A STUDY ON THE CONTAINER PORT PLANNING BY USING COST FUNCTION WITH IND BASED ON M/Ek/N SYSTEM

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abstract: The container port planning deals with many respects and conditions such as the evaluation of port performance, the analysis of optimal scale and its allocation of berth, measures of effectiveness of port improvement, and so forth, which play an important part in port system. In this paper, through the examination of the characteristics on the optimal process of port system in micro viewpoints, the relative main factors with influence on various purpose for port system can be found out, and the outcomes presented by using relevant tables and 3-D. graphs from the viewpoint of entirety can be suitably exploited to the planning of container port.

1. INTRODUCTION

In the container port planning, many respects and conditions should be considered, such as the evaluation of port performance, the analysis of optimal scale and its allocation of berth, measures of effectiveness of port improvement, and so forth, which play an important part in port system.

By now, the relevant studies in port planning have many absences from four viewpoints as: (1) most of studies discussed, only focusing on macro viewpoints, such as the determination of berth numbers, the analysis of port capacity etc., but from micro views, some important characteristics of optimum process at port system to be investigated, which is influenced by each factor, have fewly been discussed; (2) the scope of the factors of cost function to be considered is not clearly described yet; (3) based on $M/E_k/N$ queuing model, its relevant approximate solution of average waiting time (W_q) are not confirmed as a common method for investigating the port system; (4) when W_q is put in the place of cost function, its influence on the optimization of port system in various purpose is not discussed so much.

In this study, four specific points are furtherly investigated. Firstly, a simple applicable evaluation index (IND) to evaluate port system is given. And, its corresponding model for the evaluation criterion of port system is built with micro viewpoint to analyze the characteristics of port system in quantification. The model can be used to compare with the performances of different periods at the same port, or among different ports (especially in international community), so that the kind of performance evaluation would be least impacted with the changes of timeliness, currency value, and inflation etc. Secondly, the differences among various queueing models and berth scales as well as the related approximate formulas are studied, and the degree of sensitivity with the change of each parameter is analyzed so as to understand the intensity characteristics such as alternation caused by the berth occupancy factor (ρ) of port system.

Moreover, the effects of parameter variance in the cost function are also discussed through an example of container port. For different research purposes, we classify the parameters into three levels by the comparison of the intensity on sensitivity analysis. Finally, through the examination of the characteristics of port system in micro viewpoint, the relative main factors with influence on various purpose for port planning can be found out, and the outcomes presented by using relevant tables and 3D graphs from the viewpoint of entirety can be suitably exploited to the determination of the facility on port system.

2. EVALUATION INDEX AND COST FUNCTION OF PORT SYSTEM

2.1 Evaluation Indices of Port System in Previous Studies

In the past, studies of port planning are mostly conducted upon indices as the minimization of total cost when vessels are in port. And, some parameters embraced in the cost function have been founded in the related studies. Since 1966, Plumlee(1966) and Nicolau(1967) have considered nothing but two items of the idle costs of ship and pier. Wanhill(1974) and Noritake(1983) have come to consider the service cost of ship and pier, combined with relevance idle costs. Yoshikawa(1987) started to put loading and unloading cost item into consideration. Schonfeld(1985) has also taken the cost of storage yard for cargo into account.

In the meantime, most of the research reports employ M/M/N queueing model to calculate the average waiting time for ship. Nonetheless, Noritake(1983) and Yoshikawa(1987) reported that $M/E_k/N$ model could describe the situation of W_q better.

2.2 Definition of Cost Function

Usually, 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:

$$C1=C_s+C_{cg} \quad (\$/hr) \tag{1}$$

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

$$C2=C_{pf}+C_{po}+C_{bf}+C_{bo}+C_{cm}+C_{co}+C_{yd} \quad (\$/hr) \tag{2}$$

where

C_{pf}, C_{po}: In addition to the pier, the port facilities construction and its operation expenses.
C_{bf}, C_{bo}: construction expenses of the pier and its operation expenses,
C_{cm}: cost of handling machinery and its maintenance expenses,
C_{co}: working expenses of operators using machinery,
and C_{yd}: expenses of the storage yard.

All of those items of expenses in Eqs.(1) and (2) can be specified in more details in the following.

