br>Passengers |
| Ahmed Salem Al-Eraqi, et al. (2008) | 22 seaports in the Middle East and East African region for 6 years (2000 - 2005) | Berth Length(m)<br>Storage Area(m2)<br>Handling Equipment | Ship Calls (Units)<br>Throughput (Tons) |

# 3. Theoretical Backgrounds

## 3.1. CCR and BCC Model

DEA is an empirical procedure to estimate the relative efficiency score of any group of company operations, or department of a particular firm over time. Today, DEA is well-known as a productivity analysis tool for assessing the performance of a homogeneous set of Decision Making Units (DMUs), which are described by their multiple input and output measures. The term DEA and the CCR model were first coined in 1978 (Charnes, Cooper and Rhodes, 1978) and were followed by a phenomenal expansion of DEA in terms of its theory, methodology and application over the last few decades. Among other models in the context of DEA, the two most widely used DEA models, named DEA CCR and BCC models, deserve greater attention, especially since they are utilized later in this paper. The DEA-CCR model

assumes constant returns to scale so that all observed production combinations can be scaled up or down proportionally. The DEA-BCC model, on the other hand, allows for variable returns to scale and is graphically represented by a piecewise linear convex frontier.

Formally, let inputs be $x_k=(x_{1k}, x_{2k} \cdots x_{Mk}) \in R^M$ to produce outputs $y_k=(y_{1k}, y_{2k} \cdots y_{Nk}) \in R^N$. The row vectors $x_k$ and $y_k$ form the kth rows of the data matrices X and Y, respectively. Let $\lambda=(\lambda_1, \lambda_2 \cdots \lambda_k) \in R^k$ be a non-negative vector, which forms the linear combinations of the k firms.

The output-oriented DEA model seeks to maximize the proportional increase in output while remaining within the production possibility set. An output - oriented efficiency measurement problem can be written as a series of K linear programming envelopment problems, with the constraints differentiating between the DEA-CCR and DEA-BCC models, as shown in Equations (1) through (5).

$$\text{Maxmize} \quad \theta \tag{1}$$

$$\text{Subject to} \quad \theta\chi_o - X\lambda \le 0 \tag{2}$$

$$Y\lambda - y_o \le 0 \tag{3}$$

$$\lambda \ge 0 \text{ (CCR Model)} \tag{4}$$

$$\sum_i \lambda_i = 1 \text{ (BCC Model)} \tag{5}$$

The combination of Equations from (1) through (4) and (1) through (5), respectively, form the DEA-CCR and DEA-BCC models. The output-oriented measure of technical efficiency of the k -th DMU, denoted by TEk, can be computed by equation (6).

$$TE_k = 1 / \Theta_k. \qquad (6)$$

The technical efficiency derived from DEA-CCR and DEA-BCC models are frequently used to obtain a measure of scale efficiency, as shown in equation (7) (Cooper, Seiford and Tone, 2000).

$$SE_k = \Theta_{CCR_k} / \Theta_{BCC_k}. \qquad (7)$$

Where $SE_k$, indicates scale efficiency and $\Theta_{CCR_k}$ and $\Theta_{BCC_k}$. are the estimated technical efficiency of $DMU_k$ respectively derived from the DEA-CCR and DEA-BCC models. $SE_k$ =1 indicates scale efficiency and $SE_k$ < 1 indicates scale inefficiency. Scale inefficiency is due to either increasing or decreasing returns to scale which can be determined by inspecting the sum of weights, λ, under the specification of the CCR model. If this sum is equal to one, the law of constant returns to scale prevails, whereas increasing returns to scale and decreasing returns to scale prevail when the sum is less than or greater than one.

CCR efficiency assuming constant return to scale (CRS) is said to technical efficiency, while BCC efficiency assuming variable to return to scale (VRS) is said to pure technical efficiency. Using these concepts technical efficiency can decompose of pure technical efficiency and scale efficiency as equation (8). This equation is used to analyze whether the causes of inefficiency come from either inefficient operation or unfavorable conditions by scale or both.

