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Key words: port management, terminal operators, operation performance.

ABSTRACT

Management performance of container terminal is an important factor of port competitiveness. In the past, ports had often increased performance by expanding the number of berths and equipment. However, recent global recession has significantly dampened the growth of the international trade. Thus, port authority must seek effective utilization of the capacities of its container terminals. Most ocean carriers in the Port of Kaohsiung in Taiwan rent multiple berths that are often dispersed to different container terminals, resulting in inefficient handling. Establishing terminal operators to optimize berth assignment may resolve this problem. The objective of this research is to construct a simulation model to assess the positive effects of establishing effective terminal operators, which may be achieved through port privatization. The research results show that once terminal operators are established to optimize berth reassignment, terminal capacity could increase 20~30% with a related cost reduction in the range of 10~20%. These positive results suggest that the studied model offers potential benefit to other port authorities seeking to enhance their container handling capacity.

I. INTRODUCTION

Most large-scale container terminals in the world have currently adopted the terminal operation mode because of its operating advantages. Change in the operation mode of the container terminal affects loading/unloading (handling) efficiency and mooring cost, and it is also a key factor influencing port development.

The development of Taiwanese container terminals followed a strict hierarchy. First of all, government authorities prioritized mooring access for publicly owned operators. Berths in turn maybe rent by ocean carriers. Since success is measured by the effective control of the costs associated with handling, the operation modes and deploying strategies of berths and equipment would play important roles in the cargo handling performance of a container terminal.

In recent years, the private ocean carrier has presented container terminals with a significant challenge turn to global terminal operator. To retain its competitive advantage, a container terminal must invest in complex equipment or dredge a deep port to allow for the increasing large containerships to berth. Many simulation models developed for analyzing container terminal operations were found in the literatures [2, 5, 12, 25, 36, 38]. Recent contributions appearing on container terminals were included in the literatures [3, 4, 19, 28, 29]. Many of the studies have focused on the general competitive characteristics of container terminals [26, 31, 41], as well as criteria of efficiency [8, 9, 16, 39]. Various methods have been used to ascertain and optimize the operational productivity of cargo-handling at berth and in container yard [1, 6, 7, 10, 11, 13, 17, 18, 21-24, 26, 34, 35, 37, 40]. However, there appears a common limitation among these studies that they tend to only consider a single-berth facility. None of the studies has discussed the impacts of berth assignment strategies would have on the overall performance of multiple berths and container terminals. The simulation model presented in this paper stresses the detailed operations at a multiple-berth facility deploying over a specified period of time.

In the operation of Port of Kaohsiung, except the three public berths, the others are all exclusively used container terminals. The main purpose of this operation is to increase the throughput and efficiency by fully matching the needs of the containership. Although the container throughput of Kaohsiung Harbor is growing annually, there appears inability for ocean carriers to exploit their resources to their full potential. The Build-Operate-Transfer (BOT) project pertaining to the intercontinental (T6) container terminal is a case worth mentioning. To-date, only the parastate-operated Yang-Ming Group (YML) has submitted a tender. The YML has negotiated with HAHJIN shipping, MAERSK line, China COSCO, China shipping, Nippon Yusen and others. This negotiation

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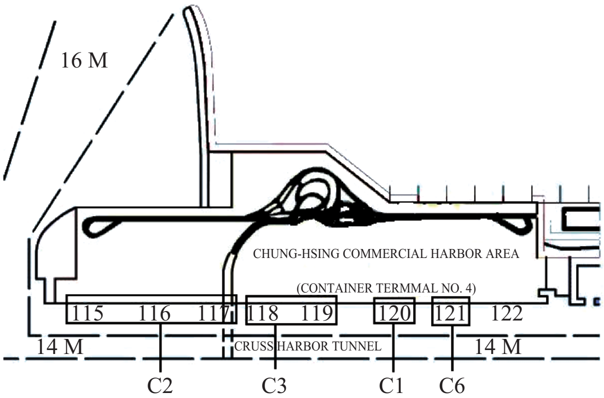


Fig. 1. The berth deploys at the T4 container terminal.

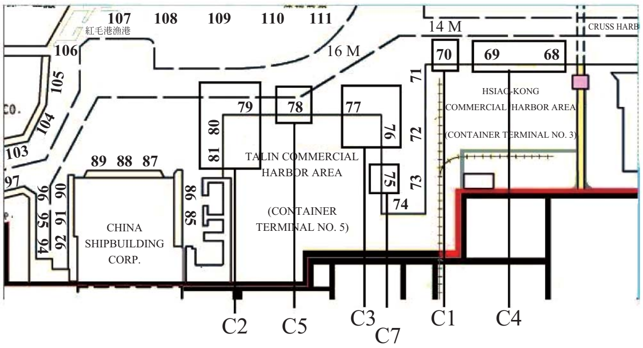


Fig. 2. The berth deploys at the T3 and T5 container terminals.

would likely result in partnerships designed to build and operate the T6 container terminal for mutual benefit among the carriers.

On the other hand, the economic development in Taiwan holds an important stake in the successful completion and effective operation of the T6 container terminal. The project mentioned above required sixteen hundred million NT dollars in investment to develop an area of 75 hectares with the rear zone being 475 meters along with 4 sets of container ports that are 16 meters in depth. The presented research assumed that the T6 container terminal will be completed on schedule, leading to improved rental berth returns of the T3, T4 and T5 containers terminals in the Port of Kaohsiung. It is also expected that this T6 container terminal could support ocean carrier for chartered berths. These container terminals and berth arrangements discussed above were factored into a simulation model to analyze the relationships between container terminal facility deployment, operational performance and capacity.

Furthermore, the presented research was motivated by the fact that although the Port of Kaohsiung has been adopting the operation mode (including reduced mooring fees, port handling fees and construction of port facilities and so on), it still has not been able to effectively increase the efficiency of handling. Investigation of the operational modes of major container terminals around the world indicates that concentration of berth rentals by carriers would lead to improved overall efficiency [14-17]. As the numbers of carriers in the same container terminal are few, each carrier has collinear berths that can increase with the sharing of cranes. Operating costs will be reduced remarkably with efficient utilization of equipment resources, which in turn would yield benefits resulted from economy of scale. It was believed that the main reasons for this lack of improvement in efficiency at the Port of Kaohsiung were that the operating facilities had not been rationally deployed in the port operation and the ocean carriers had hired multiple berths scattered in different terminals. Thus, this research used management tools and system simulation models to evaluate the potential improvement on operational performance of container terminals based on a comprehensive indicator including efficiency and effectiveness.

In addition to the operation efficiency analysis, the presented research also addressed several contingent scenarios that would benefit the operations of container terminals. These scenarios include the management performed by one carrier in the same container terminal. This management could involve changes to operational strategies and the formation of Terminal Operator pattern. This study made limited allowance for prioritizing the ocean carrier in terms of a First-Come-First-Served (FCFS) rule, so that due consideration will be given to the expenses incurred by carriers berthing at the port.

II. ANALYSIS OF THE PRESENT SITUATION IN THE PORT OF KAOHSIUNG

Presently, the Port of Kaohsiung has five container terminals and two deployment patterns, including the linear type and the protruding type. The linear type configuration of berth that berth and equipment, forming a straight line, can be used together, e.g. the T3 and T4 container terminals shown in Figs. 1 and 2. The protruding type configuration of berth, on the other hand, forms the convex geometric shape that berth and equipment cannot support common usages, e.g. the T5 container terminal illustrated in Fig. 2.

The basic data of the three container terminals in the Port of Kaohsiung were depicted in Table 1.

III. CONSTRUCTION OF THE PORT SYSTEM SIMULATION MODEL

1. Design of the Simulation Model

Because ship arrivals and departures as well as the operation procedures of different harbor are various in practice, there is no standard port system simulation model existed. Based on the understanding of the port procedures and simulation objectives, the researcher of this study constructed a customized simulation model for use in this study. Factors influencing ship operations include ship arrival interval distribution, the time of ship entering and leaving port, mooring

Table 1. Basic data of the T3, T4 and T5 container terminals in the Port of Kaohsiung.

