OPTIMAL DETERMINATION OF BERTHS AND CRANES IN CONTAINER PORTS

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abstract: With regard to the calculating process of the optimal combinations of berth and crane, this study provides an analytical method which divides the ships and berths into three classification according to their size, and it follows the principle that large ships berthing large berths, and small ships berthing small berths. Then with the information from KEELUNG port for 1989 and 1993, the optimal solutions are analyzed and compared with conventional method of queuing theory (non-classification). The non-classification method and classification method in the theoretical analysis are extreme hypotheses to the substantial condition; the results of ideal simulation should be on the interval of classification and non-classification. This study provides a simple approximate resolution, which has the error within 5% comparing with the high accurancy and perfect-designed simulation program. Finally, considering the uncertainty condition of port demand forecasting, one could evaluate the optimal combinations of berth and crane by the year of 2001 in port of KEELUNG as a case study.

1. INTRODUCTION

During the last thirty years, containerized transportation has become the main focus of seaborne trade. In modernized container ports, the gantry cranes and related facilities are improved or renewed in order to meet the high efficiency of container operation. However, port development requires suitable geographical conditions, lots of hardware facilities and large amounts of investment. Therefore, an important topic in port development is how to optimise port facilities effectively, to prevent the imbalance of demand and supply, resolve problems of congestion, and optimize cost-effectiveness.

The optimal determination of port facilities is fairly important in the process of port development. The port capacity could be produced sufficiently well with a berth scale and crane determination. However, most studies of optimization hypothesize that regular amount of cranes were installed at each berth which only aim at the determination of the number of berths. And analyzing the optimal scheme of the determination of berth and crane should be adopted to the system simulation. Queueing theory and system simulation are two methods used to analyze optimal combinations of berths and cranes in container ports, which have the individual advantages and disadvantages. The advantages of queueing calculations theory are that it involues convenient calculations and fewer information requirements; the disadvantages are that the result differs from the actual operation, and the number of berths and cranes seem to be higher than what is actually required. For example, for small berths, as a large ship comes in, the analysis could not consider the case as it calculates by berth utilization. The advantages of system simulation are that the well-designed program could well meet the actual operational condition; nevertheless, it requires lots of information and is only suit for an individual case study. Further, there is still no regular formula about the adopted queuing model, the settled cost function and the approximate formula of average waiting time by each related research institute. An international index is developed to evaluate the effectiveness of port systems, it is used to analyse the optimal berth and crane combinations in container ports. The model minimizes total port cost per TEU, including the costs of ships, cargo, containers, facilities (wharf, break water, entrance channel, yard, etc.), equipment (cranes), labor, and maintenance. The content of the port optimal scheme includes the optimal number and length of each type of container berth, the total length of berths and the optimal sets of cranes installed in each type of berth.

Located at the northern tip of Taiwan, the hinterland of service by KEELUNG port embraces seven cities and counties in northern Taiwan. Since the quantity of containers in these areas amounts to sixty percent of the importing and exporting containers in Taiwan area, KEELUNG port stands at the center of commerce and industry in Taiwan. Furthermore, as most imports and exports of sundry goods have been containerized, this study used container transport at KEELUNG port to investigate the issue of optimal scheme of the facilities of container terminals.

This study exploits fluctuating service rates as its optimal idea, and analyzes the optimal berth and crane combinations in the container port of KEELUNG. Most studies of optimal programming of terminals are conducted in regard to the number of berths and do not consider the impact levied by the determination of cranes installed for loading and unloading. This paper employs the uncertainty of demand prediction and the performance evaluation indices of port operation to seek the optimal number of berths and determination of crane numbers in the objective year. The result can be cited as a reference for the re-construction of container terminals in KEELUNG port.

This study utilizes queueing theory and cost functions to investigate container transport demands in each year using the port system evaluation index(IND) to find the optimal berth and crane combinations. The primary purposes of this study are:

1. To explore the number of berths as well as the crane numbers, and decide optimal combinations.
2. To propose a classification for the berth and crane combination in container ports.

3. To propose a "approximate optimal programming", which lies between the theoretical solution and simulation solution for port planning.

2. FACTORS OF INFLUENCE ON THE OPTIMAL DETERMINATION OF BERTHS AND CRANES

Factors influencing on the optimal determination of berth and crane can be classified in to three categories, which are each of the parameters of the queueing systems, cost function, and relevant factors to the service rate. They are elaborated in the following, respectively.

2.1Factors of Queueing System:

a. arrival rate and probabilistic models of interarrival times. b. service rate and probabilistic models of service time. c. service system(FCFS, priority). d. scale of berth.

2.2Factors of Cost Function:

a. ship cost in port per hour(U_s, depend on the type and scale of ship). b. cost of cargo(C_{cg}, depend on the average payload of goods X and it's value). c. construction expenses of port facilities except that of the pier and its operation expenses(C_{pf}, C_{po}.). d. construction expenses of the pier and its operation expenses (C_{bf}, C_{bo}). e. cost of handling machinery and its maintenance expenses (C_{cm}). f. working expenses of operators using machinery(C_{co}). g. expenses of the storage yard(C_{yd}).