Technical efficiency ($TE_{CCR}$) = Pure technical efficiency ($TE_{BCC}$) x Scale efficiency ($SE_k$) (8)

### 3.2 DEA/Window Model

DEA is initially used to analyze cross-sectional data, where a given DMU is compared with all other DMUs that produce during the same time period and where the role of time is ignored. However, this can be rather misleading since a dynamic context may give rise to seemingly excessive use of resources that are intended to produce beneficial results in future periods. As such, panel data prevail over cross-sectional data in that not only do they enable a DMU to be compared with other counterparts, but also because the movement of efficiency of a particular DMU can be tracked over a period of time. In so doing, panel data are more likely to reflect the real efficiency of a DMU.

Initiated by Charnes, Clark, Cooper and Golany (1985), windows analysis is a time dependent version of DEA. The basic idea is to regard each DMU as if it were a different DMU in each of the reporting dates. Then each DMU is not necessarily compared with the whole data set, but instead only with alternative subsets of panel data. The windows analysis is based on the assumption that what was feasible in the past remains feasible forever, and that the treatment of time in windows analysis is more in the nature of an averaging over the periods of time covered by the window.

The method that captures the variations of efficiency over time assesses the performance of a DMU over time by treating it as a different entity in each time period and also allows for tracking the performance of a unit or a process. For example, if there are n units with data on their input and output measures in k periods, then a total of nk units need to be assessed simultaneously to capture the efficiency variations over time. In the

traditional window analysis described above, when a new period is introduced into the window the earliest period is dropped out. A variation to this method was proposed by Talluri et al. (1997) to effectively monitor the performance of a unit over time and assist in process improvement and benchmarking.

## 4. Research Model and Variable Selection

### 4.1 Research Model

Fig 2 shows the research model for this study. The study considers seaport operation and management as a system which is producing outputs by inputs. Inputs of the model are number of berth, berth length (m), and Storage (m2), and output is container throughput (TEU). The primary outcomes of the seaports operation are efficiency and profitability. The efficiency can be measured as a ratio of inputs to outputs. This study analyzes 10 seaports at Middle and South American with data from Containerization International Yearbook 2007 and Ports Authorities of each port from 2000 to 2005 using DEA and DEA/Window.

### 4.2 Inputs and Outputs Variable Selection

The choice of inputs and outputs is a critical decision when performing an efficiency evaluation. Different variables originate different results. One

must ensure that the model results are actually pointing in the right direction. An incorrect or less scrutinized choice of variables may induce biased results. In this study this choice was especially difficult because the previous literature is scarce. In addition, literatures reviewed focus mainly on container terminals efficiency and not on the port as a whole as this study does. This research selected the container throughput (TEU) as outputs, and number of berth, berth length (m), and Storage (m2) as input variables based on previous studies as mentioned in literature review.

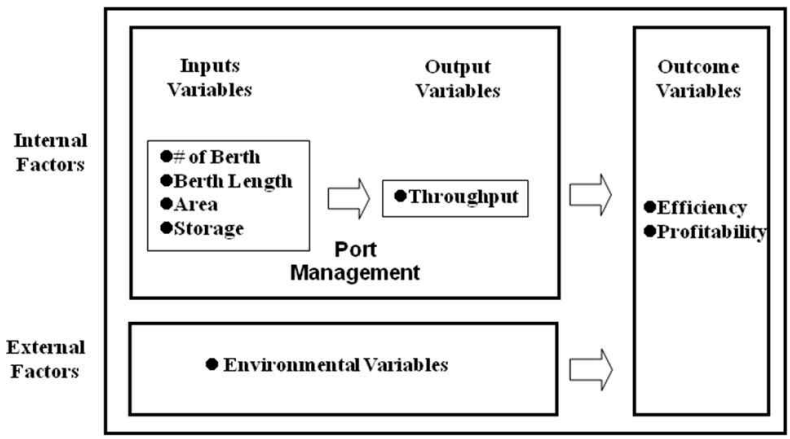


Fig. 2. Research Model

## 4.3 Data Collection

The sample for analysis comprised a total of 10 ports. The required secondary data are mainly taken from various issues of both the Containerization International Yearbook 2007 and Ports Authorities of each