Container Terminal	Ocean Carrier	Berth number	Length (Meter)	Draft (Meter)	Crane number	remark
T3	C4	# 68~69	752.16	14	7	Linear type
	C1	# 70	320.00	14	3	
T4	C2	# 115~117	916.88	14	8	
	C3	# 118~119	640.00	14	5	
	C1	# 120	320.00	14	3	
	C6	# 121	320.00	14	3	
T5	C7	# 75	319.93	14	3	protruding type
	C3	# 76	320.07	14	2	
		# 77	356.01	15	4	
	C5	# 78	320.00	15	3	
	C2	# 79	355.00	15	3	
		# 80~81	460.00	14	5	

Source: (http://www.khb.gov.tw) (2007.12.09).

berth pattern, ship handling operation system, the type of machines deploy, disposition and regulation of the yard and so on. With more detailed consideration of the port operations, the results generated from the simulation will be closer to the reality.

To reduce computer processing time, the research adopted the Incident Scanning Method in the simulation. Such a method is an approach for maximizing or minimizing a function by means of sequential sorting and comparison of its values at all points of some subset of the admissible set. Furthermore, to better conform to the actual conditions, this study used cumulative probability distributions characterized by many parameters.

The detailed simulation flow chart was shown in Fig. 3. Based on the flow chart, the steps of the simulation are outlined below:

(1) Setting the starting values: At the beginning the program will firstly read the established data of the basic port setting values including the ship data, port data and yard data.

(2) Ship parameter establishment: Statistical cumulative probability tables were prepared including the previously analyzed (a) ship data including ship arrival-interval, length, draft and handling volume, (b) port data including the amount of quay cranes (QC) dispatched and handling efficiency of QC, and (c) yard data including the amount of yard cranes (YC) as well as yard trucks (YT). The operation of different berths may also differ from yard data in practice. Thus the data of the QC, YC, and YT facilities, QC:YC:YT, were used on a 1:2:6 fixed deployment rate. For instant, at least 2 YCs and 6 YTs are typically needed per QC to keep the QCs smoothly working at a high speed.

(3) Ship arrival: The event scanning method is utilized and the operation of the simulation model will be activated starting from the time of ship arrival and the ship being assigned to the berth. The ship berthing system of the port generally has three main events, namely the ship leaving, the ship arriving, and the ship entry.

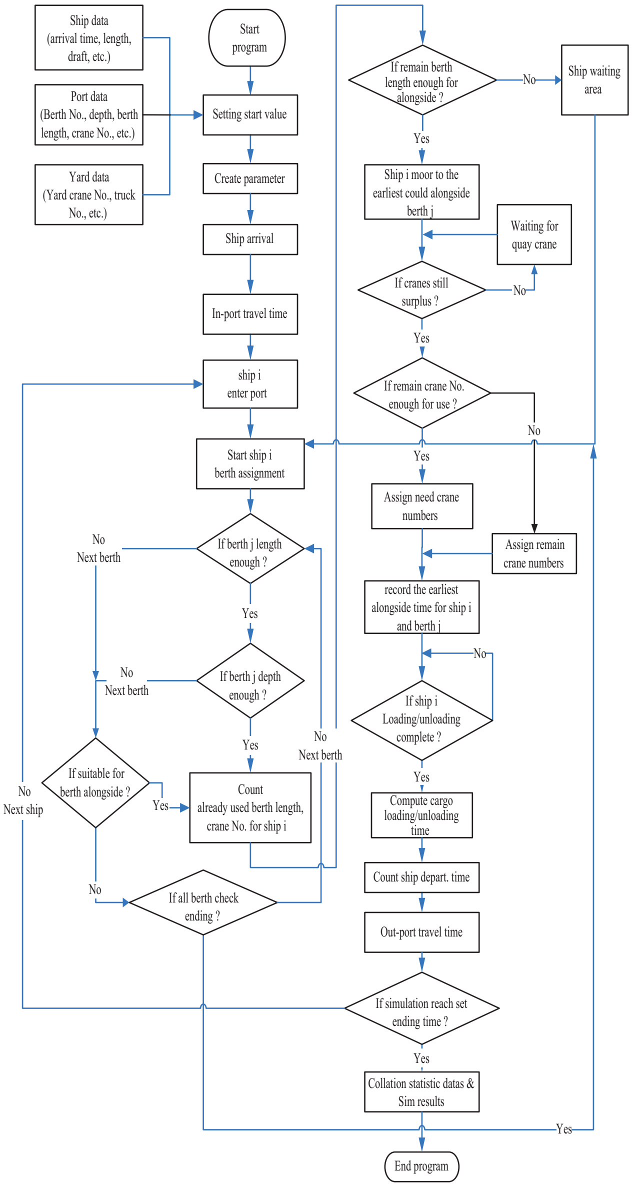


Fig. 3. Port system simulation flow chart.

Table 2. Ship arrival time interval distribution KS-test result.

No.	Ca.	Berth	Ship No.	AVG	Std. error	$\hat{K}$	Max prob. error K=				significance level		
							1	2	3	4	0.10	0.05	0.01
1	C1	2	862	0.42	0.38	1.23	0.05^	0.13	0.19	0.24	0.04	0.05	0.06
2	C2	6	1637	0.23	0.27	0.72	0.39	0.17^	0.23	0.27	0.03	0.03	0.002
3	C3	4	1301	0.28	0.28	1.03	0.03^	0.12	0.19	0.23	0.30	0.04	0.05

^: Approximate distribution.

(4) Look for the wharf that can be berthed as early as possible: When the ship arrival event in the simulation program is generated, the ship will start to enter the port and will look for the first available wharf that can conform to the berthing condition and provide berthing. When there is no available wharf exists for berthing, the ship will wait till the former ship operation is completed in the port and then berth at the first available wharf that can conform to the berthing condition of the ship.

(5) Set the berthing time and calculate the handling operation time: After searching for the wharf, the ship will be assigned to the berth at the wharf followed by calculating its required handling operation time and ship departure time. At the end of this step, the status of this ship is set to be in the process of departure in the port.

(6) Check whether the pre-set system time is reached: Check to see whether the program has reached the pre-set simulation time. If not, return to the first step of the program and continue to conduct the simulation. Otherwise, stop the operation of the simulation model and prepare to carry out relevant statistical compilation and analysis.

(7) Collectively sort the statistical information and simulation results: Calculate the data generated from the simulation model and collect relevant parameters such as average ship waiting time in port (W_q), average arrival interval time ($1/\lambda$), average service time ($1/\mu$), average handling volume (V) and berth usage ratio (ρ).

2. Input of Simulation

Lorenzoni *et al.* [30] highlighted the mechanisms of defining the time limits for the attendance of the ships, usually called layday periods, which will be used in the simulation. These periods cannot be determined solely based on the interests of the port, since they are defined based on the negotiations between the shipper and the port operators.

This study used the collected ship arrival data regarding the ocean carriers to execute the Kolmogorov-Smirnov test (KS-test) of the arrival interval pattern. The results are shown in Table 2.

The KS-test tries to determine if two datasets differ from each other significantly. The KS-test has the advantage of making no assumption about the distribution of data. Thus technically speaking, the test is non-parametric and distribution free. Furthermore, to facilitate a closer matching of probability distributions of arrival time intervals as well as other parameters to the real situation, this study used the cumulative probability distributions for the simulation.