2.3 Factors of Service Rate:

a. exchange volume of cargo(V). b. crane handling rate(γ). c.number of cranes per berth(AC) d. crane interference exponent(f,0.5 $\sim$ 1.0). e. dwelling time as ship taking berth, waiting for operation, logistic support, leaving shore, an so on(DT). f. the average deposit time for unit cargo(H)

3.METHODS OF THE OPTIMAL DETERMINATION OF BERTHS AND CRANES

Generally speaking, there are four kinds of methods to resolve for the berth determination, which are as follows:

3.1 Empirical Formula

$$N=(\alpha \cdot \lambda)/\mu$$

where,

N: number of berth.

α:empirical coefficient (1.5 $\sim$ 2.5).

λ: mean arrival rate.

μ: mean service rate.

Three problems are noticed in the empirical formula:

(1) costs of user and supplier have not been taken into consideration.

(2) service rate is defined as a constant, thus the change of crane number has not been taken into consideration.

(3) economic benefit of the future berth scale has not been taken into consideration.

3.2 To Use Relevant Evaluation Indices of Queueing Systems Directly

Using relevant evaluation indices, charts, or figures of the queueing systems directly to decide the annual demand of the port transportation(Q) and evaluation indices (degree of congestion(DC), average waiting time (W_q), average waiting time factor (W_q.u)), then the number of berth can be derived from them. However, the problem of this method would be how the criterion value of the evaluation index is decided if the cost item has not been taken into account. Each of the evaluation indices as well as its practical applications are elaborated in the following:

1.**DC**: Degree of congestion is the probability to wait for berths when vessels arrive at the port.

$$DC=\sum_{V=N+1}^{\infty} P_N(j)$$

2.**W_q**: Average waiting time is a vessel spends in the waiting line for service.

$$Wq = Lq/\lambda = \sum_{j=N+1}^{\infty}(j-N)\cdot P_N(j)/\lambda$$

3.**Wq·μ**:Waiting time factor is the ratio of the average waiting time(AWT) to average service time(AST).

$$Wq\cdot\mu = AWT/AST$$

where,

λ: arrival rate of vessel, μ: average service rate, N: number of berth;

L_q: expected number of ships that are waiting for service in the port system

$P_N(j)$:N is the number of berth, and $P_N(j)$ is the probability of j vessels in the port within the period T.

When we use each of the evaluation indices as the criteria, the number of berths are decided as follows:

(a) Berth Determination by the Degree of Congestion(DC)

We can designate the degree of congestion of port system with the viewpoint as under a certain criterion level so as to determine the number of berth. The degree of congestion and berth scale as well as their relationship of demand is as shown in **Fig.1**. For instance, when k=1 and Q=100*10^4 TEU, DC will be taken under 10% as its criterion and the reasonable number of berth will be N*=8. Should the criterion be taken as 30%, the reasonable number of berth will be N*=6.

(b) Berth Determination by the Average Waiting Time (W_q)

The average waiting time and berth scale as well as their relationship of demand is as shown in **Fig.2**. Thus, if the ceiling limit of waiting time is used for the designation, the confines of operation capacity of the berth can then be concluded. For instance, when k=1 and Q=100*10^4 TEU, the average waiting time will be within two hours and the reasonable number of berth will be N=7. If four hour is taken as its criterion, N=6.

(c) Berth Determination by the Waiting Time Factor ($W_q \cdot \mu$)

Basically, when the service rate in the queueing system increases the waiting time will be reduced, and vice versa. Upon such trade-off viewpoint, the waiting time factor is defined in terms of their relationship, and it is upon this as its evaluation criterion for deciding the scale of berth. The waiting time factor and berth scale as well as their relationship of demand is as shown in **Fig.3.** For instance, when k=1 Q=100*10^4 TEU, the waiting time factor is designated as under 10%,the reasonable number of berth will be N=7. If the waiting time factor is designated at 30% as its criterion, it will also be N=6.

Though the method using relevant evaluation indices of queueing systems directly can help decide the number of terminal facilities and can be very swift, its main handicaps are:

1. It is quite difficult to determine the criterion value.
2. Cost fluctuations of user and supplier have not been taken into consideration.

Therefore, method of such kind can only be exploited to conduct crude judgment, and is unable to analyze the changes of parameters of each and every system, while it is most common that cost function, if optimized, can be used as evaluation index for making judgment. That is to combine the features of queueing system and that of cost function, and then to decide the number of berth as the minimization of total cost. Besides, such method can be further divided into theoretical analysis and system simulation categories for resolution.

3. Method of OR

For the last thirty years, most studies have used to employing such OR skills of queueing theory and cost functions to determine the number of berths, thus it is why the optimal determination has been so widely used. Nonetheless, if the numbers of fluctuating crane installed at the terminal, if there is any constraint to share the cranes among berths, and the fluctuation in terms of service rate, all these problems can hardly be articulated.

4. Method of System Simulation

When system simulation method is used for calculation, it is necessary that the features of port system and the type of terminal have to be well accounted for. Then comprehensive judgment is made according to the following points.

1. One has to possess exhaustive appreciation toward the characteristics of port system

   a. the probabilistic models of interarrival times and service time, and the intensity of its impact to port system.

   b. the impact of berth scale(N) and the initial solution of berth determination(N_0).

2. One has to have comprehensive understanding toward the optimized characteristics of port system

   a. each item of parameters in the cost function and relevant factors found in the service rate, and the intensity of its impact.

   b. the optimal combinations of berth and crane, the features of the port system.