port. And data that Korea Maritime Institute (KMI) performed in 2007 also was chosen as the basis for the analysis. The inputs remain unchanged within this time; by contrast, change occurred in the cargo throughput. To estimate the efficiency of the ports under study, this paper used data for the years 2000−2005; the ports considered in analysis are listed in Table 2 and the summary of their characteristics are described in Table 3. The output is measured by one indicator: Throughput (movement of general cargo dry and liquids and containers) load/unload, while the inputs are measured by the indicators, such as number of berth, berth length, and storage area.

## 5. Empirical Analysis

### 5.1 Efficiency Change Analysis by Cross−sectional Data

This study uses inputs and outputs data of seaports each year and analyzes efficiency change by year of 10 seaports for five years. Efficiency values by model mentioned in chapter 3 are reorganized as Table 4. Fig 2 shows the graph to compare seaport efficiency of Middle and South Americans by year and by seaport.

Table 2 Characteristics of seaports in Middle and South America regions at 2005

| No. | Seaport | Nation | Throughput (1000 TEU) | # of Berth (no.) | Area (m2) | Berth Length (m) | Storage (TEU) |
|---|---|---|---|---|---|---|---|
| 1 | Santos | Brazil | 1,464 | 12 | 691,000 | 2,410 | 30,000 |
| 2 | San Juan | Puerto Rico | 1,695 | 9 | 46,800 | 1,688 | 6,200 |
| 3 | Kingston | Jamaica | 1,164 | 16 | 1,080,000 | 3,254 | 15,788 |
| 4 | Puerto Manzannillo | Panama | 1,185 | 5 | 52,000 | 1,660 | 46,500 |
| 5 | Buenos Aires | Argentina | 895 | 15 | 1,270,500 | 4,487 | 352,995 |
| 6 | Callao | Peru | 609 | 18 | 441,080 | 4,000 | 3,700 |
| 7 | Manzanillo | Mexico | 656 | 12 | 318,000 | 2,205 | 19,000 |
| 8 | Coco Solo | Panama | 444 | 2 | 25,000 | 612 | 5,850 |
| 9 | San Antonio | Chile | 534 | 5 | 482,601 | 1,155 | 17,100 |
| 10 | Puerto Cabello | Venezuela | 562 | 25 | 211,400 | 6,380 | 8,000 |

Table 3 Summary statistics for years 2000-2005

| | Throughput | # of Berth | Area | Berth Length | Storage |
|---|---|---|---|---|---|
| Max | 1,695 | 25 | 1,270,500 | 6,380 | 352,995 |
| Min | 444 | 2 | 25,000 | 612 | 3,700 |
| Average | 921 | 11.9 | 461,838.1 | 2,785.1 | 50,513.3 |
| SD | 434.25 | 6.61 | 412,782.68 | 1,668.59 | 101,589.77 |

According to DEA-CCR efficiency, San Juan seaport at Puerto Rico is relatively most efficient; Puerto Manzannillo (0.98) and Coco Solo (0.69) at Panama are followed. The others are low efficient less than 0.5. Efficiency values for year 2004 (0.64) and 2005 (0.63) are relatively higher than the other years. The efficiency value increases from year 2000 to 2005.

According to Efficiency Change by Year (Fig 3), San Juan and Puerto Manzannillo are consistent in high efficiency every year. Coco Solo rises constantly and is relatively efficient at 2005. Fig 2 shows that efficiency of

four seaports is declined, while the other is rising at the point of 2004.