1.C_s and C_{cg}

According to $M/E_k/N$ model of queueing theory, the expected number of ships in the port system can be written as

$$L=(\lambda/\mu)+L_q \text{ (ship)} \tag{3}$$

where, λ: arrival rate of ship at port (ship/hr); $(1/\mu)$: service duration (hr); and L_q: average number of ships for waiting (ship).

Supposing that the unit time cost of ship in port is U_s($/hr·ship),the following formula can be given.

$$C_s=U_s\cdot(\lambda/\mu+L_q) \quad (\$/hr) \tag{4}$$

In addition, supposing that the cargo of the unit ton (or TEU) and unit time as well as the interest cost of its relevant equipment is U_{cg} ($/hr·TEU), then the unit time cost of cargo(C_{cg}) on board and relevant equipment can be given by C_{cg} as follows:

$$C_{cg}=U_{cg}\cdot X\cdot(\lambda/\mu+L_q) \quad (\$/hr) \tag{5}$$

where X is the average payload of goods (TEU), $1/\mu=T+DT$, and DT is the dewelling time as ship taking berth, waiting for operation, logistic support, leaving shore, and so on.

2. C_{pf}, C_{po}, C_{bf} and C_{bo}

Four separate items includes the construction cost(C_{pf}) as well as the expenses of operation (C_{po}) besides those of the pier, the construction expenses of the pier(C_{bf}) and its operation expenses(C_{bo}). They are able to be calculated through the corresponding unit cost of single berth, which are respectively defined as U_{pf}, U_{po}, U_{bf} and U_{bo}. And supposing that there are N berths at port, the expenditure of port facilities and its relevant expenses in port system are able to be found as follows:

$$C_{pf}=U_{pf}\cdot N,\quad C_{po}=U_{po}\cdot N,\quad C_{bf}=U_{bf}\cdot N,\quad C_{bo}=U_{bo}\cdot N \quad (\$/hr) \tag{6}$$

3. C_{cm} and C_{co}

Supposing that the average number of handling machinery installed in a berth is AC, then handling machinery and its maintenance cost(C_{cm}) and the operation cost(C_{co}) can be obtained as follows:

$$C_{cm}=U_{cm}\cdot N\cdot AC \quad (\$/hr) \tag{7}$$

$$C_{co}=U_{co}\cdot AC\cdot T\cdot\lambda \quad (\$/hr) \tag{8}$$

where, Ucm: the cost of machine per crane hour; Uco: the cost of operation per gang hour; $T=V/(AC^f\cdot\gamma)$: the average operating time per ship(hour); V: the average exchange (loading and unloading) volume per ship (ton or TEU); γ : the operation efficiency of machinery(ton or TEU/hr); f: crane interference exponent.

4. C_{yd}

Supposing that the storage yard cost of the unit time for the unit cargo (ton or TEU) can be indicated by U_{yd}, then the expenses for storage will be :

$$C_{yd}=U_{yd}\cdot V\cdot H\cdot\lambda \quad (\$/hr) \tag{9}$$

where H: the average deposit time for unit cargo(hr/TEU).

If Eqs. (4) to (9) are substituted into Eqs. (1) and (2), then the aggregate expenses of ship in port can be obtained as follows:

$$\begin{aligned}TC=C1+C2=&(U_s+U_{cg}\cdot X)(\lambda/\mu+L_q)+(U_{pf}+U_{po}+U_{bf}+U_{bo})\cdot N\\ &+U_{cm}\cdot N\cdot AC+U_{co}\cdot AC\cdot T\cdot\lambda+U_{yd}\cdot V\cdot H\cdot\lambda \quad (\$/hr)\end{aligned} \tag{10}$$

2.3 Evaluation index (IND)

The non-dimension evaluation index (IND) is used to measure the performance of port system, based upon the consideration of following three items.

1. Comparisons of system performance of the same ports in different periods.
2. Comparisons among domestic and international ports.
3. Minimization of effects caused by price fluctuation, inflation, and change of currency value etc.