3. It is necessary to be equipped with computer program of high precision.

a. Model calibration is necessary, and helps decide the times of simulation.

b. To each pier, designate 1 to 3 cranes with range of changes.

4. It is necessary to handle large amount of data efficiently.

a. It is necessary to keep one year round data, then the characteristics of changes of week and month can be well under control.

b. It is necessary to keep detailed record of every minute from the time the vessel arrives at and leaves the port.

c. Each item of information the vessel arrives at the port :captain, code number of the ship taking berth, number of crane used to load and unload, quantity of goods loaded and unloaded, and time of loading and unloading.

d. It is necessary to keep detailed records of the number of crane used by each type of berth as a whole, duration of operation, operation efficiency, break-down record.

4. THE CONCEPT OF OPTIMAL PROGRAMMING AND ITS PROBLEM REGARDING QUEUEING THEORY

Since there exists such differences of viewpoint in terms of transportation demands of the port by diverse departments, what the economic department sees highly would be the rejuvenation of area industry, what the financial department considers important would be the issue of tax and tariff, what the transportation company is concerned most would be of the increment of goods transportation, while what the port authorities regard highly would be the construction and operation of port facilities. As for the concept of optimal programming and the problem of queueing theory, they are elaborated as follows:

4.1 The Concept of Optimal Programming

1. What port planning takes highly is not of the demand of port transportation (Q), but the optimal berth and crane combinations of port facilities.

2. There are more than just a few relevant parameters to the optimal plan of the port facility, and optimal examination regarding the priority ranking of intensity of each of the parameters in the optimal plan must be taken into assessment.

3. Should there be any change regarding the number of crane, there would also be change in the optimal number of berth(N). Thus, it will not be enough just to resolve for the optimal solution of berth number, what is more, it should be that both the number of crane as well as that of berth should be resolved concurrently.

4. Even if it is of same number of berth, length of piers will be different because of diverse types of berths, besides, and the construction expenditure will also not be the same. Therefore, the classification of berth has become quite essential.

5. When the optimal determination of port facility is to be considered, it is imperative that each and every of the combinations of berth and crane should be taken into assessment.

6. When the uncertainty of transportation demand_are to be studied, it is most important that, within a certain interval of confidence, the number of berth(N*) and crane (C*), length of pier

(L*), and the construction expenditures of terminal facility should be reviewed.

4.2 Problem about the Queueing Theory Regarding the Port Planning

The analysis regarding the optimal programming of terminal has following problems:

1. There is either over- or under-evaluation for the average waiting time (W_q), and its reasons are :

   a. What, in fact, is $M/E_k/N$ queueing model has now been abridged by M/M/N model, and it explains why there will be over-evaluation for the average waiting time.

   b. About $M/E_k/N$ model waiting system, should Lee-Longton approximate equation be employed, then there will be under-evaluation for the average waiting time.

2. As for cost function, it would not be judicious enough should only the expenses of ship and berth be taken into account.

3. Should there be concern that the number of berth might be reckoned too small, the reason can be resorted to different types of berth and the non-classification of ship length.

4. Should the service rate be defined with a constant, only the number of berth can be found out. Due to the impact that the number of crane installed cannot be taken into account, the optimal determination of the number of berth and crane installed will be the hub that hinders the completion of calculation.

There is detailed investigation in the relevant studies for the reason that the average waiting time (W_q) is either too small or too large, while this study would base on the data of KEELUNG port in the years of 1989 and 1994 to conduct review and analysis regarding the optimal combination of berth and crane.

5. ANALYSIS OF THE OPTIMAL PROGRAMMING FOR CONTAINER PORTS

5.1 Queueing Analysis of the Optimal Programming for Terminal (Conventional Non-Classification)

The optimal design for terminal is of the most important part throughout port planning, nevertheless, most studies have, without exception, employed queueing theory analysis and system simulation to conduct their work on optimal berth for resolution. With gains and losses found in these two methods, even the definition_of cost function from the relevant studies as well as the queueing models employed have not reached any positive outcome, not to say of the approximate formula_of average waiting time(W_q). The queueing model and parameters taken into consideration in this study have subsequent features, which are elaborated as in the following:

1. Decision of Queueing Model

In the past, relevant studies on port systems have mostly been conducted with M/M/N queueing model, only there are now some scholars who have, as well, advocated $M/E_k/N$ queueing model to conduct the demonstration. As a matter of fact, the choice of model should be made according to the nature of goods, features of arrival vessel (cargo exchange volume, route), features of the port system (time of the port to be close, terminal operation duration). Each of the terminals had better find its most befitting alternative after taking previous factors into account, and testing its goodness-of-fit of interarrival times and service time. This paper has employed $M/E_k/N$ queueing model for discussion, and its k=3.

2. Settlement of the Approximation Formula of Average Waiting Time (W_q) of Ship at Port.

The average waiting time of vessel at port is one of the most important parameters in the cost function, which is found in accordance to the queueing model employed within the port system. Based on the $M/E_k/N$ queueing model, this paper will use the approximation formula by Cosmetatos.

