A HYBRID DATA ENVELOPMENT ANALYSIS AND SIMULATION METHODOLOGY FOR MEASURING CAPACITY UTILIZATION AND THROUGHPUT EFFICIENCY OF CONTAINER TERMINALS

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ABSTRACT

As growth in international trade slowed down in the recent years, inter-modal traffic volume declined and subsequently led to reduction in demand for container services. The reduced demand in container services and the on-going glut of container port facilities throughout the world have sparked fierce competition among international container terminals. In an effort to help port authorities develop a winning strategy in the increasingly competitive container market, this paper develops a meaningful set of benchmarks that will set the standard for best practices. In particular, we propose a hybrid data envelopment analysis (DEA)/simulation model that is designed to evaluate the relative efficiency of container terminal operations. To illustrate the usefulness of the proposed hybrid DEA/simulation model, we used the real examples of major container terminals in South Korea.

Key Words: *Container terminals, data environmental analysis, simulation*

1. INTRODUCTION

Due to the worldwide economic downturn for the past several years, growth in international trade has slowed down. Growth in international trade was estimated to be merely 2% in 2001, compared to 12% in 2000 (Boyes, 2002). Given that approximately 60% of international trade moves via water transportation (e.g., ocean carriers), slow growth in international trade significantly affects demand for container traffic and seaports (Wood et al., 2002). Since growth in international trade often dictates container traffic volume, a majority of container ports throughout the world have experienced a substantial decline in demand for their services. The entire loop of Asia/Europe and Trans-Pacific were hit hard especially by reduced container traffic. As the container traffic declines, a growing number of international container ports such as Hong Kong, Singapore, Busan, Rotterdam, Kobe, Seattle, and Long Beach suffer from the glut of container terminal facilities (e.g., the enormous slack of container berths, idle equipment, and excessive workforce). Exploiting the overcapacity of container terminals at the port, many ocean carriers ask for deep discounts in container services. With the intensified competition among container terminals, the survival of container terminals depends upon their ability to keep their operations lean.

One way to develop a survival strategy is to set a reliable performance standard for the operational efficiency (productivity) of container terminals, find out which terminals are most effective at meeting those standards, then identify the practices which make them effective. Examples of such standards include a financial audit, an industry norm, and a benchmark. Since a container terminal needs to measure its productivity relative to its competitors to constantly strengthen its market position and then gain a position of "the best of breeds," benchmarking seems to be the most effective way of setting a reliable performance standard and then measuring the operational efficiency of the container terminal.

In general, benchmarking is a continuous quality improvement process by which an organization can assess its internal strengths and weaknesses, evaluate comparative advantages of leading competitors, identify the best practices of industry leaders, and incorporate these findings into a strategic action plan geared to gain a position of superiority (Min and Galle, 1996). The main goals of benchmarking are to:

> "Identify key performance measures for each function of a business operation;
> Measure one's own internal performance levels as well as those of the leading competitors;
> Compare performance levels and identify areas of comparative advantages and disadvantages; Implement programs to close a performance gap between internal operations and the leading competitors (Furey 1987, p.30)."

In setting the benchmark, this paper will measure the operational efficiency of container terminals relative to prior periods and their competitors. The operational efficiency measured by input/output ratios can reflect the true overall productivity of container terminals better than traditional financial ratios, such as return on investments and assets that tend to focus on myopic aspects of financial performances. As a way of comparatively assessing the productivity of container terminals with multiple inputs and outputs, this paper proposes a data envelopment analysis (DEA).

In general, DEA is referred to as a linear programming (non-parametric) technique that converts multiple incommensurable inputs and outputs of each decision-making unit (DMU) into a scalar measure of operational efficiency, relative to its competing DMUs. Herein, DMUs refer to the collection of private firms, non-profit organizations, departments, administrative units, and groups with the same (or similar) goals, functions, standards and market segments. DEA is designed to identify the best practice DMU without *a priori* knowledge of which inputs and outputs are most important in determining an efficiency measure (i.e., score) and assess the extent of inefficiency for all other DMUs that are not regarded as the best practice DMUs (e.g., Charnes et al., 1978). Since DEA provides a relative measure, it will only differentiate the least efficient DMU from the set of all DMUs. Thus, the best practice (most efficient) DMU is rated as an efficiency score of one, whereas all other less efficient DMUs are scored somewhere between zero and one. To summarize, DEA determines the following (Sherman and Ladino, 1995):

- The best practice DMU that uses the least resources to provide its products or services at or above the quality standard of other DMUs;
- The less efficient DMUs compared to the best practice DMU;
- The amount of excess resources used by each of the less efficient DMUs;
- The amount of excess capacity or ability to increase outputs for less efficient DMUs without requiring added resources.

In measuring the operational efficiency of container terminals, we chose DEA over other alternative techniques, such as Cobb Douglas functions and analytic hierarchy process (AHP), because DEA reflects the multiple aspects of organizational performances, does not require *a priori* weights of performance measures, and provides valuable insights as to how operational efficiency can be improved. Also, DEA is proven to be useful for benchmarking since it can measure the relative efficiency of DMUs. Thus, we propose a two-stage, hybrid DEA/simulation model that enables the port authority to measure the relative efficiency of container terminal operations. The proposed DEA/simulation model will help the port authority establish the benchmark standard for container terminals and evaluate their competitiveness in the saturated container market.

2. LITERATURE REVIEW

In previous literature, DEA was successfully explored in measuring the operational efficiency of banks (e.g., Thanassoulis, 1999), hospitals (Valdmanis, 1992), nursing homes (Kleinsorge and Karney, 1992), purchasing departments (Murphy et al., 1996), cellular manufacturing (Talluri et al., 1997), travel demand (Nozick et al., 1998), information technology investments (Shafer and Byrd, 2000), airports (Sarkis, 2000), airport quality (Adler and Berechman, 2001), airline networks (Adler and Golany, 2001), customer service performances of less-than-truckload (LTL) motor carriers (Poli and Scheraga, 2000), and trucking firms (Min and Joo, 2003). The further details on other DEA applications during the 1970's and 1980's can be found in Seiford (1990).

Built upon the past success of applying DEA for various performance metrics, several attempts have been made to explore the possibility of applying DEA for measuring the overall performance of seaports (see Table 1). Roll and Hayuth (1993) are one of the first to apply DEA for the evaluation of seaport efficiency. In their study, port efficiency was measured in terms of throughput, level of service, port users' satisfaction, and frequency of calls made by ocean carriers. Three inputs were given: size of labor force, capital investment, and cargo uniformity. Although Roll and Hayuth (1993) considered multiple outputs, they did not use actual data to measure the port efficiency. Also, their study was limited to a single-period, cross-sectional analysis.