Then, the total cost of unit cargo in port is defined as:

$$\begin{aligned}IND=TC/(\lambda\cdot U_s\cdot V)=&((1+R_{cg})(1/\mu+W_q)+(R_{pf}+R_{po}+R_{bf}+R_{bo})\cdot N/\lambda\\ &+R_{cm}N\cdot AC/\lambda+R_{co}\cdot AC\cdot T+R_{yd}\cdot V\cdot H)/V\end{aligned} \tag{11}$$

where W_q: the average waiting time (hr) per ship, and R_{cg}, R_{pf}, R_{po}, R_{bf}, R_{bo}, R_{cm}, R_{co}, and R_{yd} are the cost ratios of $U_{cg}\cdot X$, U_{pf}, U_{po}, U_{bf}, U_{bo}, U_{cm}, U_{co}, U_{yd} divided by U_s respectively.

3. IMPACT ANALYSIS OF EACH PARAMETERS

3.1 Illustration of Computation

Fig.1 shows the relevant basic concept for analysing the characteristics on the optimal process of port system. The fluctuation of factorial variance of the cost function can be measured through comparison with the values of IND* and ρ * at the criterion point which minimizes the total cost of unit cargo.
In order to state the degree of impact caused by each of parameters in the model, the calculation of container port (M/E_k/N queueing model) showed in following example has especially been conducted in this study. The baseline values of parameters in the example are as follows:

R_{cg}=1.0, R_{pf}=0.15, R_{po}=0.02, R_{bf}=0.15, R_{bo}=0.03, R_{cm}=0.05, R_{co}=0.08, R_{yd}=6.10^{-5}, k=3, N=1~30, AC=2.0, V=727TEU, γ=24(TEU/hr), f=0.75, DT=6 hours, H=120 hrs/TEU

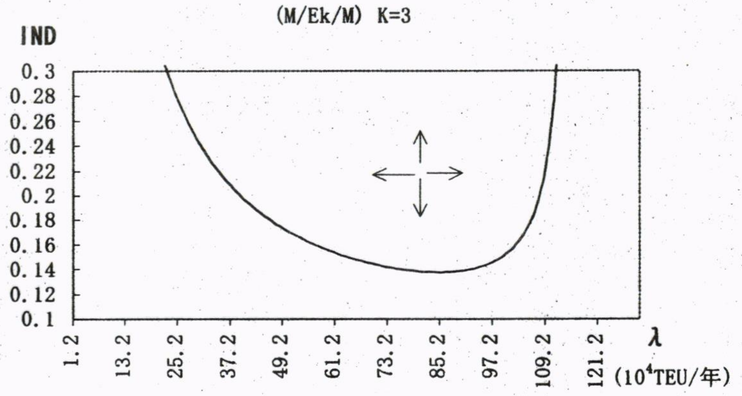

Fig.1 Concept of Characteristics Analysis of Port System

3.2 Analysis on Each Models of Queueing System

1. Differences of ρ * or IND* in the use of models of M/E_k/N and M/M/N.
As a matter of fact, the container port should be thought as M/E_k/N queueing system which is to be employed, and M/M/N queueing model is only used for the sake of convenience. The difference between M/E_k/N and M/M/N models of the port queueing system is compared by means of the microscopical criteria of ρ and IND. Should M/M/N be considered as the basic standard, the differences(%) among various corresponding values to phases k and N are found as in Table 1.

The following characteristics can be categorized: (1) for the same berth(N), the more the phases k increase, the larger its relative difference becomes; (2) the value of $W_q(k\to\infty)$ is the half of W_q(k=1) for theoretical value, but the differences of ρ * are −19.88%(N=1) and −4.56% (N=30); and (3) for the same phases k of Erlang distribution, the more the berth's numbers(N) increase, the smaller its relative differences become.

Table 1 Differences of ρ * in (M/ Ek /N) Model based on (M/M/N) Model (%)

k \ N	1	2	3	6	9	15	21	30
2	-9.10	-6.89	-5.69	-4.00	-3.25	-2.50	-2.10	-1.73
3	-12.46	-9.48	-7.85	-5.57	-4.52	-3.48	-2.92	-2.42
4	-14.21	-10.85	-9.01	-6.39	-5.19	-4.00	-3.36	-2.79
5	-15.30	-11.70	-9.74	-6.93	-5.62	-4.34	-3.65	-3.03
∞	-19.88	-15.60	-13.27	-9.80	-8.13	-6.39	-5.43	-4.56

2. Differences at ρ * are caused by variouse approximate formulas for W_q in M/E_k/N model.

When M/Ek/N model is adopted, W_q can be given by two approximate equations. If the Cosmetatos approximate solution is used as the criterion, the relative differences to ρ^* value are shown as in Table 2. Its features are found out as follows: (1) the difference related to ρ^* increases with the change of the phase k; and (2) when k=5 and N=9, the maximum difference is only 0.54%.