Table 4. Efficiency of Middle and South American Seaports by Year

| | | Santos | San Juan | Kingston | Puerto Manzan | Buenos Aires | Callao | Manzanillo | Coco Solo | San Antonio | Puerto Cabello | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | CCR | 0.319 | 1.000 | 0.229 | 0.971 | 0.359 | 0.368 | 0.174 | 0.492 | 0.436 | 0.227 | 0.46 |
| | BCC | 0.412 | 1.000 | 0.368 | 1.000 | 0.368 | 1.000 | 0.342 | 1.000 | 0.669 | 0.666 | 0.68 |
| | SE | 0.77 | 1.00 | 0.62 | 0.97 | 0.98 | 0.37 | 0.51 | 0.49 | 0.65 | 0.34 | 0.67 |
| | RTS | IRS | CRS | IRS | IRS | IRS | IRS | IRS | IRS | IRS | IRS | |
| 2001 | CCR | 0.430 | 1.000 | 0.302 | 0.944 | 0.213 | 0.379 | 0.192 | 0.507 | 0.366 | 0.255 | 0.46 |
| | BCC | 0.485 | 1.000 | 0.377 | 1.000 | 0.254 | 1.000 | 0.353 | 1.000 | 0.625 | 0.668 | 0.68 |
| | SE | 0.88 | 1.00 | 0.80 | 0.94 | 0.84 | 0.38 | 0.54 | 0.51 | 0.59 | 0.38 | 0.69 |
| | RTS | IRS | CRS | IRS | IRS | IRS | IRS | IRS | IRS | IRS | IRS | |
| 2002 | CCR | 0.646 | 1.000 | 0.427 | 1.000 | 0.178 | 0.691 | 0.351 | 0.629 | 0.532 | 0.281 | 0.57 |
| | BCC | 0.485 | 1.000 | 0.377 | 1.000 | 0.254 | 1.000 | 0.353 | 1.000 | 0.625 | 0.668 | 0.68 |
| | SE | 1.33 | 1.00 | 1.13 | 1.00 | 0.70 | 0.69 | 0.99 | 0.63 | 0.85 | 0.42 | 0.87 |
| | RTS | IRS | CRS | IRS | IRS | IRS | IRS | IRS | IRS | IRS | IRS | |
| 2003 | CCR | 0.688 | 1.000 | 0.381 | 1.000 | 0.275 | 0.556 | 0.325 | 0.857 | 0.530 | 0.177 | 0.58 |
| | BCC | 0.689 | 1.000 | 0.389 | 1.000 | 0.286 | 1.000 | 0.414 | 1.000 | 0.662 | 0.658 | 0.71 |
| | SE | 1.00 | 1.00 | 0.98 | 1.00 | 0.96 | 0.56 | 0.79 | 0.86 | 0.80 | 0.27 | 0.82 |
| | RTS | IRS | CRS | IRS | CRS | IRS | IRS | IRS | IRS | IRS | IRS | |
| 2004 | CCR | 0.803 | 1.000 | 0.450 | 1.000 | 0.282 | 0.620 | 0.381 | 0.987 | 0.587 | 0.278 | 0.64 |
| | BCC | 1.000 | 1.000 | 0.450 | 1.000 | 0.292 | 1.000 | 0.438 | 1.000 | 0.693 | 0.663 | 0.75 |
| | SE | 0.80 | 1.00 | 1.00 | 1.00 | 0.96 | 0.62 | 0.87 | 0.99 | 0.85 | 0.42 | 0.85 |
| | RTS | DRS | CRS | IRS | CRS | IRS | IRS | IRS | IRS | IRS | IRS | |
| 2005 | CCR | 0.711 | 1.000 | 0.474 | 0.920 | 0.181 | 0.861 | 0.311 | 1.000 | 0.506 | 0.329 | 0.63 |
| | BCC | 1.000 | 1.000 | 0.526 | 1.000 | 0.215 | 1.000 | 0.312 | 1.000 | 0.530 | 0.658 | 0.72 |
| | SE | 0.71 | 1.00 | 0.90 | 0.92 | 0.84 | 0.86 | 1.00 | 1.00 | 0.95 | 0.50 | 0.87 |
| | RTS | DRS | CRS | DRS | DRS | DRS | IRS | CRS | CRS | CRS | IRS | |
| Average | CCR | 0.58 | 1.00 | 0.36 | 0.98 | 0.26 | 0.52 | 0.28 | 0.69 | 0.49 | 0.24 | 0.54 |
| | BCC | 0.61 | 1.00 | 0.39 | 1.00 | 0.29 | 1.00 | 0.38 | 1.00 | 0.65 | 0.66 | 0.70 |
| | SE | 0.96 | 1.00 | 0.91 | 0.98 | 0.89 | 0.52 | 0.74 | 0.69 | 0.75 | 0.37 | 0.78 |