Martinez-Budria et al. (1999) extended the work of Roll and Hayuth (1993) to include multiple periods (1993-1997) and actual data involving 26 Spanish ports. In applying DEA for port performance evaluation, they took into account three inputs: labor expenditure, depreciation charges, and miscellaneous expenditure, while using two outputs: revenue through port rentals and the total amount of cargo moved through docks. As such, Martinez-Budria et al. (1999) focused on the financial performance of ports. Similarly, Tongzon (2001) identified factors influencing port efficiency and used six of those factors as inputs: the number of cranes, the number of container berths, the number of tugs, size of the terminal areas, length of delay, and size of labor force in measuring the efficiency of Australian ports. The outputs of his DEA model include cargo throughput and ship working rate. The DEA model developed by Tongzon (2001) was also confined to a single period.

In an effort to verify that the trend of port privatization has something to do with the improved efficiency created by private ownership, Valentine and Gray (2001) compared the efficiency of privately-owned ports with that of publicly-owned ports or that of both privately-and publicly-owned ports using the DEA model. They considered only two inputs: the total length of berth and container berth length, while using two outputs: the number of containers and total throughput. Their findings suggest that a simple organizational structure (e.g., lack of bureaucracy) often contributed to the efficiency of given container ports.

As discussed above, most of prior DEA studies on port efficiency focused on a cross-sectional analysis that aimed to capture a single-period snapshot of port performance and attempted to measure the overall efficiency of ports relative to others without recognizing the regional, organizational, and ownership differences. For instance, certain ports in North America tended to perform poorly compared to ports in Europe due to the level of competition and bureaucracy (Valentine and Gray, 2001). Also, the performance of ports prioritizing container traffic may differ from non-container ports. As such, Alderton (1999) argued that there was little that could be measured on a whole port basis; instead, terminal basis comparison made more sense than port basis comparison. To overcome some shortcomings of prior studies (i.e., comparison of "apples versus oranges"), we focus on the relative and absolute performance measurement of container terminals at the same or similar ports in the same region (e.g., country) over multiple periods. As an example, our study used actual data obtained from two major container ports (Busan and Kwangyang) and their terminals in South Korea (Korea hereafter) during the period of 1999 through 2002.

3. SPECIFICATION OF INPUT AND OUTPUT MEASURES

The assessment of operational efficiency using DEA begins with the selection of appropriate input and output measures that can be aggregated into a composite index of overall performance standards. Although any resources used by DMU should be included as input, we selected four different metrics as inputs in this study. These are: the number of gantry cranes, terminal quay length, size of yard areas, and size of labor force (e.g., number of stevedore gangs).

Since a larger number of gantry cranes can expand the loading capacity of a container terminal, gantry cranes can be a key resource for increasing cargo throughput at the container terminal. Thus, the number of gantry cranes should be chosen as one of the inputs. The quay length of a container terminal dictates the size of container vessels that the terminal can accommodate and consequently influences container volumes that can be handled at the terminal. Thus, the quay length of a container terminal is regarded as input. Similarly, a fixed asset such as size of container yard areas is considered to be input given that it can add capacity and flexibility to container traffic flows, container storage, and container maintenance and repair that are crucial for enhancing the efficiency of the container terminal. Due to the labor-intensive nature of container port operations, typical container terminals hire a large personnel consisting of managers, terminal operators, transloaders, and stevedore gangs among others; their payroll represents one of the major costs of doing business. In particular, the operational efficiency of a container terminal can be measured by the rate at which containers are loaded and discharged by a given number of employees or man-shifts. In other words, as Talley (1994) noted, size of labor force is one of the most important indicators of port or container terminal efficiency. Thus, size of labor force is included as input.

On the output side, the overall performance of container terminals can be measured by cargo throughput that represents the total volume of containers (in TEUs) loaded and unloaded at each terminal. Another good indicator for the performance of container terminals is the utilization rate of terminal capacity that shows how efficiently the existing facilities and equipment available at the container terminal are used in a given year (Frankel, 1987). These existing facilities and equipment include: quay structure, loading/unloading facilities, yard facilities, and equipment on duty. The utilization of these existing facilities and equipment are often influenced by a multitude of factors such as: type of vessel, ship maneuvering, berthing/de-berthing (berth utilization), crane allocation, ship service time, ship waiting time, stacking area's activities, and the demand of carriers/shippers. Since these factors dictate costs of ship's time in port and the subsequent total costs in port, the utilization of terminal capacity can reflect the performance of container terminals. As shown in Figure 1, notice that total costs in port are a summation of cost of ship's time in port and port costs.

Other well-known financial ratios such as profit margin and return-on investment were not considered relevant, because a less profitable terminal may be more efficient in utilizing its personnel and equipment than the more profitable terminal. For example, a favorable change in currency exchange rate, negotiation terms, wage, and tax rate can increase profitability, but not necessarily the operational efficiency (e.g., equipment utilization or labor productivity) of container terminals. In fact, Sherman (1984) observed that profit measure was not a good indicator of how efficiently resources were used to provide customer services.

With the exception of terminal capacity data, we obtained the aforementioned input and output data from the annual reports available from the Korean port authorities and Containerization International Yearbook 2002 (Degerlund, 2002). The reports shown in Table 2 listed four years of data for 11 different container terminals situated at two major international container ports (Busan and Kwangyang) in Korea. The terminals at the port of Busan were chosen because, with a port traffic volume of 7,540,387 TEU, Busan was the third largest container port in the world during 2000 (Degerlund, 2002). Although Kwangyang is a newly developed container port with a limited capacity, its expansion will continue until 2011 and grow to mirror the capacity of Busan in the next decade. Thus, we chose terminals at the port of Kwangyang for the DEA analysis. The terminals considered in this study are: Busan Jasungdae (B1); Busan Shinsundae (B2); Busan Uam (B3); Busan Gamman Sebang (B4); Busan Gamman Hanjin (B5); Busan Hutchison (B6); Busan Korex

(B7); Kwangyang Sebang (G1); Kwangyang Hanjin (G2); Kwangyang Hutchison (G3); Kwangyang Korex (G4). To keep the homogeneity of these terminals for equitable comparisons, we excluded other terminals that were built after 2000 and only included terminals within the two designated ports for the current DEA analysis. We also limited the comparison of container terminals to the ones within the same country (i.e., Korea) to maintain the homogeneity of climate, port policy, labor rules, working hours, and economic conditions.

Unlike other input and output data, terminal capacity data is not readily available for DEA analysis due to its random nature (Fararoui, 1989; Kia et al., 2002). For example, terminal capacity can be restrained by ship's service time at the quay that affects ship's waiting time depending on the ship's arrival pattern (see Figure 2). Since the ship's arrival pattern represents a random variable that can vary from one arrival to another, we decided to estimate terminal capacity data based on a simulation model shown in Figure 3. Specifically, the simulation model mimicked the ship's arrival time, service time, waiting time, departure time, and duration of ship's occupancy at the berth under a uniform distribution. Herein, we adopted a uniform distribution rather than a negative exponential distribution, since a container ship's arrival pattern seldom follows pure Poisson queues. In practice, a container ship is usually required to call a terminal a week prior to its arrival and schedule its arrival time in advance. As such, either early or late arrival is often caused by unexpected weather or ship's operating condition and subsequently a discrepancy between its actual arrival time and scheduled arrival time is not dramatic.