Table 2. Related differences of ρ^* by L.-L. formula based on Cosm. formula (%)

K \ N	1	2	3	6	9	15	21	30
2	0	0.132	0.233	0.309	0.299	0.275	0.249	0.226
3	0	0.214	0.341	0.416	0.414	0.38	0.351	0.324
4	0	0.232	0.375	0.492	0.499	0.46	0.414	0.372
5	0	0.25	0.39	0.521	0.54	0.485	0.438	0.396

As mentioned above, should Lee-Longton approximate formula be used for resolution, the difference at ρ^* is 0.416%, and the difference at IND* is only 0.246%, when N=6 and k=3. Therefore, it is seemed that the Cosmetatos approximate formula are not absolutely necessary to be used for optimal analysis. It's very important that through the comparsion between the theoretical values obtained separately by Cosm. or L.-.L. formula the relative errors about W_q is investegated as the case of $M/E_3/5(\infty)$ model. Although the errors of W_q by L.-L. formula are more than those by Cosm. formula, the maximum relative error between ρ_C^* by Cosm. formula and ρ_L^* by L.-L. formula is only 0.42% in the optimal solution of ρ^* by the example as in §3.1 (seeTable.3).

Table 3. Differences of Wq by L.-L. or Cosm. formula and $(\rho_L^* - \rho_C^*)/\rho_C^*$

ρ	e(Wq,C)	e(Wq,L)	N*	ρ_L^*	ρ_C^*	$(\rho_L^* - \rho_C^*)/\rho_C^*$
0.5	-0.70%	-8.50%	3	0.5451	0.5271	0.34%
0.6	-1.00%	-6.30%	6	0.6508	0.6248	0.42%
0.7	-0.90%	-4.30%	9	0.705	0.677	0.41%
0.8	-0.60%	-2.70%	15	0.7639	0.7359	0.38%

3. Impact on $\rho\cdot$ at criterion point with the change of N and k.

ρ refers to the berth occupancy factor in the port queueing system and it is able to be calculated by $\lambda = N \cdot \mu \cdot \rho$. It is seen that the more the value of ρ increases, the larger the port capacity (λ) becomes, when berth's numbers (N) and service rate (μ) are constant. The impact characteristics exerted to ρ^* by the changes of N and phases k are concluded as follows: (1) when the phases of Erlang distribution k increase under the same berth scale (N), its corresponding ρ^* increases; (2) it is seen that the effects of phases k to small berth scale are much more than that to large berth scale; (3) ρ^* increases as berth scale enhances with the same phases k;(4) if N=1 and k=1, then ρ^*=32.17%, and if N=30 and k≒∞,then ρ^*= 80.26%. Therefore, $\rho\cdot$ can be respectively considered as the low and high values of optimal berth occupancy factor of the criteria points employed in this illustration. Strategy of both port planner and manager revealed in these values should be given more regards.

3.3 Fluctuation of the Cost Ratios on ρ^* and IND*

1. The sensitivity of R_{cg} which impacts on ρ^* and IND* is as follows: (1) in the case of N=1~30, ρ^* will decrease with the increases of R_{cg}, but IND will increase; (2) however, R_{cg} will exert more on ρ^* value, when N is smaller. Supposing that R_{cg}=1.0 is taken as the criterion, then the fluctuation of ρ^* value for R_{cg}=0.25 and R_{cg}=1.5 are +15.3% and −7.0% respectively in the case of N=1; and their fluctuation are +3.2% and −1.5% in the case of N=30. Thus, their changes are obviously related to N.

2. The following impacts of R_p and R_b on ρ * are found out. (1) Supposing that R_p=0.17 is taken as the criterion, the fluctuations of ρ * value for R_p=0 and R_p=0.85 will be −12.5% and +28.0% respectively in the case of N=1; and those fluctuation are −2.8% and +5.7% when N=30; (2) From the preceding analysis, it is seen that the smaller N value is, the larger the influence on ρ * from R_p and R_b in folds become; and the larger N value is, the smaller relevant influence will be obtained. As a matter of fact, the change of R_p is similar to R_b.