CCR: Charnes, Cooper and Rhodes, BCC: Banker, Charnes and Cooper, SE: Scale Efficiency, RTS: Return to Scale

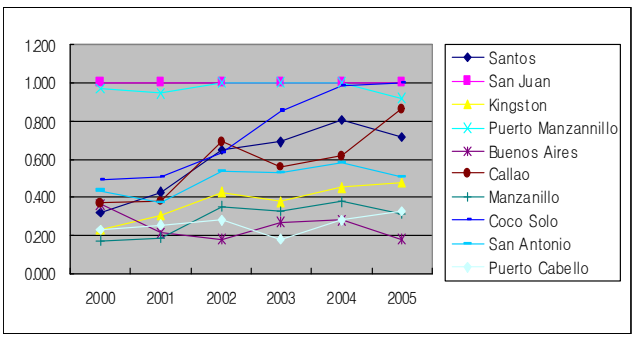


Fig. 3 Efficiency Change by Year

Seaports which pure technical efficiency assuming VRS is one are five, and technical efficiency of San Juan and Coco Solo of them also is one at 2005. And then scale efficiency of only these two is one. The scale efficiency of Puerto Cabello is less than 0.5 with CCR efficiency 0.329 and BCC efficiency 0.658. This indicates that Puerto Cabello operated inefficiently and is unfavorable situation as small-sized scale. In return to scale four seaports has DRS, four CRS, and the others IRS. This shows that since seaports with DRS have large-sized scale relatively, they have to reduce their scale and improve their efficiency.

## 5.2 Efficiency Variation Analysis by Panel Data

This section analyzes operational efficiency of Middle and South American with panel data from 2000 to 2005 using DEA/Window technique. In this study length and number of window is 3 years and 4, respectively. Efficiency values by DEA/Window model mentioned in chapter 3 are reorganized as Table 5. Fig 4 and 5 show the graph to analyze seaport efficiency variation trend of Middle and South Americans through window. The DEA/Window analysis is to obtain efficiency value comparing seaports operation with similar times or similar situation.

Taking Santos port of Brazil as an example, in Table 4 the efficiency of Santos port in the first window is 0.319, 0.417 and 0.487. These figures correspond to the estimated relative efficiency of Santos port for 2000, 2001 and 2002. In the third window, relative efficiency estimates of 52.2, 66.5 and 80.3. According to Fig 3 and 4, overall average efficiency of seaports from window 1 to window 3 is rising constantly except some ports. At the

point of 2004, average efficiency value of most ports in window 4 is declining. They need to benchmark seaports with high efficiency value and strive to improve their efficiency and profitability.

## 5.3 Scale Efficiency Variation Analysis

Scale efficiency measure can be calculated by dividing the technical efficiency by pure technical efficiency as mentioned at equation (7). This scale efficiency can be interpreted as follows: (1) if SE = 1, then a seaport is scale efficiency, i.e. its combination of inputs and outputs are efficiency both under CRS and VRS. (2) If SE <1, then combination of inputs and outputs is not efficient. This approach does not allow identifying whether a seaport operates under increasing return to scale (IRS) or decreasing return to scale (DRS). This problem can be solved by application of further DEA model.