4. DEA/SIMULATION MODEL DESIGN AND TESTING

The DEA model, with the inputs and output summarized in Tables 2 and 3, was adopted for this study. The DEA model is mathematically expressed as:

$$\text{Maximize efficiency score } (jp) = \frac{\sum_{r=1}^{t} u_r y_{rjp}}{\sum_{i=1}^{m} v_i x_{ijp}} \qquad (1)$$

$$\text{Subject to} \quad \frac{\sum_{r=1}^{t} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad \text{j} = 1, \ldots, n, \qquad (2)$$

$$u_r, v_i \geq \varepsilon, \qquad \forall r \text{ and } i, \qquad (3)$$

where

y_{rj} = amount of output r produced by DMU j,

x_{ij} = amount of input i used by DMU j,

u_r = the weight given to output r,

v_i = the weight given to input i,

n = the number of DMUs,

t = the number of outputs,

m = the number of inputs,

ε = a small positive number.

By solving the above equations (1), (2), and (3), the efficiency of DMU (jp) is maximized subject to the efficiencies of all DMUs in the set with an upper bound of 1. The above model is solved n times to evaluate the relative efficiency of each DMU. Notice that the weights u_r and v_i are treated as unknown variables whose values will be optimally determined by maximizing the efficiency of the targeted DMU *jp*. An efficiency score (*jp*) of 1 indicates that the DMU under consideration is efficient relative to other DMUs, while an efficiency score of less than 1 indicates the DMU under consideration is inefficient. In a broader sense, an efficiency score represents a trucking firm's ability to transform a set of inputs (given resources) into a set of outputs. The above model also identifies a peer group (efficient DMU with the same weights) for the inefficient DMU (Boussofiane et al., 1991).

A complete DEA analysis was conducted by applying a non-linear fractional program formulated in equations (1)-(3) to actual data containing a sample of 11 terminals firms with four consecutive years of performance measures. To elaborate, we adopted an inter-temporal (so-called *window*) DEA analysis that aimed to capture the time-series trends of efficiency ratings. Unlike the cross-sectional DEA analysis, the inter-temporal DEA analysis disaggregates efficiency scores and input utilization rates into a series of moving average data as illustrated in Tables 4 and 7. For example, if the window width is set to be three years, the first set of efficiency scores includes data obtained from the first, second, and third year operations. By the same token, the second set of efficiency scores include the second, third, and fourth years of data. As such, each time window has a new and different set of DMUs with different efficiency scores (Bowlin, 1998). This data disaggregating procedure often enables us to examine the stability of efficiency scores and consequently the time-sensitivity of terminal performances in a multiple planning horizon. The further illustrative details of inter-temporal DEA can be found in Bowlin (1987).

The results obtained from the use of DEA-Solver-Pro software developed by Cooper et al. (1999) show that the Busan Gamman Hanjin terminal (B5) recorded an efficiency score of 1 (100%)

in 2000. However, Busan Gamman Hanjin lost its efficiency in both 2001 and 2002 (see Table 5). Busan Shinsundae (B2) peaked in 2001 with an efficiency score of 1 (100%) and dipped its efficiency in 2002. Four different terminals: Busan Gamman Sebang (B4), Busan Gamman Hutchison (B6), Busan Gamman Korex (B7), and Kwangyang Sebang (G1) achieved an efficiency score of 1 (100%) in 2002. Overall, with the exception of these four terminals, the relative efficiency scores of other container terminals ranged from 57.72% to 90.53%, suggesting that there is room for substantial improvement in cargo throughput and terminal capacity (see Tables 5 and 6).

Surprisingly, Busan Jasungdae (B1), which was regarded as the largest terminal in Korea in terms of total cargo throughput and terminal capacity, were never rated as efficient (below group average) throughout the investigation period (see Tables 2, 4, and 5). That is to say, the sheer volume of cargo throughput generated by a container terminal does not necessarily reflect its operating efficiency, despite its opportunity to exploit economies of scale. For example, Busan Jasungdae (B1) underutilized its equipment (gantry cranes) and property (quay and container yard), while fully utilizing its labor force as shown in Tables 7 and 8.

All the terminals at the newly developed port of Kwangyang except Kwangyang Sebang (G1) performed poorly throughout the investigation period due to their learning curve and time lag required to be on the right track. For example, Kwangyang Hanjin (G2), Kwangyang Hutchison (G3), and Kwangyang Korex (G4) scored below average for the entire investigation period, leaving ample room for improvement (Table 6). However, these three terminals gradually improved their efficiency in cargo throughput and terminal capacity as they mature (Tables 5 and Figure 4). Its early struggle stems from the significant underutilization of equipment and property that is not uncommon among newly established terminals (see Tables 7 and 8).

Regardless of newness and economies of scale, most container terminals evaluated in this study have shown steady improvement in their efficiency scores over time (see Figures 4 and 5). They also experienced gradual increases in cargo throughput and terminal capacity over time (Figures 6 and 7). The results of inter-temporal analysis also confirmed this pattern of upswings among most of the Korean container terminals. The only exceptions are Busan Uam (B3), and Kwangyang Hutchison (G3) which suffered from the trend of declining efficiency in the latest set of three-year windows (see Tables 4 and 5). For instance, Busan Uam (B3) damages its efficiency by limiting its working hours (especially gate hours) (21 hours versus 24 hour of gate services available from its neighboring competitors) and not establishing rail facilities. Kwangyang Hutchison (G3) also has hurt its productivity by limiting its client bases to vessels originating from China and by the recent change of its terminal operating company.

More importantly, we discovered that each one of four inputs (number of gantry cranes, terminal quay length, size of yards, and size of labor force) has significant correlation (at least correlation coefficient of .79) with cargo throughput throughout the investigation period. Among four inputs, size of labor force has the strongest correlation with cargo throughput (correlation coefficients ranging from .97 to .98), thereby influencing the overall efficiency score more than other inputs. The number of gantry cranes also has strong ties with cargo throughput (correlation coefficients ranging from .93 to .96). On the other hand, size of yard areas has the weakest correlation with cargo throughput (correlation coefficients ranging from .79 to .83). This finding implies that terminals that manage their human resources and gantry cranes better are likely to perform better and survive in this fiercely competitive environment.