3. Cost Function, Evaluation Index and Port System Parameters

Using the result of relevant studies(HUANG 1990,1995), we defined the cost function, evaluation index and system parameters as:

The total costs of ship in port can be classified as the costs of ship and cargo(C1) and the service cost of terminal(C2). The former is the expenses paid by the berth user(shipagent). It consists of two parts. One part is given with C_s which indicates the whole of ship cost including construction, maintenance and operation expenditures of ship, and the other is defined as C_{cg} which describes the cargo loaded aboard and the interest cost of its related equipment. Therefore, relevant formula can be obtained as follows:

$$C1=C_s+C_{cg} \text{ (\$ship/hr)}$$

As to service costs of the berth comprise(C2), it is composed of construction, maintenance and operation expenditures of port facilities, the operation costs of machinery, and expenses of the working operators and storage yard. So, C2 can be defined as

$$C2=C_{pf}+C_{po}+C_{bf}+C_{bo}+C_{cm}+C_{co}+C_{yd} \text{ (\$ship/hr)}$$

The total cost in port, TC is defined as:

$$\begin{aligned}TC&= C1+C2\\ &=(C_s+C_{cg})+(C_{pf}+C_{po}+C_{bf}+C_{bo}+C_{cm}+C_{co}+C_{yd})\\ &=(U_s+U_{cg}\cdot X)(\lambda/\mu+L_q)+(U_{pf}+U_{po}+U_{bf}+U_{bo})\cdot N+U_{cm}\cdot N\cdot AC+U_{co}\cdot AC\cdot T\cdot\lambda+U_{yd}\cdot V\cdot H\lambda\end{aligned}$$

and evaluation index of unit cargo, IND is also defined as follows:

$$IND=TC/(\lambda\cdot U_s\cdot V)=((1+R_{cg})(1/\mu+W_q)+(R_{pf}+R_{po}+R_{bf}+R_{bo})\cdot N/\lambda+R_{cm}\cdot N\cdot AC/\lambda+R_{co}\cdot AC\cdot T+R_{yd}\cdot V\cdot H)/V$$

where,

R_{cg}, R_{pf}, R_{po}, R_{bf}, R_{bo}, R_{cm}, R_{co}, and R_{yd} are the cost ratios of $U_{cg}X$, U_{pf}, U_{po}, U_{bf}, U_{bo}, U_{cm}, U_{co}, U_{yd} divided by U_s respectively.

5.2 The Optimal Programming for Container Terminals by Classification

In terms of the optimal determination for berths and cranes, a systematic simulation approach has been brought forth to avoid the defect that unjustifiable hypothesis might incur from queueing theory analysis regarding vessels taking berth. To put it more solidly, it can be learned:

1. Non-classification and classification can be taken to be of two extreme hypothetical requirements.

2. The meaning of conventional non-classification is that vessels of any sizes can park at the berths of whatever types, and the suppositional conditions are, in fact, quite loose. Thus, the outcome of the calculation is dubiously too small.

3. The meaning of the proposal put forward in this study is follows the principle that large ships berthing large berths, and small ships berthing small berths. Smaller vessels cannot park at larger berth even when it is vacant. The suppositional terms are more harsh, in fact, thus the outcome of the calculation is dubiously too large.

The calculation of classification would have to put the following characteristics into analysis:(1) the relation between the tonnage (DWT) with the length of the container ship;(2) the relation between the ship length (SL) with the cargo exchange volume(V) of the container ship;(3) the relation between the designed length (DL) with the cargo exchange volume(V);(4) the relation between the designed length of the container pier with the designed cargo exchange volume,(5) classification of the type of container ship and pier;(6) distribution of the types of container vessels arriving at the port;(7) distribution of the cargo exchange volume of the container ship, and so forth. Using the data of KEELUNG port, the following relation equations are thus derived. **Fig. 4** and equation (1) show the relationship between the tonnage(TN) with the length of the container ships.

$$SL=60.639Ln(TN)-406.93 \qquad (R^2=0.911) \text{ ------------------------ } (1)$$

Fig. 5 and equation (2) show the relationship between the length of the container ships with the cargo exchange volume(V).

$$V=144.45e^{0.2739(SL)} \qquad (R^2=0.925) \text{ ------------------------ } (2)$$

Fig. 6 and equation (3) reveal the relationship between the designed length(DL) of the container berth with the designed capacity of loading and unloading.

$$DC=298.11(DL)^{0.7598} \qquad (R^2=0.946) \text{ ------------------------ } (3)$$

5.3 Analysis of Container Ships and Container Terminals

1. Classification of Container Ships

In order to cope with ships and berthing operation, this study has divided container ships into six categories, and the payload of cargo is made the criterion for classification, while the segmentation for each type of container ships and its length are as shown in **Table 1**.

2. Comprehensive Analysis of Container Ships and Container Terminals

The distribution of container ships arriving at the KEELUNG port analyzed is as shown in **Table 2**, and it can be learned that there are prominent changes regarding the types of container ships for the last twenty years. **Table 3** shows the length of pier and numbers of berth and crane in KEELUNG container port. **Table 4** shows the comprehensive classification of container ship and container terminal.