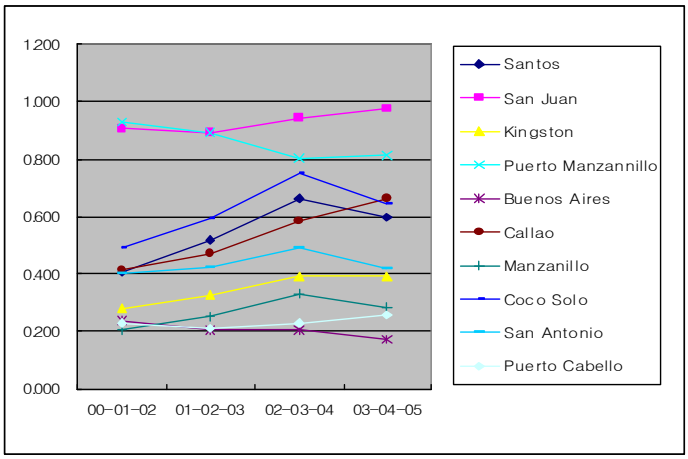


Fig 4. Efficiency Variation through Window

Table 6 details the scale properties of each seaport at different times and over different windows. Most seaports (90% or more) at window 1, window 2, and window 3 exhibit increase return to scale and 37% at window 4 exhibits increase return to scale and decrease return to scale, compared to 27% in constant return to scale. This indicates that production scale is the main source of inefficiency for most seaports.