5. CONCLUSIONS AND MANAGERIAL IMPLICATIONS

At the end of 2000, there were more than 350 container ports and thousands of container terminals around the globe (Degerlund, 2002). In Korea alone, there are four major container ports and approximately 20 container terminals serving ocean carriers from all over the world. Over the last few years, the fragmented market segment coupled with continued expansion of terminal capacity resulted in intense competition and low profit margins for container terminals that struggled to develop survival strategies. In an effort to help these terminals formulate survival strategies, this paper proposed a hybrid DEA/simulation model that was designed to analyze the operational efficiency of container terminals over time, identify potential sources of inefficiency, and provide useful information (hindsight) for the continuous improvement of operational efficiency. This paper also summarizes several major findings of this benchmarking study and develops practical guidelines for improving the operational efficiency of container terminals.

First, with growth in container traffic volume down, all investigated container terminals but two (Busan Shinsundae and Busan Uam) showed an improved operational efficiency in 2002 (see Figures 4 and 5). Ironically, this improved efficiency within container terminals coincides with a decline in international trade growth, which is commonly regarded as one of the key indicators for container traffic volume. Although reduced container traffic volume can negatively affect the utilization of equipment and human resources at the container terminals, remarkable advancements in information technology (e.g., web-based scheduling and documentation, communication via electronic data exchange, tracking through radio frequency identification) and careful selection of terminal operating companies may have contributed to improved efficiency for most terminals in Korea. Also, fierce competition among container terminals forced their management to continuously improve operating efficiency; consequently, a gap between the high-performance group and the low-performance group shrank for the last two years (2001 and 2002).

A second finding is that the sheer size or the total cargo throughputs or the terminal capacity of container terminals is somewhat inversely correlated to the operational efficiency of terminals. For example, Busan Jasungdae produced the largest throughput (1,534,600 TEUs), had the largest terminal capacity (1,483,000 TEUs) and the largest number of gantry cranes (14 cranes) and the longest length of terminal quay (1,447 meters) among the 11 terminals that we evaluated in 2002. Yet, its overall efficiency score still remained below average in 2002. On the other hand, Busan Gamman Hanjin, Busan Gamman Hutchison, Busan Gamman Korex, and Kwangyang Sebang had perfect operating efficiency (100%), despite their relatively small throughput and limited capacity in 2002. In other words, the management of relatively large resources seems to pose more challenges for sustaining a high level of efficiency. Thus, economies of scale cannot be directly translated into operating efficiency. This finding also suggests that any plans for continued expansion should be given careful consideration.

A third finding is that an increase in terminal capacity does not necessarily result in the increase in cargo throughput as shown in Figures 6 and 7. In other words, unless terminal capacity is fully utilized or the terminal operational efficiency is improved, an increase in terminal capacity will not directly lead to an increase cargo throughput. Thus, improvement in operating efficiency should precede investment in capacity expansion.

Finally, we discovered that three underachievers (Kwangyang Hanjin, Kwangyang Hutchison and Kwangyang Korex) are newer terminals (all opened in late 1998 and mid 1999), whereas the two best performers (Busan Gamman Hanjin and Busan Gamman Sebang) are well-established terminals. This can be explained by the fact that it takes time for the terminal to recruit proper personnel, get equipment into full operating condition, and establish client bases. That is to say, older and well-established terminals may have a greater chance to sell their equipment and services, and, therefore, better utilize their resources than newer terminals that have little brand recognition. However, such a finding cannot be generalized because Kwangyang Sebang, which opened in July of 1999, performed relatively well despite being in the newly opened port of Kwangyang. Also, given that the Korean government introduced an ambitious plan to have the port of Kwangyang serve as a gateway to China and that Kwangyang is projected to grow faster than other ports for the next decade, the future revenue growth opportunity may help terminals within the port of Kwangyang better utilize their resources.

Based on the above findings, we suggest the following survival strategies:

- Make an accurate forecast for demand for container services prior to developing a capacity expansion plan. Such a forecast may require information sharing among shippers, carriers, and port authorities;
- Improve information technology infrastructure to adapt to growing needs for web-based applications in terminal operations and to prevent terminal congestion caused by slow, manual operations;
- Consider leasing fixed assets such as equipment, buildings, and land to increase the cash flow and the fixed asset turnover ratio that can, in turn, improve operational efficiency in the long run;

- Control salaries and wages by better managing human resources (e.g., stevedore gangs) and avoiding prolonged conflicts with demanding labor unions in Korea;
- Eliminate unnecessary waste (e.g., indirect costs) in service activities by implementing activity based costing principles that enable the terminal management to focus on the activities increasing the throughput productivity.

To conclude, this paper differentiates between surviving and struggling groups of container terminals on the basis of inter-temporal DEA efficiency scores. The DEA efficiency score gives management a warning signal that the lower the DEA score is, the greater likelihood a container terminal has for failure. Thus, DEA is very useful for identifying the least efficient terminals which require the closest attention. However, the proposed DEA/simulation model can be extended to include qualitative outputs (e.g., non-financial measures such as level of customer satisfaction) and a greater number of inputs (e.g., carrier's waiting time at the terminal, investment in sales promotion for liners, shippers and freight forwarders, investment in information technology, government subsidies). In particular, waiting time at the terminal will become an increasingly important issue as evidenced by the recent California law that sets fines of $250 for terminals that keep trucks waiting longer than 30 minutes to load and unload containers (Zuckerman, 2003).

Acknowledgement: This research was supported by the Korea Research Foundation Grant (KRF-2002-002-B00058).

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Table 1. Comparative Review of the Selected Prior Studies

Class / Authors	Domain	Data	Number of DMUs	Model	
				Output	Input
Roll and Hayuth (1993)	Entire world	Fictitious and Cross-sectional	20 ports	1. Container throughput 2. Service level 3. Consumer satisfaction 4. Number of ship calls	1. Size of labor force 2. Annual investment per port 3. The uniformity of facilities and cargo
Martinez-Budria et al. (1999)	Spain	Time-series (1993-97)	26 ports in five years span	1. Total cargo moved through the docks 2. Revenue from port facilities	1. Labor expenditures 2. Depreciation charges 3. Miscellaneous expenditures
Tongzon (2001)	Australian	Cross-sectional (1996)	16 ports	1. Cargo throughput 2. Ship working rate	1. Capital: • Number of berths • Number of cranes • No. of tugs 2. Labor (Number of stevedore gangs) 3. Land (Size of terminal areas) 4. Length of delay
Valentine and Gray (2001)	Entire world	Cross-sectional (1998)	21 ports	1. Total tons throughput 2. Number of containers	1. Total length of berth 2. Container berth length
Current Study (2003)	Korea	Time series (1999-2002)	11 container terminals in four year span	1. Cargo throughput 2. Terminal Capacity	1. Total length of quay 2. Number of cranes 3. Size of yard areas 4. Size of labor force