In addition, based on the import and export demand forecasting models of containers (equations 4, 5) from KEELUNG port, the demand of container transportation and the frequency of container ships(SH) coming to port in each of the objective year could come to its optimal design by these two separate methods. After having compared the number of berths(N*) and cranes (C*), length of pier (L*), investment on the terminal facilities, and IND value, the results are as shown in **Table 5**, where, IIP is of the industrial production index.

$$Q_E = -8243636 + 1756741 IIP \quad (R^2 = 0.993) \quad \text{---------------------------(4)}$$

$$Q_I = -2955419 + 3.69814 GDP \quad (R^2 = 0.954) \quad \text{- -------------------------(5)}$$

$$SH = 0.112T^4 - 5.2762T^3 + 76.14T^2 - 114.73T + 1028 \quad (R^2 = 0.993) \text{-- ---------(6)}$$

where, Q_E : export demand, Q_I: import demand and T: year.

To consider the uncertainty of transportation demand of ports in the future, two methods of terminal planning have been compiled as shown in **Table 6** and **Table 7.** The features of them are:

1. For the optimal number of berths (N*), the classification can conclude two more berths.
2. For the optimal number of cranes (C*), the classification can conclude two to four more cranes.
3. In terms of pier length, the absolution value of its difference is around 9%～ 11.1 %.
4. In terms of the investment on the terminal facilities, the difference is around 7.1% ～ 11.6%.
5. In terms of IND value, the absolute value of its difference is around 2.8%～ 4.95%.

The approximate optimal determination of container base on KEELUNG port in the objective year is as shown in **Table 8.** The optimal number of berths in 2001 would be 21 to 23, and the optimal number of cranes would be 38 to 42, while the optimal length of pier would be 5225m to 5750m. As for the notions of approximate optimal determination and practical solution, they are as shown in **Fig.** 7, and they should, in theory, lie between the interval of the two methods of design as classification and non-classification.

6. CONCLUSIONS

This study has formulated an evaluation index for the fluctuating service rate as viewed from the perspective of port system programming, and the service rate is employed to conduct the optimal determination plan of the terminal. Theoretical analysis of the optimal berth and crane combinations in container ports has come to the following conclusions and recommendations.

1. The conventional theory exercises non-classification regarding vessels and berths, which contradicts the reality and results in dubiously smaller calculation outcome. This study will put the ideas into practice as vessels are to be found in six categories and berths in three, only the calculation outcome is dubiously too large as those suppositional terms are too strict.

2. This study is based on the actual data of KEELUNG port in the years of 1989 and 1994 for resolution so as to compare the results of these two calculation methods, and it is found that the difference of the optimal determination of berth numbers is one, while that of crane lies within two. Furthermore, the difference regarding the three indices as pier length, construction expenditure of terminal, and IND value are respectively 7.3%～ 10.9%, 8.5%～ 11.0%, and 5.1%～ 6.4%.

3. This study has considered both the results of the two calculation methods as classification and non-classification. Due to the fact that these two methods are of two extremes (either too large or too small) for the optimal determination plans, the idea putting forth the middle point "approximate optimal determination" from the center of the two has been put forth, and the marginal error of which from the actual optimal solution should be within 5%～ 6%.

4. With additional detailed and precise system simulation program design and calculation input of authentic data from the ports, the results can further reveal that the optimal determination of simulation solution will fall within the interval of classification and non-classification. Asides from providing proof to the previous hypothesis, it has also offered the idea of approximate optimal solution, which lies between theory and simulation analysis.

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Table 1: Classification of Container Ship (Unit : m)

Ship	Pavload of Cargo	Length of Ship	
Type	TEU	Low Boundary	High Boundary
A1	0 ~ 499	100	160
A2	500 ~ 899	145	190
B1	900 ~ 1,299	170	220
B2	1,300 ~ 1,699	200	240
C1	1,700 ~ 2,099	210	265
C2	2,100 ~ 4,000	250	297