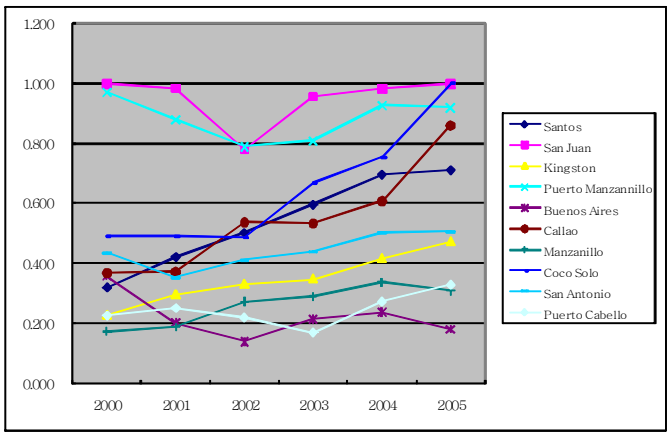


Fig 5. Efficiency Variation by Year

Table 5. Result of DEA/Window Analysis based on CCR-I Model

| Ports | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average | Column Average | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|
| Santos | 0.319 | 0.417 | 0.487 | | | | 0.408 | 0.547 | 0.110 |
| | | 0.425 | 0.496 | 0.633 | | | 0.518 | | |
| | | | 0.522 | 0.665 | 0.803 | | 0.664 | | |
| | | | | 0.489 | 0.590 | 0.711 | 0.597 | | |
| San Juan | 1.000 | 0.971 | 0.740 | | | | 0.904 | 0.929 | 0.039 |
| | | 1.000 | 0.762 | 0.910 | | | 0.891 | | |
| | | | 0.836 | 0.999 | 1.000 | | 0.945 | | |
| | | | | 0.965 | 0.966 | 1.000 | 0.977 | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Kingston | 0.229 | 0.293 | 0.318 | | | | 0.280 | 0.348 | 0.056 |
| | | 0.301 | 0.326 | 0.348 | | | 0.325 | | |
| | | | 0.352 | 0.376 | 0.450 | | 0.393 | | |
| | | | | 0.323 | 0.386 | 0.474 | 0.394 | | |
| Puerto Manzannillo | 0.971 | 0.917 | 0.901 | | | | 0.930 | 0.859 | 0.061 |
| | | 0.845 | 0.830 | 1.000 | | | 0.892 | | |
| | | | 0.640 | 0.771 | 1.000 | | 0.804 | | |
| | | | | 0.661 | 0.857 | 0.920 | 0.813 | | |
| Buenos Aires | 0.359 | 0.207 | 0.154 | | | | 0.240 | 0.206 | 0.027 |
| | | 0.195 | 0.145 | 0.270 | | | 0.203 | | |
| | | | 0.119 | 0.222 | 0.282 | | 0.208 | | |
| | | | | 0.151 | 0.192 | 0.181 | 0.175 | | |
| Callao | 0.368 | 0.368 | 0.511 | | | | 0.416 | 0.534 | 0.112 |
| | | 0.379 | 0.527 | 0.506 | | | 0.471 | | |
| | | | 0.578 | 0.556 | 0.620 | | 0.584 | | |
| | | | | 0.537 | 0.599 | 0.861 | 0.665 | | |
| Manzanillo | 0.174 | 0.186 | 0.260 | | | | 0.206 | 0.269 | 0.054 |
| | | 0.192 | 0.267 | 0.296 | | | 0.252 | | |
| | | | 0.293 | 0.324 | 0.381 | | 0.333 | | |
| | | | | 0.251 | 0.295 | 0.311 | 0.286 | | |
| Coco Solo | 0.492 | 0.492 | 0.492 | | | | 0.492 | 0.621 | 0.108 |
| | | 0.492 | 0.492 | 0.802 | | | 0.595 | | |
| | | | 0.482 | 0.786 | 0.987 | | 0.752 | | |
| | | | | 0.415 | 0.521 | 1.000 | 0.645 | | |
| San Antonio | 0.436 | 0.355 | 0.419 | | | | 0.404 | 0.435 | 0.038 |
| | | 0.353 | 0.417 | 0.498 | | | 0.423 | | |
| | | | 0.402 | 0.480 | 0.587 | | 0.490 | | |
| | | | | 0.343 | 0.419 | 0.506 | 0.422 | | |
| Puerto Cabello | 0.227 | 0.248 | 0.208 | | | | 0.227 | 0.231 | 0.019 |
| | | 0.255 | 0.214 | 0.161 | | | 0.210 | | |
| | | | 0.235 | 0.177 | 0.278 | | 0.230 | | |
| | | | | 0.171 | 0.268 | 0.329 | 0.256 | | |