3. The impact of R_{cm} on ρ * and IND* can be derived as follows: (1) supposing that R_{cm}=0.05 is taken as the criterion, the fluctuation of ρ * value for R_{cm}=0.2 and R_{cm}=0.025 will be +16.6% and −3.7% respectively in the case of N=1; and its changes will be +3.5% and −0.008% in the case of N=30. Similarly, for the value of IND*, the relevant influence are +17.3% and −3.2% in the case of N=1; and it will be +12.5% and −2.1% in the case of N=30; (2) it can be known from the preceding analysis that the smaller N value is, the more the flctuation of R_{cm} in folds will exert on ρ * and IND*.

4. The impact of R_{co} and R_{yd} on IND* can be obtained as follows: supposing that R_{co}=0.08 is taken as the criterion, the fluctuation of IND* value for R_{co}=0.16 and R_{co}=0.04 will be +2.8% and −1.4% in the case of N=1 respectively; and its changes will be +4.1% and −2.0% in the case of N=30. Similarly, for the impact of R_{yd} value on IND* value, if R_{yd}=$6\cdot10^{-5}$ is taken as the criterion, the influence for R_{yd}=0 and N=1 is . −5.0%, and it is −7.4% in the case of N=30.

3.4 Impact of the Service Rate on IND*

γ is denoted by the handling rate of crane, f is the interference exponent among the cranes, and DT is the dwelling time of ship in berth. These three parameters do not effect on ρ *, and the impact feature on IND* with the changes of γ, f, and DT are as follows: (1) for N=1~30, IND* decreases when values of γ and f increases, but IND* increases when DT increases; (2) it can be learned from the preceding analysis that the impact on IND* with the change of γ, f and DT is hardly related to N.

4. SYNTHETICAL ANALYSIS OF PORT SYSTEM

Table 4: The fluctuation of factorial variance with ρ^* and IND*

Parameters	N	ρ^*					IND*				
		3	6	9	21	30	3	6	9	21	30
K	1	-7.85	-5.57	-4.52	-2.92	-2.42	2.85	1.57	1.13	0.61	0.48
(3)	2	-2.3	-1.63	-1.31	-0.84	-0.7	0.79	0.44	0.32	0.17	0.13
	∞	6.24	4.69	3.93	2.65	2.24	-2.34	-1.48	-1.1	-0.63	-0.51
Rcg	0.25	9.75	7.06	5.81	3.83	3.2	-25.02	-25.4	-25.64	-26.03	-26.17
(1)	0.5	5.96	4.34	3.56	2.35	1.98	-16.56	-16.85	-17.03	-17.32	-17.41
	1.5	-4.57	-3.36	-2.78	-1.84	-1.53	16.23	16.65	16.85	17.21	17.33
Rp	0	-8.25	-6.1	-5.05	-3.35	-2.8	-8.58	-7.72	-7.31	-6.64	-6.44
(0.17)	0.34	6.64	4.82	3.96	2.62	2.19	9.03	8.29	7.92	7.31	7.12
	0.85	17.55	12.64	10.37	6.79	5.68	30.02	28.01	26.95	25.16	24.61
Rcm	0.025	-2.41	-1.78	-1.48	-0.97	-0.81	-2.78	-2.52	-2.4	-2.19	-2.13
(0.05)	0.1	4.15	3.02	2.48	1.65	1.38	5.37	4.93	4.69	4.32	4.21
	0.2	10.61	4.67	6.31	4.15	3.48	15.59	14.41	13.79	12.8	12.47
Rco	0.04	() is baseline value					-1.74	-1.87	-1.94	-2.01	-2.04
(0.08)	0.16	the unite is %					3.47	3.76	3.86	4.04	4.07
Ryd	0						-6.74	-6.81	-7.02	-7.32	-7.41
(0.00006)	0.00003	λ					-3.16	-3.4	-3.51	-3.66	-3.7
γ	36	33.34					-23.71	-23.61	-23.57	-23.51	-23.49
(24)	48	60					-35.57	-35.41	-35.35	-35.26	-35.23
f	0.9	8					-7.03	-6.99	-6.99	-6.96	-6.96
(0.75)	0.6	7.6					7.79	7.77	7.74	7.73	7.72
DT	3	14.3					-11.28	-11.18	-11.14	-11.08	-11.06
(6)	9	11.11					11.27	11.18	11.13	11.08	11.06

The fluctuation of parameter variance for the analysis of the optimal process on port system. The impacts on ρ * and IND* value of the criterion point occurred by the changes of each parameters are found as shown in Table 4. For each parameters, k and N is related to queueing models. R_{cg}, R_p, R_{cm}, R_{co} and R_{yd} are related to the cost ratios of cost function. γ, f and DT are also related to service rate.