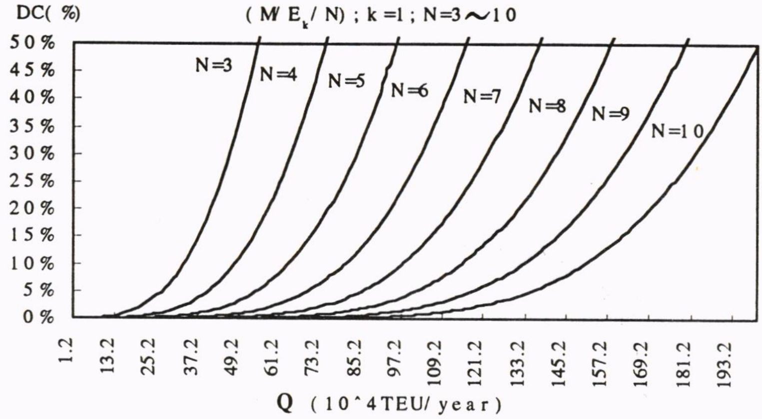

Fig.1 :The Relationship of DC, Berth scale and Demand

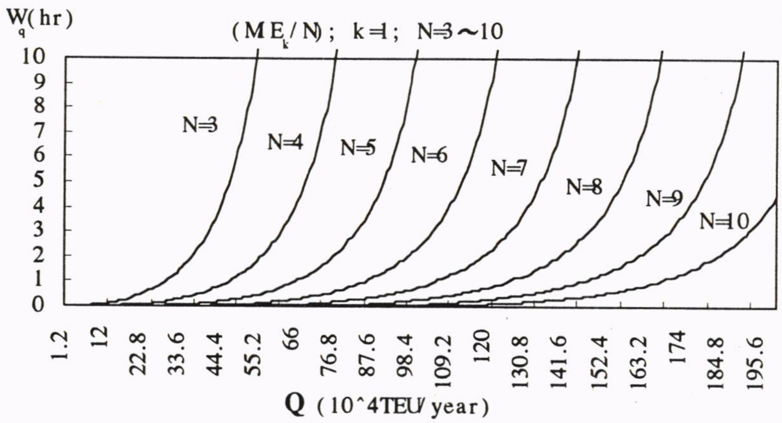

Fig.2 :The Relationship of W_q, Berth scale and Demand

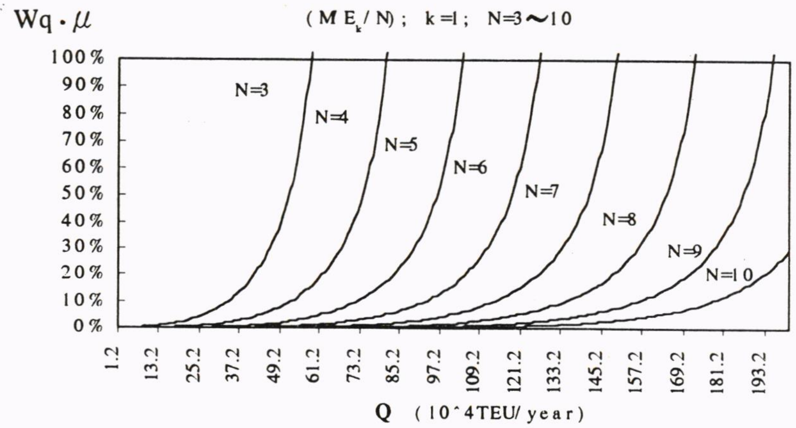

Fig.3 : The Relationship of $Wq \cdot \mu$, Berth Scale and Demand

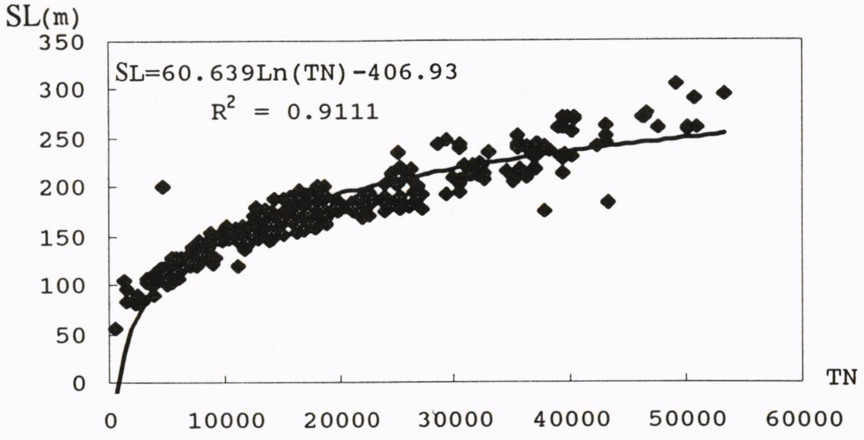

Fig.4: Relationship between the Tonnage with the Length of Container Ship

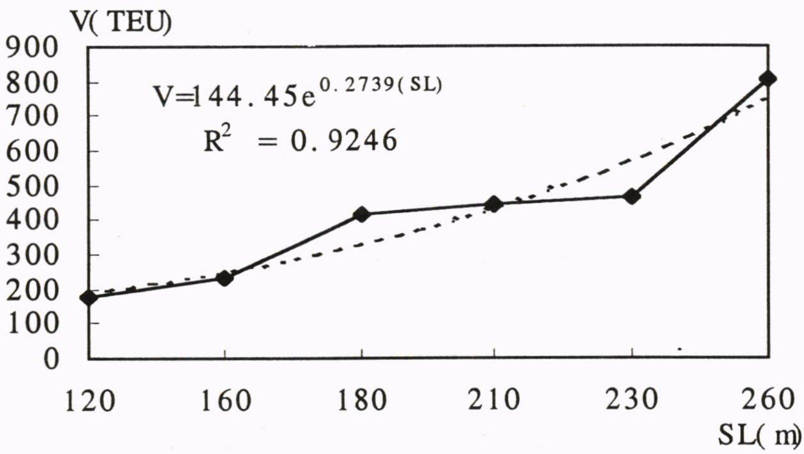

Fig.5: Relationship between Length of Ships with Cargo Exchange Volume

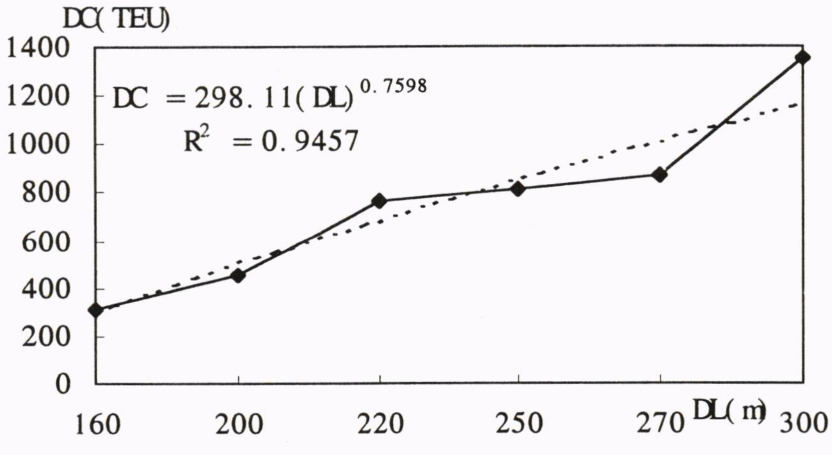

Fig.6: Relationship between Designed Length with Designed Capacity

Table 2: Distribution of Arrivaled Container Ships at KEELUNG Port

Type	1976	1981	1983	1989	1994	1998	2001
A1	53.0	44.0	32.0	29.7	18.2	18.0	15.0
A2	12.0	16.0	18.0	19.9	26.4	26.0	25.0
Σ	65.0	60.0	50.0	49.6	44.6	44.0	40.0
B1	5.0	5.0	6.0	16.5	23.2	25.0	28.0
B2	20.0	20.0	24.0	7.9	15.0	15.0	17.0
Σ	25.0	25.0	30.0	24.4	38.2	40.0	45.0
C1	6.0	8.0	10.0	11.0	4.6	6.0	5.0
C2	4.0	7.0	10.0	15.0	12.6	10.0	10.0
Σ	10.0	15.0	20.0	26.0	17.2	16.0	15.0
SH	1,020	1,915	2,907	4,072	4,681	5,814	6757
Q	26.5	65.5	94.3	177.2	204.7	335.6	411.7
V	251TEU	342TEU	324TEU	435TEU	437TEU	577TEU	609TEU

Note : Q is 10^4TEU

Table 3: The Distribution of Length, Numbers of Berths and Cranes in KEELUNG Port

Type	DL	BL	KEELU	N	C	AC
AA	200	150 ～ 219	157,190 200,207 216,210*2	7	10	1.43
BB	250	220 ～ 269	220,237 240,257	4	6	1.50
CC	300	270 ～ 320	300 324*2	3	8	2.67
Σ			3,292	14	24	1.71

Note ： DL is Designed Length of Pier;BL is Interval of the Length of Berth 。

Table 4: The Comprehensive Classification of Container Ship and Terminal in KEELUNG Port

Container Ship		Payload of Cargo	Container Berth			
Type	SL(M)	V(TEU)	DL(M)	DC(TEU)	Capacity	Type