Table 2. Container Terminal Data

Terminal	Year	Throughput (in 1000 TEUs)	Capacity (in 1000 TEUs)	No. of cranes	Quay length (in meters)	Yard area (in 1000 m^2)	Size of Labor force
B1 (Busan Jasungdae)	1999	1,065.6	950.0	14	1,447	419.4	638
	2000	1,405.7	1186.0	14	1,447	419.4	648
	2001	1,310.3	1402.0	14	1,447	419.4	648
	2002	1,534.6	1483.0	14	1,447	419.4	648
B2 (Busan Shinsundae)	1999	1,211.7	1370.0	11	1,200	900.7	659
	2000	1,310.5	1381.0	11	1,200	900.7	659
	2001	1,360.1	1505.0	11	1,200	900.7	659
	2002	1,528.3	1452.0	11	1,200	900.7	659
B3 (Busan Uam)	1999	367.5	305.0	4	500	81.3	214
	2000	356.8	307.0	4	500	155.4	214
	2001	406.2	411.0	4	500	155.4	214
	2002	502.5	362.0	4	500	155.4	214
B4 (Busan Gamman Sebang)	1999	263.8	375.0	3	350	94.9	125
	2000	439.3	356.0	3	350	94.9	148
	2001	389.9	387.0	3	350	94.9	148
	2002	492.5	397.0	3	350	94.9	148
B5 (Busan Gamman Hanjin)	1999	424.6	375.0	3	350	97.0	174
	2000	565.7	356.0	3	350	97.0	180
	2001	555.3	387.0	3	350	97.0	180
	2002	514.4	397.0	3	350	97.0	180
B6 (Busan Gamman Hutchison)	1999	461.0	375.0	3	350	96.5	211
	2000	499.1	356.0	3	350	96.5	206
	2001	495.0	387.0	3	350	96.5	206
	2002	596.8	397.0	3	350	96.5	206
B7(Busan Gamman Korex)	1999	374.6	375.0	3	350	139.6	185
	2000	506.0	356.0	3	350	139.6	187
	2001	579.8	387.0	3	350	139.6	187
	2002	659.9	397.0	3	350	139.6	187
G1(Kwangy ang Sebang)*	1999	19.9	174.0	2	350	144.8	73
	2000	133.7	168.0	2	350	144.8	67
	2001	133.4	188.0	2	350	144.8	73
	2002	149.3	213.0	2	350	144.8	73
G2 (Kwangyang Hanjin)	1999	94.3	174.0	2	350	144.8	100
	2000	139.7	168.0	2	350	144.8	93
	2001	236.3	188.0	2	350	144.8	100
	2002	292.1	213.0	2	350	144.8	100
G3 (Kwangyang Hutchison)	1999	143.6	174.0	2	350	144.8	86
	2000	148.7	168.0	2	350	144.8	102
	2001	164.1	188.0	2	350	144.8	100
	2002	163.5	213.0	2	350	144.8	100
G4 (Kwangyang Korex)	1999	180.8	174.0	2	350	144.8	117
	2000	272.9	168.0	2	350	144.8	121
	2001	360.1	188.0	2	350	144.8	128
	2002	398.2	213.0	2	350	144.8	128

Notes: * Open in July 1999, labor in 2001 used as employees in 2002.

Sources: Korea Container Terminal Authority

Table 3. Descriptive Statistics for Input and Output Measures

	No. of data	Minimum	Maximum	Mean	Standard deviation	Type
Cargo throughput (in 1000 TEUs)	44	19.9	1,534.6	527.5	422.5	Output
Terminal Capacity (in 1000 TEUs)	44	168.0	1,505.0	480.0	428.2	Output
Number of gantry cranes	44	2.0	14.0	4.5	4.0	Input
Terminal quay length(in meters)	44	350.0	1,447.0	540.6	379.6	Input
Yard area (1000 m^2)	44	81.3	900.7	224.0	233.5	Input
Size of Labor force	44	67.0	659.0	238.5	202.5	Input

Table 4. Efficiency Scores for Cargo Throughput and Capacity

Terminals	Year				Summary Measures		
	1999	2000	2001	2002	Mean	CR	TR
B1	60.03%	75.79% 71.96%	87.17% 85.07%	89.98%	78.33%	3.83%	29.95%
B2	91.03%	92.70% 92.34%	100.00% 100.00%	98.48%	95.76%	0.36%	8.97%
B3	92.94%	59.42% 57.72%	76.85% 75.20%	68.87%	71.83%	1.70%	35.22%
B4	100.00%	100.00% 89.67%	100.00% 97.48%	100.00%	97.86%	10.33%	10.33%
B5	96.84%	100.00% 100.00%	100.00% 99.89%	99.96%	99.45%	0.11%	3.16%
B6	96.88%	92.35% 89.66%	99.99% 97.45%	100.00%	96.06%	2.69%	10.34%
B7	95.19%	91.45% 89.13%	100.00% 97.08%	100.00%	95.47%	2.92%	10.87%
G1	79.45%	87.17% 87.26%	86.08% 88.39%	100.00%	88.06%	2.30%	20.55%
G2	66.72%	65.72% 66.34%	79.21% 71.01%	85.90%	72.48%	8.20%	20.18%
G3	71.26%	64.27% 63.14%	72.27% 70.88%	80.31%	70.35%	1.39%	17.17%
G4	64.97%	71.97% 64.17%	93.17% 81.87%	90.53%	77.78%	11.31%	29.00%
Average	83.21%	80.56%	89.05%	92.18%			

Notes:

CR: column range

TR: total range

Table 5. Average Efficiency Scores for Cargo Throughput and Capacity

Container Terminals	Year				
	1999	2000	2001	2002	Average
B1	60.03%	73.88%	86.12%	89.98%	77.50%
B2	91.03%	92.52%	100.00%	98.48%	95.51%
B3	92.94%	58.57%	76.03%	68.87%	74.10%
B4	100.00%	94.84%	98.74%	100.00%	98.39%
B5	96.84%	100.00%	99.95%	99.96%	99.19%
B6	96.88%	91.01%	98.72%	100.00%	96.65%
B7	95.19%	90.29%	98.54%	100.00%	96.00%
G1	79.45%	87.22%	87.23%	100.00%	88.48%
G2	66.72%	66.03%	75.11%	85.90%	73.44%
G3	71.26%	63.70%	71.58%	80.31%	71.71%
G4	64.97%	68.07%	87.52%	90.53%	77.77%
Average	83.21%	80.56%	89.05%	92.18%	86.25%

Table 6. Average Potential Improvements in Cargo Throughput and Capacity

Container Terminals	Year				
	1999	**2000**	**2001**	**2002**	**Average**
B1	66.57%	35.36%	16.12%	11.14%	32.30%
B2	9.85%	8.09%	0.00%	1.54%	4.87%
B3	7.60%	70.75%	31.53%	45.20%	38.77%
B4	0.00%	5.44%	1.28%	0.00%	1.68%
B5	3.26%	0.00%	0.05%	0.04%	0.84%
B6	3.22%	9.88%	1.30%	0.00%	3.60%
B7	5.05%	10.76%	1.48%	0.00%	4.32%
G1	25.86%	14.66%	14.63%	0.00%	13.79%
G2	49.88%	51.45%	33.13%	16.41%	37.72%
G3	40.33%	56.98%	39.71%	24.52%	40.39%
G4	53.91%	46.91%	14.26%	10.46%	31.38%
Average	24.14%	28.21%	13.95%	9.94%	19.06%