The parameters simulated include:

- The ship arrival intervals: The accumulated probability table of the ship arrival interval is listed in Appendix Table A1.
- The ship length and draft, and handling container volumes: To ensure precision in our simulation, the data shown in the Appendix Table A2 are classified by the ship length and draft, displaying in the case of certain classification for the handling container volume and the permillage number of arriving ships. The cumulative probability distribution for use in generating these data is listed in Appendix Table A2.
- The number and efficiency of QCs: This study determined the number of cranes the ship needs to operate based on the statistical data of the handling of container volumes. In the simulation process, if the port has less than the required number of cranes for the ship, the assigned number of cranes were adjusted to match the available cranes in the port. Otherwise, if the required number of cranes is less than the number of equipped cranes in the port, the simulation assigns the number of cranes equal to that required for the ship. If the port is equipped with more cranes than are required but some of them are being used by another vessel resulting in the remainder being less than that are required, the number of cranes remained were assigned. The cumulative probability distributions of container volumes and the assigned number of the cranes are listed in Appendix Tables A3-1, A3-2 and A3-3, respectively. Table A3-1 shows the number of arrived ships in accordance with the actual ship handling volume and the number of assigned cranes, and the accumulative number of ships (Acc. ship numbers) as well. Table A3-2 shows the estimations of the probability of ship numbers in accordance with Table A3-1. Table A3-3 shows the ship accumulative probability in accordance with Table A3-2. For example, a ship with length of 250 meters and draft of 6 meters would yield possible handling container volumes of 332 TEUs and permillage of arrival ship would be 1.16, estimated by using data demonstrated in Table A2. With the estimated volumes of 332 TEUs as discussed above, the probability of assigning two cranes is 0.93, based on Table A3-2.
- The handling container volumes and the number of QCs: The cumulative probability distributions of these parameters are listed in Appendix Table A4. Table A4 could be used to estimate the time of handling containers based on the average usage of one crane per handling piece per hour.

Table 3. Comparison of the actual values and simulated values.

Carrier	C1			C2			C3		
Indicator	Act. Value (A)	Sim Value (B)	Error Per.	Act. Value (A)	Sim Value (B)	Error Per.	Act. Value (A)	Sim Value (B)	Error Per.
V (units/ship)	626	635	**-1.44**	866	855	1.27	761	751	1.31
λ (ships/hr)	0.99	0.1	-0.91	0.181	0.183	-0.77	0.149	0.150	-0.81
W_q (hrs/ship)	3.91	3.77	**3.58**	2.72	2.81	-3.31	2.36	2.44	-3.39
$1/\mu$ (hrs/ship)	25.15	24.5	2.58	24.32	24.70	-1.56	19.34	19.7	-1.86
Berth No.	**#70(T3) #120(T4)**			**#76-77(T5) #118-119(T4)**			**#79-81(T5) #115-117(T4)**		

Notes: 1. Error Per.: Error percentage (%) = (A-B)/A.
2. Among ( ) text represents Terminal Number.

- The berth condition: This study set the condition of the berth based on practical data. For each berth, the following data were required: berth code number, berth length, depth and width, number of QCs deployed, and rental number of berths.
- The time period of the simulation: The simulation time was set to be one year.

3. Model Verification and Validation

Law *et al.* [27] provides the classic definitions of model verification and validation. According to Law, "Verification is determining that a simulation computer program performs as intended, i.e., debugging the computer program.... Validation is concerned with determining whether the conceptual simulation model (as opposed to the computer program) is an accurate representation of the system under study". Jack [20], however, argued that validation cannot be assumed to result in a perfect model, since the perfect model would be the real system itself.

Based on these definitions and limitations, this study has verified the simulation model by using a customized FORTRAN program written for this study instead of utilizing a commercial software package. The verification results have found no programming errors associated with the FORTRAN program. For model validation, this study has tried to measure the inputs and outputs of the real container terminal and the attributes of the intermediate variable. Due to the fact that the real data are generally difficult to obtain as they involve the operational secret of the shipping company, this research used the data of the dynamic data files of ships and handling provided by the administration office of the Port of Kaohsiung. These data are considered realistic as the number of annual berthing ships has only changed slightly in recent years.

Validation of the simulation model was based on comparing the simulation results and empirical measurement. The UC evaluation indicator, defined in the next section, is adopted for the output items. The parameters which needed to be collected in this indicator include: (1) average handling volume (V); (2) average arrival interval time ($1/\lambda$); (3) average waiting time (W_q); and (4) average service time ($1/\mu$). One can then assess the validity of the simulation model by comparing the output values in the simulation and the collected actual values from the Port of Kaohsiung.

The data shown in Table 3 indicate that the difference between the model results of this research and the actual conditions appears to be very small. As shown in Table 3, all the errors are within ±3% except for the errors associated with average waiting time of ships which were 3.58% (Carrier C1), -3.31% (Carrier C2) and -3.39% (Carrier C3), respectively. It should be noted that the method used to validate the model is similar to that proposed by Nevins *et al.* [33].

This study also uses quantitative data to assess the quality of the simulation model. There are four variables, namely V, λ, W_q and $1/\mu$, were assessed in the simulation. Let w_i and v_i denote the average parameter on run i in the simulation and real system, respectively. Suppose n runs are simulated and observed in reality, respectively. In the case when n is set to 30, one can write that $i = 1, \ldots, 30$. These calculations form the individual basic parameters of all ships arriving at the port.

Statistically, this trace-driven simulation means there are n paired differences $d_i = w_i - v_i$, which are identically and independently distributed (i.i.d.). Thus, the t statistic can be defined as follows,

$$t_{n-1} = \frac{\bar{d} - \phi}{s_d / \sqrt{n}} \tag{1}$$

where $\bar{d}$ denotes the average of the n sets of d's, ϕ is the expected values of d, and s_d represents the estimated standard deviation of d. It is assumed that the null-hypothesis is $H_0{:}\varphi = 0$, and Eq. (1) yields a value, t_{n-1}, that is significant if ($|t_{n-1}| > t_{n-1;\alpha/2}$). The data illustrated in Table A5 in the appendix reveal that the simulation model should be retained for the three ocean carriers (C1, C2 and C3) and the four parameters discussed above since when $\alpha = 0.05$, all of the ($|t_{n-1}| > t_{n-1;\alpha/2}$) and the p value greater than $\alpha = 0.05$. The results shown in Table A5 concluded that the simulation model would produce average variables per run that do not deviate significantly from reality. In the validation process, the simulation results of this research generally do not converge when the number of simulation runs increases. However, by performing comparative

Table 4. Berth improvement of plan I.

Ocean carrier	Present condition		after adjustment		Exchange principle
	Berth No.	Terminal No.	Berth No.	Terminal No.	
C1	#70	T3	***#123-126***	***T6***	#123~126 (Carrier **C1**'s subsidiary company)
	#120	T4			
C2	#79-81	T5	***#115-119***	***T4***	1. #79 of Carrier **C2** exchanges with #118 of Carrier **C3**. 2. #80~81 of Carrier **C2** exchanges with #119 of Carrier **C3**.
	#115-117	T4			
C3	#76-77	T5	***#76-79***	***T5***	1. #119 of **C3** Carrier exchanges with #78 of Carrier **C5**. 2. #118 of Carrier **C3** exchanges with #79 of Carrier **C2**.
	#118-119	T4			
C4	#68-69	T3	#68-70	T3	increase chartering #70.
C5	#78	T5	#80-81	T5	#78 of Carrier **C5** exchanges with #80~81 of Carrier **C2**.

Note: #120 not yet rent out.

analysis of the simulation results, it was found the results have the minimum errors when n = 30. Thus, it was determined that the results would be averaged from the 30 simulation runs.

In conclusion, the simulation model has been verified and validated through the close comparisons with the actual data collected from the Port of Kaohsiung.

4. Explanation of the Indicator

To consider the cost items for the terminal user (shipping Carrier) and supplier (port authority), this study used the UC evaluation indicator to evaluate the various plans analyzed in this research.