Table 6. Scale Efficiency based on DEA/Window Analysis

| Ports | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average | Column Average | Standard Deviation |
|---|---|---|---|---|---|---|---|---|---|
| Santos | 0.773 | 0.873 | 0.928 | | | | 0.858 | 0.869 | 0.091 |
| | | 0.910 | 0.956 | 0.991 | | | 0.952 | | |
| | | | 0.964 | 0.995 | 0.803 | | 0.921 | | |
| | | | | 0.784 | 0.743 | 0.711 | 0.746 | | |
| San Juan | 1.000 | 0.974 | 0.756 | | | | 0.910 | 0.934 | 0.037 |
| | | 1.000 | 0.778 | 0.918 | | | 0.899 | | |
| | | | 0.849 | 0.999 | 1.000 | | 0.949 | | |
| | | | | 0.969 | 0.970 | 1.000 | 0.980 | | |
| Kingston | 0.622 | 0.781 | 0.840 | | | | 0.747 | 0.876 | 0.096 |
| | | 0.804 | 0.864 | 0.916 | | | 0.861 | | |
| | | | 0.928 | 0.983 | 0.999 | | 0.970 | | |
| | | | | 0.873 | 0.996 | 0.901 | 0.923 | | |
| Puerto Manzannillo | 0.971 | 0.956 | 0.951 | | | | 0.959 | 0.952 | 0.020 |
| | | 0.967 | 0.963 | 1.000 | | | 0.977 | | |
| | | | 0.878 | 0.932 | 1.000 | | 0.937 | | |
| | | | | 0.958 | 0.927 | 0.920 | 0.935 | | |
| Buenos Aires | 0.975 | 0.839 | 0.753 | | | | 0.856 | 0.879 | 0.022 |
| | | 0.900 | 0.839 | 0.956 | | | 0.898 | | |
| | | | 0.800 | 0.926 | 0.964 | | 0.896 | | |
| | | | | 0.934 | 0.821 | 0.844 | 0.866 | | |
| Callao | 0.368 | 0.368 | 0.511 | | | | 0.416 | 0.534 | 0.112 |
| | | 0.379 | 0.527 | 0.506 | | | 0.471 | | |
| | | | 0.578 | 0.556 | 0.620 | | 0.584 | | |
| | | | | 0.537 | 0.599 | 0.861 | 0.665 | | |
| Manzanillo | 0.508 | 0.530 | 0.644 | | | | 0.561 | 0.753 | 0.163 |
| | | 0.604 | 0.710 | 0.742 | | | 0.685 | | |
| | | | 0.809 | 0.834 | 0.871 | | 0.838 | | |
| | | | | 0.822 | 0.963 | 0.997 | 0.927 | | |
| Coco Solo | 0.492 | 0.492 | 0.492 | | | | 0.492 | 0.621 | 0.108 |
| | | 0.492 | 0.492 | 0.802 | | | 0.595 | | |
| | | | 0.482 | 0.786 | 0.987 | | 0.752 | | |
| | | | | 0.415 | 0.521 | 1.000 | 0.645 | | |
| San Antonio | 0.652 | 0.571 | 0.636 | | | | 0.620 | 0.729 | 0.084 |
| | | 0.640 | 0.702 | 0.769 | | | 0.704 | | |
| | | | 0.742 | 0.792 | 0.847 | | 0.794 | | |
| | | | | 0.647 | 0.790 | 0.954 | 0.797 | | |
| Puerto Cabello | 0.341 | 0.371 | 0.314 | | | | 0.342 | 0.349 | 0.030 |
| | | 0.384 | 0.324 | 0.245 | | | 0.318 | | |
| | | | 0.357 | 0.268 | 0.419 | | 0.348 | | |
| | | | | 0.259 | 0.408 | 0.501 | 0.389 | | |

Table 7. Summary of RTS

| | | EfficientDMU | Projected DMU | Total |
|---|---|---|---|---|
| Window 1 | No. of IRS | 5 | 24 | 29 |
| | No. of CRS | 1 | 0 | 1 |
| | No. of DRS | 0 | 0 | 0 |
| Window 2 | No. of IRS | 2 | 26 | 28 |
| | No. of CRS | 2 | 0 | 2 |
| | No. of DRS | 0 | 0 | 0 |
| Window 3 | No. of IRS | 2 | 25 | 27 |
| | No. of CRS | 2 | 0 | 2 |
| | No. of DRS | 1 | 0 | 1 |
| Window 4 | No. of IRS | 1 | 10 | 11 |
| | No. of CRS | 2 | 6 | 8 |
| | No. of DRS | 2 | 9 | 11 |

## 6. Conclusions

In this paper *DEA* cross-section data and window analysis are used to determine the relative efficiency of leading 10 ports in the Middle and South Americans countries. The results of cross-section provide information for the overall time period. The panel data provide large details of performance analysis over a period of time. According to analysis using cross-sectional data the average efficiency value increases from year 2000 to 2005, and the efficiency of four seaports is declined, while the other is rising at the point of 2004. San Juan and Puerto Manzannillo are consistent with high efficiency every year. Coco Solo rises constantly and is relatively efficient at 2005. According to analysis using panel data overall average efficiency of seaports from window 1 to window 3 is rising constantly except some ports. At the point of 2004, most ports in window 4 are declining.

In order to determine the root of estimated inefficiency, the scale properties of seaports have been examined. Most ports exhibit increase returns to scale form Window 1 to Window 3, indicating that production scale is the main source of inefficiency. This seems to imply that for increasing port efficiency, ships arrival should be encouraged to increase the scale of production; on the other hand, the inefficient ports with declining efficiency reduce their scale of operation to be efficient.

Some possible reasons that may explain empirical estimates of inefficiency in port production can include differences in seaport ownership or governance, location attributes, operation perspectives and the form and

level of competition faced. Hence there is the need to do research in these issues in the future.

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