Table 7. Resource (Input) Utilization Rates in Percentage

Resources	Terminals	Year				Resources	Terminals	Year			
		1999	2000	2001	2002			1999	2000	2001	2002
Number of Gantry Cranes	B1	-11.41	-11.41	-11.17		Yard Area	B1	-6.08	-5.92	0.00	
			-11.17	-11.17	-11.17				0.00	0.00	0.00
	B2	0.00	-0.55	0.00			B2	0.00	-4.00	0.00	
			-0.43	0.00	-1.38				-3.07	0.00	-9.96
	B3	-36.40	0.00	0.00			B3	0.00	-15.04	0.00	
			0.00	0.00	-0.70				0.00	0.00	-5.87
	B4	0.00	0.00	0.00			B4	0.00	0.00	0.00	
			0.00	0.00	0.00				0.00	0.00	0.00
	B5	0.00	0.00	0.00			B5	0.00	0.00	0.00	
			0.00	0.00	0.00				0.00	0.00	0.00
	B6	0.00	-0.39	0.00			B6	0.00	0.00	0.00	
			0.00	0.00	0.00				0.00	0.00	0.00
	B7	0.00	0.00	0.00			B7	0.00	0.00	0.00	
			0.00	0.00	0.00				0.00	0.00	0.00
	G1	-12.40	-22.20	-12.59			G1	-61.74	-66.02	-61.82	
			-12.71	-0.45	0.00				-19.91	-1.16	0.00
	G2	0.00	0.00	-0.91			G2	-24.60	-47.52	-56.62	
			0.00	0.00	-6.31				-43.89	-54.85	-53.08
	G3	-1.14	0.00	0.00			G3	-56.82	-31.05	-34.66	
			0.00	0.00	0.00				-45.38	-51.95	-51.95
	G4	0.00	0.00	0.00			G4	-12.58	-51.12	-35.70	
			-1.08	0.00	0.00				-38.23	-35.70	-35.70
Terminal Quay Length	B1	0.00	0.00	0.00		Size of Labor Force	B1	0.00	0.00	-4.47	
			0.00	0.00	0.00				-4.47	-4.47	-4.47
	B2	0.00	0.00	0.00			B2	0.00	-0.23	0.00	
			0.00	0.00	0.00				-0.18	0.00	-0.58
	B3	-40.64	-6.80	-7.54			B3	-35.50	0.00	-4.94	
			-7.54	-7.54	-7.32				-4.94	-4.94	0.00
	B4	0.00	0.00	0.00			B4	0.00	0.00	0.00	
			0.00	0.00	0.00				0.00	0.00	0.00
	B5	-0.07	0.00	0.00			B5	-9.34	0.00	0.00	
			0.00	0.00	-0.08				0.00	0.00	-10.30
	B6	-0.02	-0.39	-0.01			B6	-21.92	-14.16	-18.25	
			-0.03	-0.06	0.00				-10.64	-23.55	0.00
	B7	-1.92	-0.64	0.00			B7	-13.95	-1.30	0.00	
			-1.17	-0.79	0.00				0.00	0.00	0.00
	G1	-41.60	-48.13	-41.73			G1	0.00	0.00	0.00	
			-16.97	-0.87	0.00				0.00	0.00	0.00
	G2	-35.31	-33.88	-33.94			G2	0.00	0.00	0.00	
			-25.97	-33.37	-37.54				0.00	0.00	0.00
	G3	-34.09	-34.91	-34.68			G3	0.00	0.00	0.00	
			-34.02	-33.61	-33.61				0.00	0.00	0.00
	G4	-36.05	-33.33	-33.33			G4	0.00	0.00	-2.60	
			-34.06	-33.33	-33.33				0.00	-2.60	-2.60

Note: Negative figures represent underutilization of resources and zero indicates full utilization of resources.

Table 8. Average Resource (Input) Utilization Rates in Percentage

Resources	Terminals	Year			
		1999	2000	2001	2002
Number of Gantry Cranes	B1	-11.41	-11.29	-11.17	-11.17
	B2	0.00	-0.49	0.00	-1.38
	B3	-36.40	0.00	0.00	-0.70
	B4	0.00	0.00	0.00	0.00
	B5	0.00	0.00	0.00	0.00
	B6	0.00	-0.20	0.00	0.00
	B7	0.00	0.00	0.00	0.00
	G1	-12.40	-17.46	-6.52	0.00
	G2	0.00	0.00	-0.46	-6.31
	G3	-1.14	0.00	0.00	0.00
	G4	0.00	-0.54	0.00	0.00
Terminal Quay Length	B1	0.00	0.00	0.00	0.00
	B2	0.00	0.00	0.00	0.00
	B3	-40.64	-7.17	-7.54	-7.32
	B4	0.00	0.00	0.00	0.00
	B5	-0.07	0.00	0.00	-0.08
	B6	-0.57	-0.29	-0.29	0.00
	B7	-0.02	-0.21	-0.04	0.00
	G1	-41.60	-32.55	-21.30	0.00
	G2	-34.09	-29.33	-33.66	-37.54
	G3	-34.09	-34.47	-34.15	-33.61
	G4	-36.05	-33.70	-33.33	-33.33
Yard Area	B1	-6.08	-2.96	0.00	0.00
	B2	0.00	-3.54	0.00	-9.96
	B3	0.00	-12.90	-12.90	0.00
	B4	0.00	0.00	0.00	0.00
	B5	0.00	0.00	0.00	0.00
	B6	0.00	0.00	0.00	0.00
	B7	0.00	0.00	0.00	0.00
	G1	-61.74	-42.97	-31.49	0.00
	G2	-24.60	-45.71	-55.74	-53.08
	G3	-56.82	-38.22	-43.31	-51.95
	G4	-12.58	-44.68	-35.70	-35.70
Size of Labor Force	B1	0.00	-2.24	-4.47	-4.47
	B2	0.00	-0.21	0.00	-0.58
	B3	-35.50	-2.47	-4.94	0.00
	B4	0.00	0.00	0.00	0.00
	B5	-9.34	0.00	0.00	-10.30
	B6	-21.92	-12.40	-20.90	0.00
	B7	-13.95	-0.65	0.00	0.00
	G1	0.00	0.00	0.00	0.00
	G2	0.00	0.00	0.00	0.00
	G3	0.00	0.00	0.00	0.00
	G4	0.00	0.00	-2.60	-2.60