Through the analysis of optimal solution in the study of port system, it is found that ρ and IND values are two very important indices. ρ is used to analyze port capacity (λ), to determine the numbers of berth (N), to investigate optimal berth occupancy (ρ *) and so on. Further disccuses are needed as shown in Fig. 2.

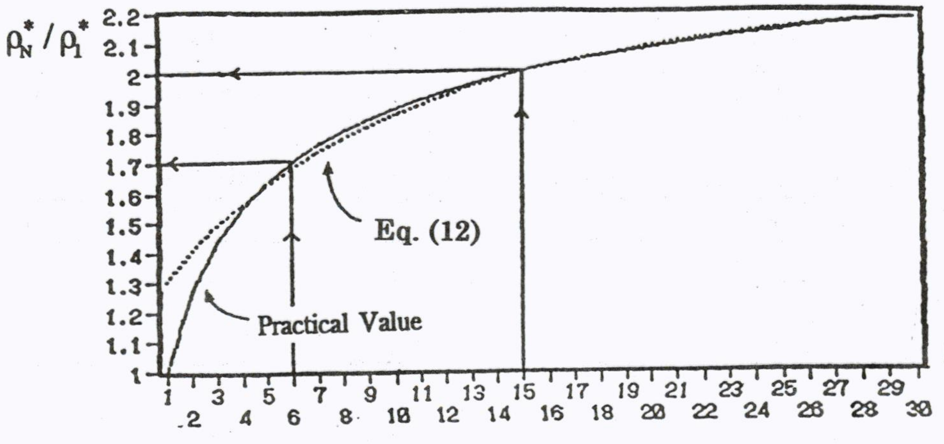

Fig. 2 Relationship between ρ_N^* / ρ_1^* and N

The ensuing relationship between ρ_N^* / ρ_1^* and N can be obtained as follow:

$$\rho_N^* / \rho_1^* = 2.27 / (1 + e^{-0.3N^{0.7}}) \tag{12}$$

From the Eq.(12), the extreme value of ρ_N^* / ρ_1^* in the case of N=∞ is found as 2.27. When the port system is in the stable state , $\rho^*_{max} \fallingdotseq 0.82$ and $IND^*_{min} \fallingdotseq 0.1$ for N=1～30. The economic berth scale in the container port is between 6～15.

On the other hand, IND can be used to measure effectiveness of port improvement, and the relationship between IND_N^*/IND_1^* and N is described in the following equation(see Fig 3):

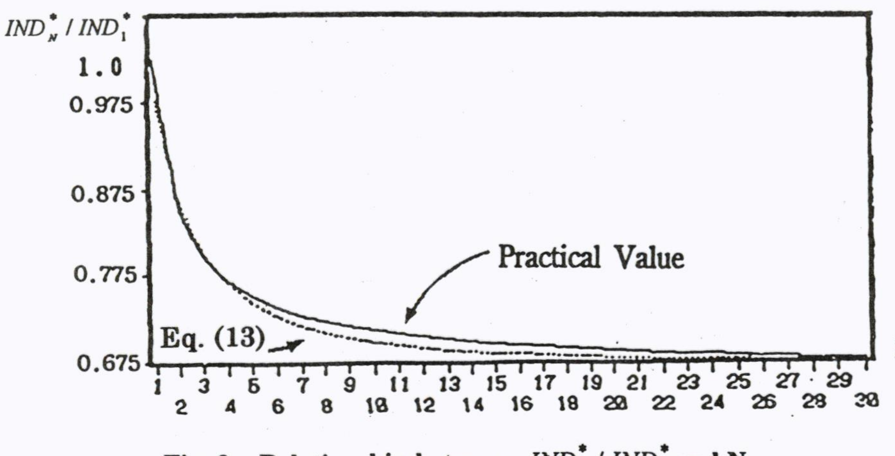

Fig. 3 Relationship between IND_N^* / IND_1^* and N

$$IND_N^* / IND_1^* = 0.675 + e^{-1.2N^{0.5}} \quad (13)$$

The practical values in Fig.2 and Fig.3 are the results of Min IND obtained by the example as in §3.1. One of the major purposes using Eqs.(12)and (13) is to show that ρ_N^* and IND_N^* of various berth scale (N) can be immediately resolved through the given data ρ_1^* and IND_1^* respectively.