The total cost of ship in port (TC) includes two major items, namely ship and cargo cost (TC_1) and terminal service cost (TC_2).

$$TC = TC_1 + TC_2 \tag{2}$$

Therefore, this study uses the total cost at the port with the unit cargo (ton, TEU) and unit time (Hour) to define the UC indicator as follows:

$$UC = TC/(\lambda \cdot U_s \cdot V) \tag{3}$$

where

Us (NT$/time per ship): the unit time cost of one ship at the port

V: Average handling volume per ship at the port (tons or TEUs)

λ: Ship arrival rate (ships/hour)

The dimensional analysis of UC in Eq. (4) is as follows:

$$UC = \frac{TC}{\lambda \cdot V \cdot U_s} = \frac{\$/hr}{ship/hr \cdot TEU/ship \cdot U_s} = \frac{\$/TEU}{U_s} \tag{4}$$

Thus, the ratio of the total cost at the port per unit cargo and the unit time cost per ship is therefore non-dimensional. Further details on the UC indicator can be found in [14, 16, 32].

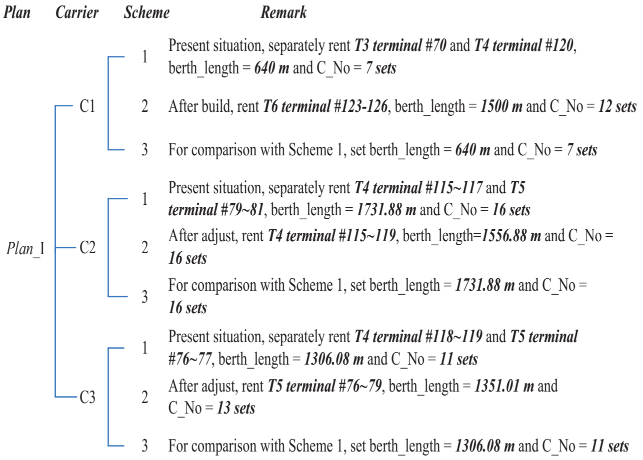


Fig. 4. The proposed comparative structures of plan I.

A reasonable evaluation criterion can be achieved by the definition of the UC. It is noted that the lower the value of the UC indicator the lower the total cost of the unit cargo. In other words, the port will be performing more efficiently. When increasing the ship number in the simulation model, the UC indicator will show concave upward trend meaning the best performance status can be determined.

Longer service times for the ships would result in longer waiting times when the port has insufficient equipment and the capacity of the terminal is also insufficient. In addition, the waiting time factor (the ratio of the average waiting time to the average service time, AWT/AST) and the average waiting times (W_q) are also presented as supplements for reference in this study.

IV. APPLICATION OF THE PORT SYSTEM SIMULATION MODEL

1. Berths Are Adjusted to Improve the Plan

Assuming that the T6 container terminal of the Port of Kaohsiung is operating, this study conducted a comparative analysis of the operational performances for the cases of before and after adjusting the berths of the container terminal.

Table 5. Berth improvement of plan II.

Ocean carrier	Present condition		after adjustment		Exchange principle
	Berth No.	Terminal No.	Berth No.	Terminal No.	
C1	#70 #120	T3 T4	#123-126	***T6***	#123~126 (Carrier **C1**'s subsidiary company)
C2	#79-81 #115-117	T5 T4	#76-81	***T5***	1. #116~117 of Carrier **C2** exchanges with #76~77 of Carrier **C3**. 2. #115 of Carrier **C2** exchanges with #78 of Carrier **C5**.
C3	#76-77 #118-119	T5 T4	#116-119	***T4***	#76~77 of Carrier **C3** exchanges with #116~117 of Carrier **C2**.
C4	#68-69	T3	#68-70	T3	Consider increase chartering #70.
C5	#78	T5	#120	T4	Exchange rent #120 of Carrier **C1**.

Note: #115 not yet rent out.

a. Plan I (Carrier C2 concentrated on the T4 terminal and Carrier C3 concentrated on the T5 terminal): Four sets of berth (#123-126) of T6 container terminal are chartered by C1 carrier's subsidiary company. The lease for berths #70 (T3) and #120 (T4) was assumed to be terminated making these berths available to other carriers for chartering. Therefore, the berths of the T3, T4 and T5 container terminals can be readjusted. In conclusion, the adjusting principle for Plan I is to concentrate Carrier C2 on the T4, Carrier C3 on the T5, and has Carrier C4 rent the #70 (T3) from Carrier C1, while surplus #120 for other carrier to charter.

Table 4 depicts the berth improvement of Plan I. The proposed comparative structures of plan I are shown in Fig. 4.

b. Plan II (Carrier C2 concentrated on the T5 terminal and the Carrier C3 concentrated on the T4 terminal): Similar to plan I, the adjusted principle for Plan II is to concentrate Carrier C2 on the T5 and Carrier C3 on the T4.

Table 5 depicts the berth improvement of plan II. The proposed comparative structures of plan II are shown in Fig. 5.

For all the Scheme of Plans I and II, the annual number of ships for Carriers C1, C2 and C3 are 863, 1,638 and 1,302, respectively.

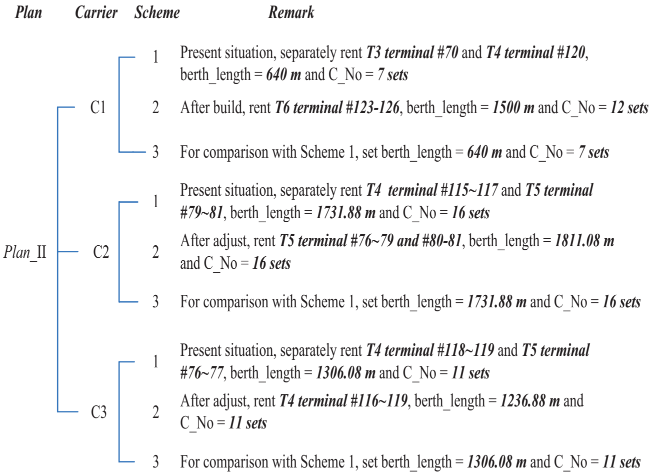
For the Carrier C1, the Plans I and II have the same design situation. The Scheme 1 scenario is the present situation regardless of how Plans I or II are proposed. The Scheme 2 scenario is the result of the actual situation of the terminal after the berth adjustment. And the Scheme 3 scenario was designed to analyze and compare with Scheme 1 provided that the berth length and the number of crane are the same.

In addition, the degree of the improvement after the adjustment can be appreciated by increasing the number of ships close to the same service standard currently been implemented.

2. Simulation Results of the Berth Improvement Plan

1) The Simulation Results of Carrier C1 Berth Adjustment

Table 1 clearly delineates how carrier C1 charters their berth dispersal in the different container terminals for ship mooring, berth dispatching, sharing of equipment and cargo turnover. The current berth arrangement results in reduced convenience, increased operating costs, and an overall reduction in efficiency for Carrier C1.



1 Present situation, separately rent ***T3 terminal #70*** and ***T4 terminal #120***, berth_length = ***640 m*** and C_No = *7 **sets***

2 After build, rent ***T6 terminal #123-126***, berth_length = ***1500 m*** and C_No = ***12 sets***

3 For comparison with Scheme 1, set berth_length = ***640 m*** and C_No = *7 **sets***

1 Present situation, separately rent ***T4 terminal #115~117*** and ***T5 terminal #79~81***, berth_length = ***1731.88 m*** and C_No = ***16 sets***

2 After adjust, rent ***T5 terminal #76~79 and #80-81***, berth_length = ***1811.08 m*** and C_No = ***16 sets***

3 For comparison with Scheme 1, set berth_length = ***1731.88 m*** and C_No = ***16 sets***

1 Present situation, separately rent ***T4 terminal #118~119*** and ***T5 terminal #76~77***, berth_length = ***1306.08 m*** and C_No = ***11 sets***

2 After adjust, rent ***T4 terminal #116~119***, berth_length = ***1236.88 m*** and C_No = ***11 sets***

3 For comparison with Scheme 1, set berth_length = ***1306.08 m*** and C_No = ***11 sets***

Fig. 5. The proposed comparative structures of plan II.