A1	100 ～ 160	150 ～ 250,180,314	160	314	SL=100 ～ 190(M)	AA
A2	145 ～ 190	200 ～ 300,234,453	200	453	V=150 ～ 300(TEU)	L=200M
B1	170 ～ 220	250 ～ 450,414,764	220	764	SL=170 ～ 240(M)	BB
B2	200 ～ 240	400 ～ 550,441,812	250	812	V=350 ～ 550(TEU)	L=250M
C1	210 ～ 265	450 ～ 650,464,873	270	873	SL=210 ～ 295(M)	CC
C2	250 ～ 257	650～1,300,802,1,35	300	1,351	V=450～1,300(TEU)	L=300M

Note ： SL is Length of Ship; DL ： Designed Length of Pier; DC Designed Capacity of Berth 。
V:Interval of Payload of Cargo;Average Payload of Cargo in KEELUNG Port;Average Upper 30% of V

Table 5: The Comparison of Two Methods with Optimal Combinations of Berth and Crane (1989;1994)

	(I)		(II)			
	BB		Σ	AA	BB	CC
Basic	1.0,0.5	R_s, Rc_g		0.6,0.3	1.0,0.5	1.2,0.6
	0.5,0.25	R_p, R_b		0.4,0.2	0.5,0.25	0.6,0.3
Data	3.0,1.24	k, R_{cm}, r		3,0.1,24	3,0.1,24	3,0.1,24
	0.75,6	f, DT		0.75,6	0.75,6	0.75,6
1989	1771930	TEU	1771930	395613	418525	957792
	435/4072	V/SH		196/2019	421/994	905/1059
	19/11	C^*/N^*	21/12	5/4	6/3	10/5
	2750M	L^*	3050M	800M	750M	1500M
	4.1	$R_{bf}.N^*+R_{cm}.C^*$	4.55	1.1	1.2	2.25
	0.1295	IND^*	0.1377	0.1548	0.1439	0.1279
	0.762	ρ		0.744	0.621	0.687
	23.5%	DC		37.1%	23.8%	24.6%
	1.48hr	W_q		4.29hr	3.80hr	4.5hr
	0.082	$W_q \cdot \mu$		0.332	0.231	0.158
1994	1742339	TEU	1742339	433013	746163	563163
	379/4594	V/SH		212/2045	425/1757	711/792
	19/11	C^*/N^*	21/12	6/4	9/5	6/3
	2750M	L^*	2950	800M	1250M	900M
	4.1	$R_{bf}.N^*+R_{cm}.C^*$	4.45	1.2	1.9	1.35
	0.1351	IND^*	0.1421	0.1416	0.1385	0.1472
	0.786	ρ		0.731	0.698	0.712
	28.0%	DC		34.9%	26.1%	36.3%
	1.74hr	W_q		3.79hr	2.98hr	9.46hr
	0.105	$W_q \cdot \mu$		0.303	0.171	0.401
e (%)			1989		1994	
		L^*	10.91%		7.27%	
		$R_{bf}.N^*+R_{cm}.C^*$	10.98%		8.54%	
		IND^*	6.35%		5.14%	