Figure 1. Variation of total costs in port with increasing traffic

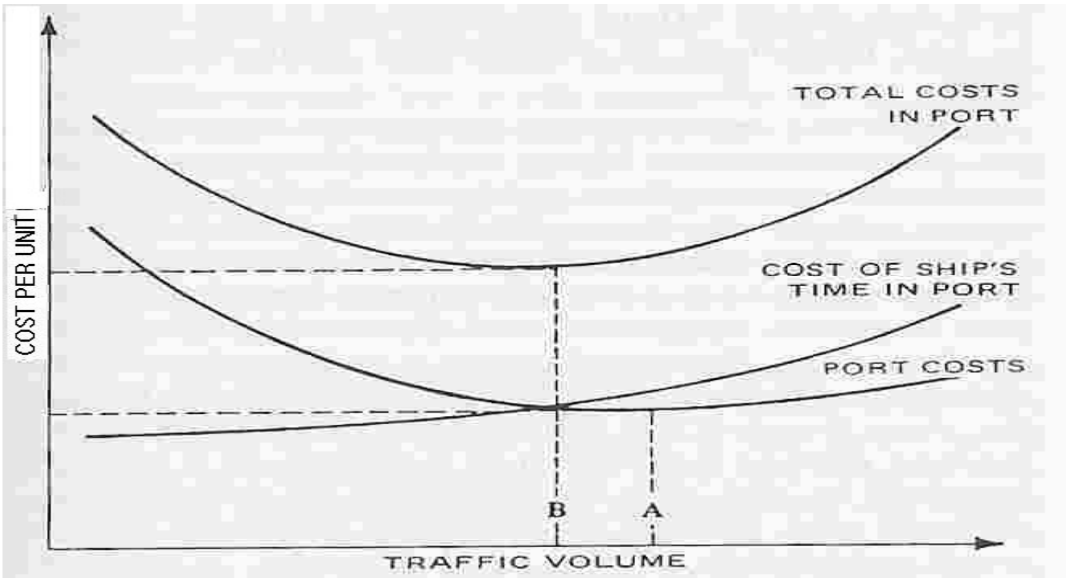

Figure 2. Linkages among Terminal Capacity Models

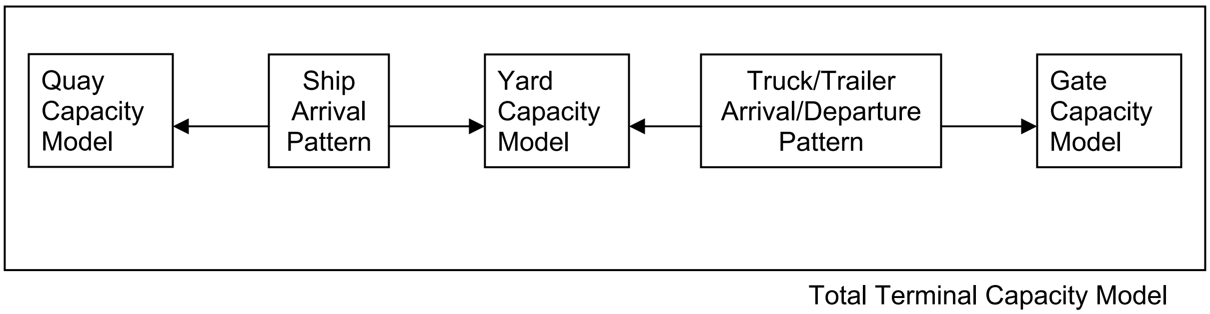

Figure 3. A Flow Chart of the Simulation Model for Estimating Terminal Capacity

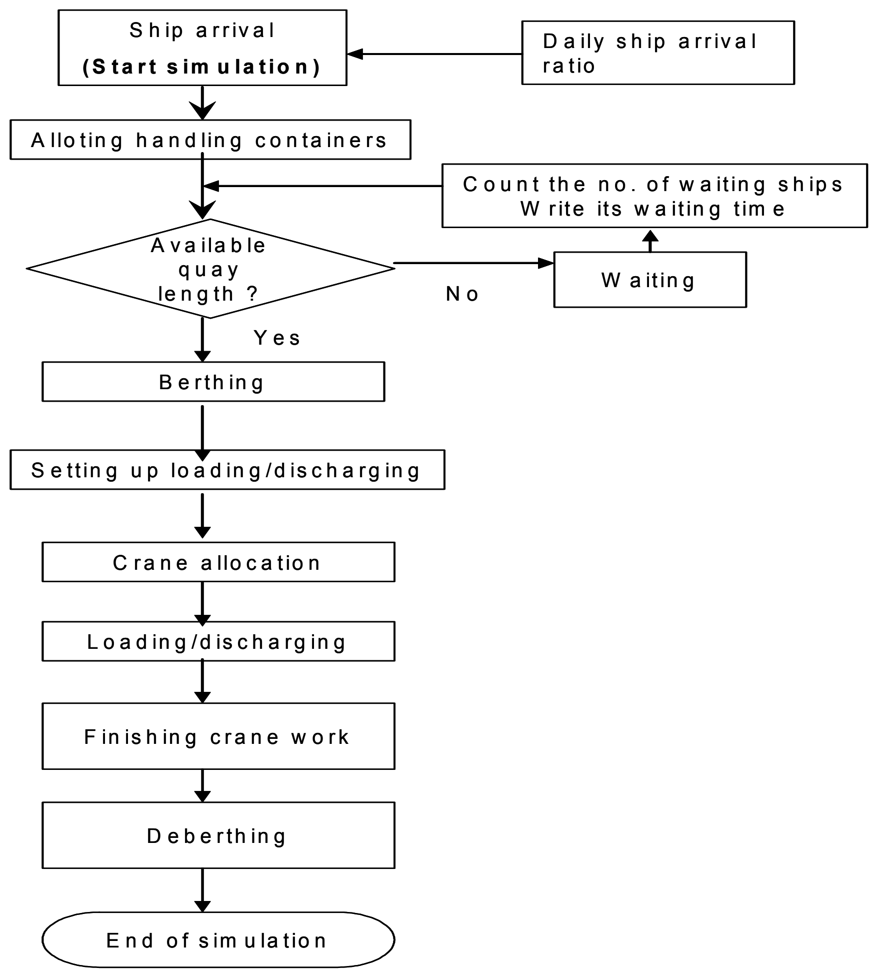