Considering the future trend of ship-size maximization, this study classified ship-lengths into six levels, based on the proposed evolution of containerships of Yang [42] as shown in Fig. 6.

Following the aforementioned classification of ships in the actual situation, the mapping of the distribution of Carrier C1 containerships can be rendered in the form shown in Fig. 7. As demonstrated in Fig. 7, Category B (in which the length of ship is between 135~215 meters) has 475 ships at the most.

Because Carrier C1 rents berths that are dispersed in different container terminals and the length of berths #70 and #120 is 320 meters, the mooring of the five containerships of C1 with lengths more than 320 meters (see Fig. 7) must require the assistance of carrier C4, an ally of C1. Thus, the berth dispatch falls short of efficiency.

Container terminal must gear up to meet the challenge of handling mega-vessels capable of carrying 10,000-12,000 TEUs. When the T6 container terminal is completed, it can

Table 6. Carrier C1–analysis of berth improvement scheme.

Scheme	C_No (sets)	C_SET	W_q (hr)	1/μ (hr)	AWT/AST	UC	Berth_No
1	7	(4,3)	3.77	24.50	0.154	0.0992	2
2	12	12	0.03	23.90	0.001	0.2225	4
3	7	7	**2.26**	23.81	0.095	0.0953	2

Note: 1. Scheme 1: present situation, separately rent T3 terminal #70 and T4 terminal #120, berth_lenth = 640 m, C_No = 7 sets, V = 635 (units/ship), SHIP_NO = 863 (ships/year).

2. Scheme 2: after build, rent T6 terminal #123-126, berth_lenth = 1,500 m and C_No = 12 sets.

3. Scheme 3: for comparison with Scheme 1, set berth_lenth = 640 m and, C_No = 7 sets.

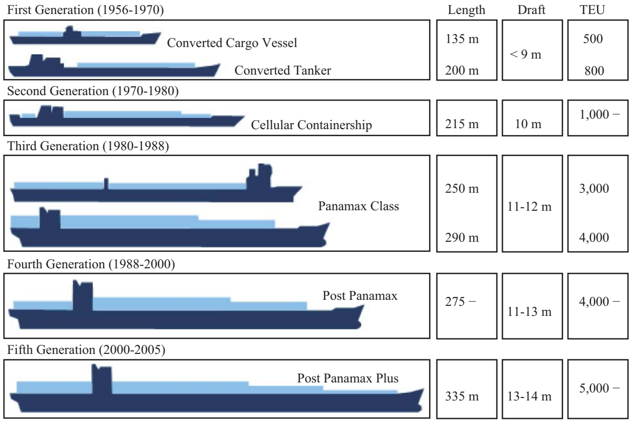


Fig. 6. Classification of containerships by progressive evolution.

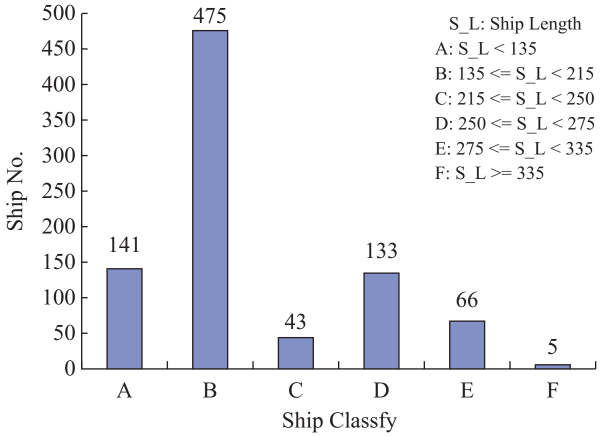


Fig. 7. Distribution of ships classified by number Carrier C1.

facilitate the services offered in supporting the large-scale of ships, by adjusting for various types of ship. By virtue of establishment of Plans I or II, the degree of the performance can be understood.

The simulation data shown in Fig. 8 with reference to the Port of Kaohsiung in 2008 provide the ship data of carrier C1, according to the length of the ship type illustrated in Fig. 6 as the analog input assumptions. The Kaohsiung harbor bureau data of ship movements and the data of harbor work records were the main input data sources for this simulation. The input data were very detail and complete, consisting of time of ship's arrival, ship's waiting time (ships waiting to alongside the berth and access port equipment), time alongside the berth (service begins), service time (loading/unloading time), ship's idle time and departure time (service ends). Other carriers also refer to this approach.

The T6 container terminals will be compatible with fixed facilities in the initial stage, namely having 4 sets of berths with the length of 1,500 meters in total and 12 sets of QCs. It is instructive to compare actual circumstances with the projected operational benefits of the T6 container terminal. Table 6 summarized the simulation results for the studied schemes.

Scheme 1 represents the present situation with 2 sets of berths being utilized, dispersing their loads into different container terminals. The disposition of cranes is C_SET = (4,3), and W_q = 3.77 hours.

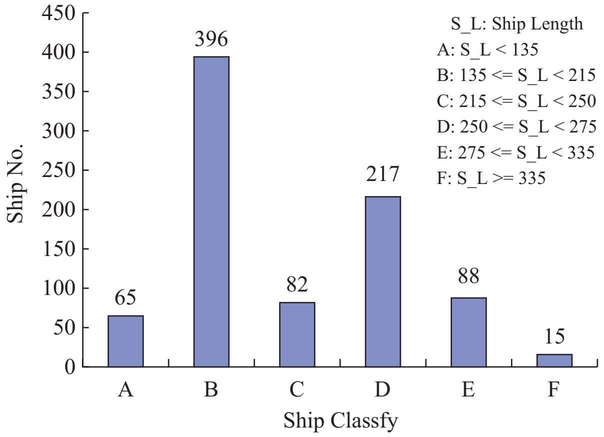


Fig. 8. Distribution of ships classified by number Carrier C1 (the assumption of increase large-scale ship).

Scheme 2 models a scenario that the T6 container terminal will be built. This scenario has characteristics that is similar to Scheme 1 with SHIP_NO = 863 (ships/year) except that the number of berth will be 4 sets and all activities will be concentrated on the same container terminal. If 12 cranes may be deployed simultaneously, the average waiting time of ship (W_q) would become 0.03 hours, presenting a significant improvement.

Table 7. Carrier C1-comparative analysis of the scheme 3.

Indicator	W_q	AWT/AST	UC
values	2.26	0.095	0.0953
Δ%	-40.1%	-38.3%	-3.9%

Notes: 1. at present: W_q = 3.77, AWT/AST = 0.154, UC = 0.0992.

2. Δ%: Change % compared with present situation. For example, W_q, (2.26-3.77)/3.77 = -0.4005.

Table 8. Carrier C1– Scheme 2 variance capacity (ship number).

SHIP_NO (ships/year)	W_q (hr)	TO_TEUs (Thousand)	Δ%(TEUs)	AWT/AST	UC
863	0.03	548		0.001	0.2225
1063	0.07	675	23.17%	0.003	0.1842
⋮	⋮	⋮	⋮	⋮	⋮
2863	**3.30**	**1835**	**234.88%**	0.120	0.1065
3063	6.41	1970	259.40%	0.227	0.1101

Notes: 1. Δ%(TEU): Change % of total handling volumes compared with present situation. For example, SHIP_NO = 1063, (675-548)/548 = 0.2317.

2. Crane_No = 12, Berth_No = 4, berth_lenth = 1500 m.

Table 9. Analysis of berth improvement for the plan_I-Carrier C2.