Note: e(%)=(II - I)*100% /I

Table 6: The Comparison of Two Methods with Optimal Combinations of Berth and Crane (1998;2001)

	(I)		(II)			
	BB		Σ	AA	BB	CC
Basic	1.0,0.5	R_s, Rc_g		0.6,0.3	1.0,0.5	1.2,0.6
	0.5,0.25	R_p, R_b		0.4,0.2	0.5,0.25	0.6,0.3
Data	3.0,1.24	k, R_{cm}, r		3,0.1,24	3,0.1,24	3,0.1,24
	0.75,6	f, DT		0.75,6	0.75,6	0.75,6
1998	33556503	TEU	3356503	834091	1437590	1084822
	577/5814	V/SH		326/2558	618/2326	1166/930
	31/17	C^*/N^*	34/19	9/6	15/8	10/5
	4250M	L^*	4700M	1200M	2000M	1500M
	6.5	$R_{bf}.N^*+R_{cm}.C^*$	7.15	1.8	3.1	2.25
	0.1139	IND^*	0.1183	0.1143	0.117	0.1232
	0.832	ρ		0.78	0.733	0.741
	30.9%	DC		37.2%	23.8%	33.0%
	1.93hr	W_q		3.97hr	2.34hr	8.23hr
	0.091	$W_q \cdot \mu$		0.248	0.106	0.236
2001	4117663	TEU	4117663	1023239	1763595	1330829
	609/6757	V/SH		379/2703	580/3041	1313/1014
	37/20	C^*/N^*	40/22	11/7	17/9	12/6
	5000M	L^*	5450M	1400M	2250M	1800M
	7.7	$R_{bf}.N^*+R_{cm}.C^*$	8.35	2.15	3.5	2.7
	0.1108	IND^*	0.1149	0.105	0.1183	0.1181
	0.848	ρ		0.76	0.81	0.743
	32.3%	DC		30.9%	36.8%	30.5%
	1.92hr	W_q		2.89hr	3.84hr	7.07hr
	0.087	$W_q \cdot \mu$		0.168	0.183	0.183

Table 7: The Optimal Combination of Berth and Crane (1989;1994)

		1998			2001		
		U	C	L	U	C	L
(I)	C_i^*/N_i^*	33/18	31/17	31/17	40/22	37/20	37/20
	L_i^*	4500M	4250M	4250M	5500M	5000M	5000M
	Cost	6.9	6.5	6.5	8.4	7.7	7.7
	IND*	0.1126	0.1139	0.115	0.1097	0.1108	0.1119
(II)	$\Sigma C_i^*/N_i^*$	37/20	34/19	33/19	44/24	40/22	39/22
	ΣL_i^*	5000M	4700M	4700M	6000M	5450M	5450M
	Cost	7.7	7.15	7.05	9.2	8.35	8.25
	IND*	0.1157	0.1183	0.1206	0.1127	0.1149	0.1166
e (%)	Length	11.11%	10.59%	10.59%	9.09%	9.00%	9.00%
	Cost	11.59%	10.00%	8.46%	9.52%	8.44%	7.14%
	IND*	2.76%	3.89%	4.87%	2.80%	3.75%	4.27%

Note : e(%)=(II - I)*100% /I

Table 8: The Optimal Combination of Berth and Crane (1998;2001)

		1998	2001
(I)	C_i^*/N_i^*	31/17～33/18	37/20～40/22
	L_i^*	4250M～4500M	5000M～5500M
	Cost	6.5～6.9	7.7～8.4
(II)	$\Sigma C_i^*/N_i^*$	33/19～37/20	39/22～44/24
	ΣL_i^*	4700M～5000M	5450M～6000M
	Cost	7.05～7.7	8.25～9.2
AOD	$\Sigma C_i^*/N_i^*$	32/18～35/19	38/21～42/23
	ΣL_i^*	4475M～4750M	5225M～5750M
	Cost	6.775～7.3	7.975～8.8

(I) : Non-Classification Method
(II) : Classification Method
AOD : Approximate Optimal Determination Method

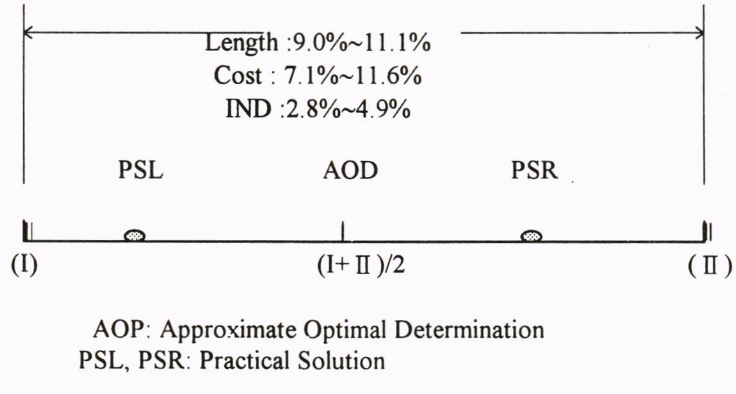

Fig. 7: The Concept of Approximate Optimal Determination of Terminal