Figure 4. Efficient Trends of Terminals with Relatively Low Efficiency Scores

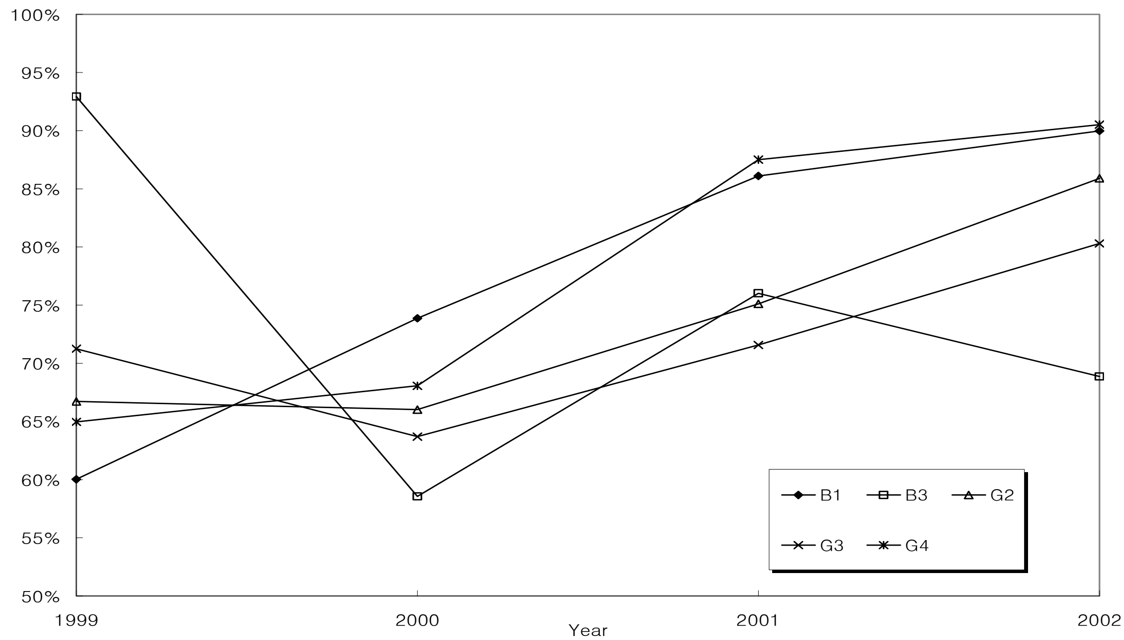

Figure 5. Efficiency Trends of Terminals with Relatively High Efficiency Scores

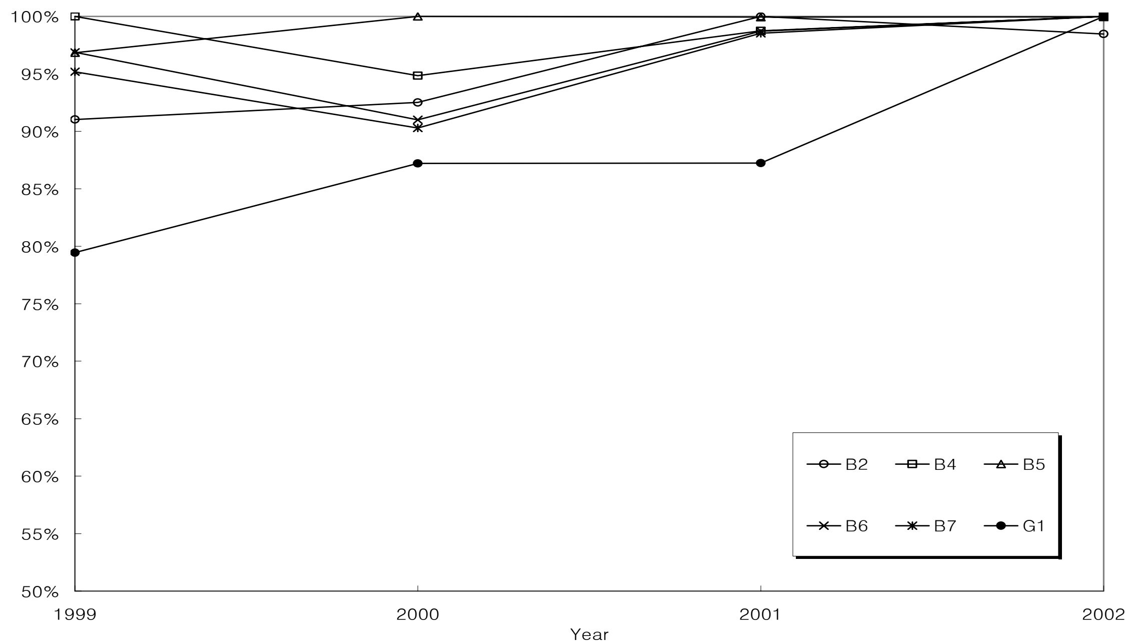

Figure 6. Changes in Annual Terminal Capacity

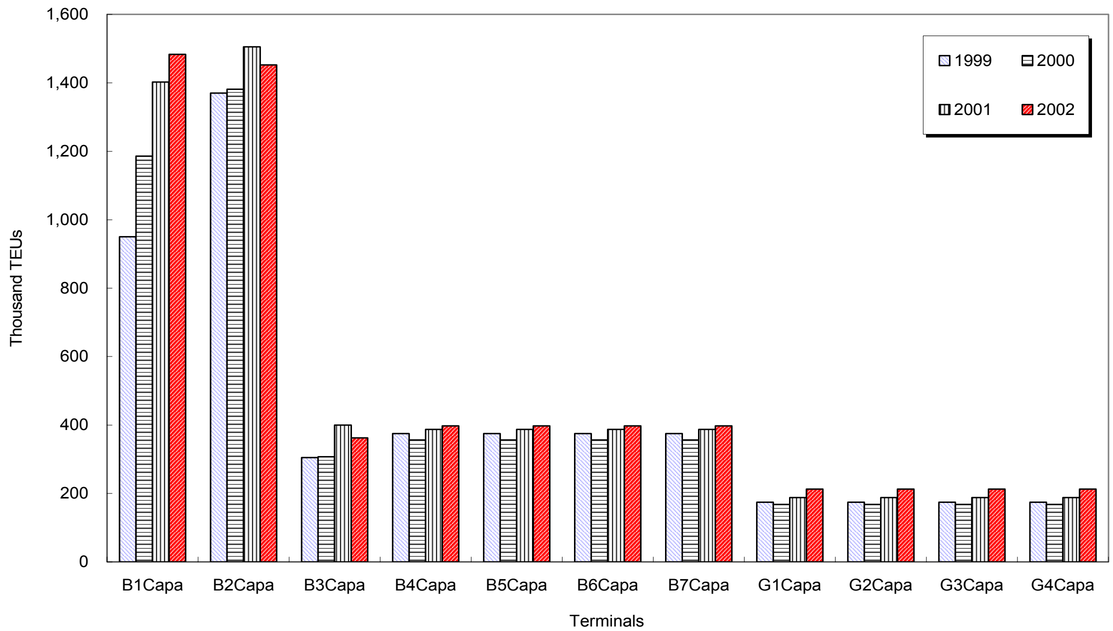

Figure 7. Changes in Annual Terminal Throughputs