Scheme	C_No (sets)	C_SET	W_q (hr)	1/μ (hr)	AWT/AST	UC
1	16	(8,4,4)	**2.81**	24.70	0.114	**0.1651**
2	16	16	1.43	21.90	0.065	**0.1383**
3	16	16	1.02	22.24	0.046	**0.1385**

Notes: 1. Scheme 1: present situation, separately rent T4 terminal #115~117 & T5 terminal #79~81 and berth_length = 1731.88 m, C_No = 16 sets, V = 855 (units/ship), SHIP_NO = 1,638 (ships/year), TO_TEUs = 1,400 (Thousand TEUs).

2. Scheme 2: after adjust, rent T4 terminal #115~119, berth_length = 1556.88 m and C_No = 16 sets.

3. Scheme 3: for comparison with Scheme 1, set berth_length = 1731.88 m and C_No = 16 sets.

Because of mixed assumptions have been made in the schemes discussed above, it is difficult to have one scheme being always superior to the other. However, some general comparison results may be observed. Specifically, Carrier C1 only charters 2 sets of berth and 7 sets of cranes with the same available service facilities, and making this scenario Scheme 3 (after adjust, for comparison with Scheme 1 have the same scenario). Furthermore, Table 7 shows that the other two types of evaluation indicators have also improved, with the W_q component reaching a reduction of 40.1%.

The simulation results for Scheme 3 summarized in Table 8 were obtained by assuming that the SHIP_NO was increased by 20 ships every year. When the SHIP_NO is increased to 2,863 ships, the result yields W_q = 3.30; that is close to that of 3.77 hours of the present situation in Scheme 1. These results indicate that Scheme 2 can produce an increase of 2,000 ships increase in capacity and about 1,300 thousand TEUs in total handling volumes (TO_TEUs) when compared to the present situation.

In addition, this research also used the UC indicator to ascertain realistic expectations of achievable volume. The simulation results shown in Table 8 reveal that when SHIP_NO = 2,863, UC = 0.1065, the lowest recorded values. This situation is also consistent with the analytical framework used to evaluate the simulation results in this paper.

2) The simulation Results of the Berth Improvement in Plan I

A. Carrier C2 operation strategy (Concentrated on the T4 container terminal)

Carrier C2 rents five sets of berth in the Port of Kaohsiung, dispersed in the T4 and T5 container terminals. The berth disposition in the T5 container terminal is protruding type, rendering its crane deployment as C_SET = (8,4,4). Although there are 16 sets of cranes, the design is not flexible enough to facilitate sharing, thus mitigating its operational efficiency. The simulation result for the same set out as Scheme 1 is shown in Table 9.

Table 9 shows that W_q = 2.81 hours, which is increased relatively to the detention time at port. For Scheme 2, Table 4 (plan I) that adjusts the berths to concentrate on the T4 container terminal is still hold. In this analysis, the number of berths and cranes remain 5 and 16 sets respectively, except that its berth deployment is the linear type. Dispatch is flexible given that all cranes can be supported and shared. After these changes, the simulation results show that W_q is lowered to 1.43 hours and the UC value is also reduced to 0.1383.

Table 10. Plan I-Carrier C2-Scheme 2 variance capacity (ship number).

SHIP_NO (ships/year)	W_q (hr)	TO_TEUs (Thousand)	AWT/AST	UC
1638	1.43	1400	0.065	0.1383
1688	2.03	1469	0.092	0.1347
1738	2.09	1512	0.094	0.1334
1788	**2.88**	**1550**	0.129	0.1325
1838	3.43	1605	0.153	0.1317

Table 11. Analysis of berth improvement for the plan I-Carrier C3.

Scheme	C_No (sets)	C_SET	W_q (hr)	$1/\mu$ (hr)	AWT/AST	UC
1	11	(5, 2,4)	**2.44**	19.70	0.124	**0.1540**
2	13	(2, 11)	0.80	18.56	0.043	**0.1593**
3	11	(2, 9)	0.92	18.99	0.048	**0.1494**

Notes: 1. Scheme 1: present situation, separately rent T4 terminal #118~119 & T5 terminal #76~ 77 and berth_length = 1316.08 m, C_No = 11 sets, V = 751 (units/ship), SHIP_NO = 1,302 (ships/year), TO_TEUs = 978 (Thousand TEUs).
2. Scheme 2: after adjust, rent T5 terminal #76~79, berth_length = 1351.01 m and C_No = 13 sets.
3. Scheme 3: for comparison with Scheme 1, set berth_length = 1316.08 m and C_No = 11 sets.

Table 12. Plan I−Carrier C3-Scheme 2 variance capacity (ship number).

SHIP_NO (ships/year)	W_q (hr)	TO_TEUs (Thousand)	AWT/AST	UC
1302	0.80	978	0.043	0.1593
1352	1.11	1019	0.060	0.1539
⋮	⋮	⋮	⋮	⋮
1552	**2.45**	**1145**	0.134	0.1457
1602	2.88	1214	0.154	0.1393

For comparability, the berth length of Scheme 2 (1556.88 m) was changed to 1731.88 meters in Scheme 3 equivalent to the Scheme 1 situation. As a result, W_q can be reduced to 1.02 hours, with the relevant UC value being reduced to 0.0002.

For Scheme 2, if the number of ship is increased to 1,788 ships, then as shown in Table 10, W_q would be 2.88 hours, very close to that of the present situation (W_q = 2.81).

The TO_TEUs would reach 1,550 thousand TEUs which is 150 thousand TEUs or 10.69% higher than that of the Scheme 1 situation. There is still a need for improvement through further concentration of the berths in T4 container terminal, along with the length of the berth being reduced to 1,556.55 meters.

B. Carrier C3 operational strategy (concentrated on the T5 container terminal)

Carrier C3, similar to Carrier C2, rents 4 sets of berth in the Port of Kaohsiung, and disperses in the T4 and T5 container terminals. Thus the disposition of its cranes is C_SET = (5,2,4), encompassing 11 sets of cranes, thereby causing considerable inconvenience to berth dispatch and equipment deployment.

The simulation result of Scheme 1 shown in Table 11 for Carrier C3 indicates that W_q = 2.44 hours. This result is notably lower than the W_q value of Carrier C2 presented in Table 9, for reducing the number of ship visits by about 300 a year.

Based on the adjustments made in Table 4, the berths that concentrate on the T5 container terminal are 4 sets and the numbers of cranes are increased to 13 sets. Its berth dispersal remains the protruding type resulting in one set of berth and 2 sets of cranes are unable to support sharing. After adjustment, all berths would concentrate on the same container terminal, causing W_q to drop to 0.8 hours, and the UC value to increase to 0.1593.

For comparability, the berth length of Scheme 2 (1351.01 m) was changed to 1316.08 meters in Scheme 3. And in berths #77-79 the number of cranes is reduced by 2 sets making the total volume of cranes is reduced to 11 sets and dispersal retains its present configuration. After making the changes discussed above in the simulation, W_q would increase to 0.92 hours, and the UC value would reduce to 0.1494.

To find out this situation, its variation degree of cargo handling capacities will be understood by increasing the annual number of mooring berth by 50 ships, as shown in Table 12.

For Scheme 2, if the number of ship is increased to 1,552 ships, then W_q would be 2.45 hours, very close to the service level of the present situation (W_q = 2.44). In this case, the TO_TEUs would reach 1,145 thousand TEUs which is 167 thousand TEUs or 17.14% more than that of the present situation.

Table 13. Analysis of berth improvement for the plan II-Carrier C2.

Scheme	C_No (sets)	C_SET	W_q (hr)	1/μ (hr)	AWT/AST	**UC**
1	16	(8,4,4)	**2.81**	24.70	0.114	**0.1651**
2	16	(2,10,4)	2.69	26.08	0.103	**0.1787**
3	16	(2,10,4)	3.73	26.17	0.143	**0.1805**

Notes: 1. Scheme 1: present situation, like plan I.
2. Scheme 2: after adjust, rent T5 terminal #76 ~79 and #80~81, berth_length = 1811.08 m and C_No = 16 sets.
3. Scheme 3: for comparison with Scheme 1, set berth_length = 1731.88 m and C_No = 16 sets.

Table 14. Plan II−Carrier C2-Scheme 2 variance capacity (ship number).

SHIP_NO (ships/year)	W_q (hr)	TO_TEUs (Thousand)	AWT/AST	UC
1638	2.69	1400	0.103	0.1787
1648	**2.94**	**1432**	0.112	0.1791
1658	3.49	1441	0.132	0.1804

Table 15. Analysis of berth improvement for the plan II-Carrier C3.

Scheme	C_No (sets)	C_SET	W_q (hr)	1/μ (hr)	AWT/AST	**UC**
1	11	(5,2,4)	2.44	19.70	0.124	**0.1540**
2	11		0.57	14.53	0.039	**0.1355**
3	11		0.43	14.53	0.029	**0.1217**

Notes: 1. Scheme 1: present situation, like plan_I.
2. Scheme 2: after adjust rent T4 terminal #116~119, berth_length = 1236.88 m and C_No = 11 sets.
3. Scheme 3: for comparison with Scheme 1, set berth_length = 1316.08 m and C_No = 11 sets.

3) *The Simulation Results of Berth Adjustment Improvement Plan II*

A. Carrier C2 operational strategy (concentrated on the T5 container terminal)

The T5 container terminal utilizes a double protruding type of berth deployment. And after the adjustment, the dispersal of the cranes is C_SET = (2,10,4). For Scheme 2, the berth numbers and crane numbers respectively remain 5 and 16 sets. However, the simulation results illustrated in Table 13 reveal that the W_q values would slightly decrease to 2.69 hours while the UC value would increase to 0.1787. These simulation results were caused mainly because that after the adjustment the length of the berth would increase by 79.2 meters.

For comparability, the berth length of Scheme 2 was changed to 1731.88 meters in Scheme 3, making it equals to the present situation. In this case, as shown in Table 13, W_q would contrarily increase to 3.73 hours which is 0.92 hours more than that of the present situation. UC value would increase to 0.1805. Thus, this scheme is unsatisfactory for Carrier C2.

For Scheme 2, as shown in Table 14, if the number of ship is increased to 1,648 ships, then W_q would become 2.94 hours, higher than the service level of the present situation (W_q = 2.81). This simulation result reveals that with the doubled protruding type of berth, berth concentration on the same terminal does not appear to improve efficiency.

B. Carrier C3 operational strategy (concentrated on the T4 container terminal)

Carrier C3, as previously mentioned, utilizes a rented berth and a protruding form of deployment, causing inconvenience in using the berth and cranes.

The Plan II demonstrated in Table 5 proposes that berths be concentrated on the T4 container terminal. After the adjustment, the numbers of berth and crane remain unchanged. Berth deployment, however, is changed to a linear type that allows sharing of the berths and cranes.

For Scheme 2, simulation results shown in Table 15 indicate that W_q would be lowered to 0.57 hours, and AWT/AST and UC values would be also reduced to 0.039 and 0.1355, respectively, representing significant improvements.

For comparability, the berth length of Scheme 2 was changed to 1316.08 meters in Scheme 3. The total number of cranes remains unchanged. Deployment remains identical to the present situation. Simulation results for this case indicate that when the length of berth is increased by 79.2 meters, W_q would decrease to 0.43 hours, and the values of AWT/AST and UC would decrease to 0.029 and 0.1217, respectively.

Table 16. Plan II−Carrier C3-Scheme 2 variance capacity (ship number).

SHIP_NO (ships/year)	W_q (hr)	TO_TEUs (Thousand)	AWT/AST	UC
1302	0.57	978	0.039	0.1355
1352	0.72	1019	0.049	0.1314
⋮	⋮	⋮	⋮	⋮
1752	**2.54**	**1340**	0.159	0.1198
1802	2.68	1357	0.166	0.1204

Table 17. Comparative analysis of plans I and II.

Plan \ Carrier		Indicator							
		Efficiency Indicator		Effective Indicator		Efficiency and Effective Indicator			
		W_q	Δ%	TO_TEUs	Δ%	AWT/AST	Δ%	UC	Δ%
I	C1	0.03	**-99.2%**	1835	**234.8%**	0.001	-98.9%	0.2225	134.2%
	C2	1.43	**-49.1%**	1550	**10.7%**	0.065	-43.0%	0.1383	**-16.2%**
	C3	0.80	-67.2%	1145	17.14%	0.043	-65.3%	0.1593	3.4%
II	C1	0.03	**-99.2%**	1835	**234.8%**	0.001	-98.9%	0.2225	134.2%
	C2	2.69	-4.3%	1432	2.26%	0.103	-9.6%	0.1787	**8.2%**
	C3	0.57	-76.6%	1340	37.07%	0.039	-68.5%	0.1355	-12.0%

Notes: 1. Carrier C1 (at present): W_q = 3.77, TO_TEUs = 548, AWT/AST = 0.095, UC = 0.0953.
2. Carrier C2 (at present): W_q = 2.81, TO_TEUs = 1400, AWT/AST = 0.114, UC = 0.1651.
3. Carrier C3 (at present): W_q = 2.44, TO_TEUs = 978, AWT/AST = 0.124, UC = 0.1540.
4. Δ%: Change % of indicator compared with present situation, for example, Plan I, Carrier C2, about W_q, Δ% = (1.43-2.81)/2.81 = -49.1%.
5. TO_TEUs units: Thousand.

The simulation results shown in Table 16 for Scheme 2 indicate that when the number of ship is increased to 1,752 ships, W_q would be 2.54 hours, very close to the service level of the present situation (W_q = 2.44). The annual total handling amount (TO_TEUs) would reach 1,340 thousand TEUs which is 362 thousand TEUs or 37.07% more than that of the present situation.

3. A Comparative Analysis of Improvement Plans I and II

For Plans I and II, the simulation results for Scheme 2 are used in Table 17 to compare with the following major evaluation indicators: efficiency (W_q), benefit (TO_TEUs), combined efficiency and benefit (AWT/AST and UC).

For Carrier C2, the data presented in Table 17 show that the evaluation indicators of plan I are superior to those of plan II. When compared to Scheme 1 of the present situation, Plan II provides minor improvements in both the W_q and the AWT/AST indicator, but a greater (8.2%) improvement in the UC indicator. On the other hand, Plan I would produces a 49.1% improvement in W_q indicator and a 16.2% improvement in the UC indicator when compared to Scheme 1 of the present situation.

After the adjustment with the berth concentrating on the T4 container terminal, total length of berth would reduce, but TO_TEUs can be improved by 10.69%. Thus, Plan I would be a more desirable candidate for Carrier C2.

The opposite situation occurs in Carrier C3 which concentrates on the T5 container terminal after adjustment. In this case, the berths would be arranged in the form of single protruding type for disposition, but the total length of the berth would increase. The results demonstrated in Table 17 show that except for UC, the indicators of W_q, TO_TEUs and AWT/AST would have more improvement in Plan II than in Plan I. The cause of this improvement is mainly due to the increased cost of berth length. If the operation in Carrier C3 was focused on efficiency, further improvement in plan I can also be achieved.

V. CONCLUSION

In the past, most governments hired out the berths to ocean carriers. In recent years, companies such as COSCO and the NEDLLOYD Ltd. (P&O) and other large-scale shipping companies have purchased container harbors in joint ventures with the terminal operator. This trend change has led to the construction of ports and an expansion of the operation plane.

The efficiency of a container terminal depends on the smooth and efficient handling of containers. The Port of Kaohsiung has successfully implemented a container terminal operation and the port is now established as a major global business hub. However, the growing trend toward ship-size maximization brings not only opportunities but also challenges to the port operator. These changes demand adaptation to the current practices at the Port of Kaohsiung. At present, this port cannot handle large-scale throughput because its quay length and berth depth of water are insufficient. Add to these tally of deficiencies are assorted technological incompatibilities (about berth, quay crane and yard crane to work in coordination and support). On the other hand, the market is now much more competitive; especially since Mainland China has already successively built and finished a deepwater wharf in recent years. If the competitiveness of the Port of Kaohsiung is no longer promoted and it doesn't actively strive for the source of goods, it will cause the ocean carriers that use the port nowadays to leave. This situation will cause deep expense to Taiwanese economy. These changes demand major reforms of the current practices at the Port of Kaohsiung.

This research used a simulation model to analyze the operation of the Port of Kaohsiung after the completion of the T6 container terminal. Major recommendations based on the research results are summarized as follows:

1. The key result of the research shows that berth concentration and facility optimization can produce significant improvements in efficiency and effectiveness of port performance. To achieve these changes, this study strongly recommends terminal privatization and technology upgrade. Terminal privatization will enable terminal operators to conduct business with full authority and offer professional services with fast decision-making procedures. Technology upgrade, on the other hand, will increase the utilization rate of port terminals. Implementation of both recommendations will attract more cargoes in turn would reduce the unit cost of the container cargo handling. Specifically, the simulation results show that the initial stage has 4 sets of berth with a total berth length of 1,500 meters, requiring 12 sets of crane to operate. Changes based on these recommendations will be able to offer mooring to large-size containerships that load more than 10,000 TEU. Furthermore, it would accommodate a reasonable capacity for Carrier C1 with an annual berthing increase of 2,000 ships higher than the present situation, and total throughput of up to 1,835 thousand TEUs. Besides, it may be expected that these changes could increase the throughput by about 1,300 thousand TEUs containers every year. This result is an improvement of 2.35 times in handling capacity when compared to the present situation (548 thousand TEUs). If Carrier C1 only builds and charters 2 sets of berth and 7 sets of cranes while retaining the same service facilities at the present level, four major evaluation indicators discussed in this study will all improve with a projected 40.1% reduction in W_q.
2. For the case of post completion of the intercontinental container terminal, the research results show that if Carrier C1 relinquishes charter berths (#70 and #120), Carriers C2 and C3 should seize the opportunity to charter and disperse in accordance with the proper berth adjustment improvement plan. This research provides two kinds of rational and feasible plans. Its operating assumption is that the rent of carrier berths should be concentrated in the same container terminal. Simulation results are presented through four major evaluation indicators, offering a basis for comparative analysis. The analysis indicates that one of the two plans, Plan I, is particularly effective and efficient and can be used by the port authority as an important basis for future port operation improvements.

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APPENDIX TABLE

Table A1. Accumulated probability table of ship inter-arrival.

classify	L_value (MIN)	U_value (MIN)	Number (ships)	Acc. Number (ships)	Acc. Per. (%) (ships)
1	0	60	102	102	0.118
2	60	120	63	165	0.191
3	120	180	39	204	0.237
4	180	240	58	262	0.304
5	240	300	50	312	0.362
6	300	360	46	358	0.415
⋮	⋮	⋮	⋮	⋮	⋮
52	3060	3120	0	858	0.995
53	3120	3180	2	860	0.998
54	3180	3240	0	860	0.998
55	3240	3300	2	862	1

Notes: 1. Carrier C3 (#76~77, #118~119) an example.
2. Acc. Per.: Accumulate percentage.

Table A2. Accumulated probability table of ship length, and draft, and load and unloading of container volumes.

Draft (m) / Ship length (m)	4~5	5~6	6~7	7~8	8~9	9~10	~	>13
>100	521	0	521	1248	1947	0	~	0
	(1.16)	(0)	(2.32)	(10.4)	(1.16)	(0)		(0)
100~120	287	243	655	923	0	0	~	0
	(8.11)	(113.5)	(15.3)	(1.16)	(0)	(0)		(0)
120~140	377	308	633	875	0	0	~	0
	(5.79)	(44.0)	(3.48)	(5.79)	(0)	(0)		(0)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
240~260	0	**332**	1338	1101	983	1165	~	0
	(0)	**(1.16)**	(3.48)	(12.25)	(3.48)	(2.32)		(0)
260~280	618	295	720	1086	1460	1002	~	0
	(3.48)	(12.75)	(23.17)	(44.03)	(69.52)	(5.79)		(0)

Notes: 1. Carrier C3 (#76~77, #118~119).
2. Among ( ) represents the permillage of ship arrival rate.

Table A3-1. Accumulate ship numbers of container volumes and the assigned number of cranes.

Vol.		50	100	150	200	250	300	350	400	450	500
cranes	1	2	7	13	7	8	6	3	3	0	1
	2	0	7	19	26	40	68	67	64	57	47
	3	0	0	0	0	0	0	1	3	8	10
	4	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0
Acc. ship numbers		2	14	32	33	48	74	71	70	65	58

Note: This Table shows the number of arrived ships in accordance with the actual ship handling volume and the number of assigned cranes and the accumulative number of ships (Acc. ship numbers) as well.

Table A3-2. Ship probability table of container volumes and the assigned number of cranes.

Vol.		50	100	150	200	250	300	350	400	450	500
cranes	1	1	0.5	0.41	0.21	0.17	0.08	0.04	0.04	0	0.02
	2	0	0.5	0.59	0.79	0.83	0.92	0.94	0.91	0.88	0.81
	3	0	0	0	0	0	0	0.01	0.04	0.12	0.17
	4	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0

Note: The Table estimates the ship number probability in accordance with Table A3-1.

Table A3-3. Ship accumulative probability table of container volumes and the assigned number of cranes.

Vol.		50	100	150	200	250	300	350	400	450	500
cranes	1	1	0.5	0.41	0.21	0.17	0.08	0.04	0.04	0	0.02
	2	1	1	1	1	1	1	0.99	0.96	0.88	0.83
	3	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1

Note: This Table shows the ship accumulative probability in accordance with Table A3-2.

Table A4. Accumulate probability table of number of cranes and efficiency of crane.

units: TEU/hour

rate		26	26.5	27	~	32	32.5	33
cranes	1	0.0137	0.0137	0.0137	~	0.9863	0.9932	0.9932
	2	0.0135	0.0212	0.027	~	0.9942	0.9981	0.9981
	3	0.0088	0.0132	0.0175	~	0.9956	0.9956	0.9956
	4	0	0	0	~	1	1	1
	5	0	0	0	~	1	1	1
	6	0	0	0	~	1	1	1

Note: Carrier C3 (#76~77, #118~119) an example.

Table A5. Test the significance of the variables for an ocean carrier.

	variables	V	λ	W_q	$1/\mu$
Carrier C1	ψ	2.100	0.001	0.206	0.095
	S_d	11.6422	0.0033	0.7001	0.2821
	$\alpha = 0.05$	2.0452	2.0452	2.0452	2.0452
	T =	**0.9880**	**1.4126**	**1.6122**	**1.8507**
	P value =	0.3313	0.1684	0.1178	0.0744
Carrier C2	ψ	0.6667	0.0014	0.0638	0.1379
	S_d	16.2084	0.0052	0.6394	0.4373
	$\alpha = 0.05$	2.0452	2.0452	2.0452	2.0452
	T =	**0.2253**	**1.4972**	**0.5468**	**1.7271**
	P value =	0.8233	0.1451	0.5887	0.0948
Carrier C3	ψ	5.9670	0.0012	0.0347	0.1538
	S_d	18.1041	0.0037	0.6578	0.4516
	$\alpha = 0.05$	2.0452	2.0452	2.0452	2.0452
	T =	**1.8053**	**1.8058**	**0.2887**	**1.8654**
	P value =	0.0814	0.0813	0.7748	0.0723

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