5. APPLICATION TO THE CONTAINER PORT PLANNING

5.1 Three Factor Levels for Port Planning

Analysis of port capacity, berth determination and effectiveness measures of port improvement are the main purpose for port planning. From Table 4 based on the intensity of each parameters effecting upon ρ^* and IND*, we can classify the parameters into three levels: A(Large), B(Medium) and C(Small) for different study purpose as in Table 5.

Table 5 Three Factor Levels For Different Purpose of Port Planning

Research Purpose	A-Level	B-Level	C-Level
Port Capacity; λ	Us, γ, DT, Rcg, Rp, Rb, K	Rcm, f	—
Optimum Berth; ρ	Us, Rcg, Rp. Rb, K	Rcm	—
Effect Measure; IND	Us, γ, Rcg, DT, Rp, Rb, f	Rcm, Ryd	K, Rco

5.2 Determination of the Optimal Number of Berths and Cranes

For example, only if there are R_{cg}; R_p, R_b, R_{cm}, K and AC in analysis of port system , we can determine the optimal number of berths on the basis of the arrival rate(λ) of ship. Assuming that the number of berths N* are optimal, the following relation must be held:

$$IND(N^*-1, \lambda_B) \geqq IND(N^*, \lambda) \quad \text{and} \quad IND(N^*+1, \lambda_C) \geqq IND(N^*, \lambda) \quad (14)$$

In Fig.4, if the arrival rate is λ_B, then

$$IND(N^*-1, \lambda_B) \geqq IND(N^*, \lambda_B) \quad (15)$$

Substituting Eq.(11) into Eq.(15), we obtain

$$\lambda_B \cdot (W_q(N^*-1, \lambda_B) - W_q(N^*, \lambda_B)) \geqq (R_p+R_b+R_{cm} \cdot AC)/(1+R_{cg}) \quad (16)$$

Because of $\lambda \cdot W_q = L_q$, we can derive as follows:

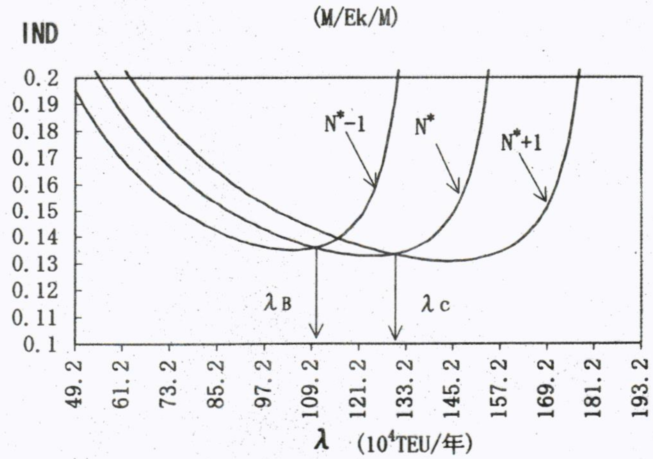

Fig. 4 Comparison between IND(N* − 1, λ B) and IND(N*+1, λ c)

$$L_q(N^*-1, \lambda_B) - L_q(N^*, \lambda_B) \geqq (R_p+R_b+R_{cm} \cdot AC)/(1+R_{cg}) \quad (17)$$

Similarly, the following equation is obtained on the basis of the arrival rate λ_c

$$IND(N^*+1, \lambda_c) \geqq IND(N^*, \lambda_c) \quad (18)$$

Substituting Eq.(11) into Eq.(18),we can get:

$$L_q(N^*, \lambda_c) - L_q(N^*+1, \lambda_c) \leqq (R_p+R_b+R_{cm} \cdot AC)/(1+R_{cg}) \quad (19)$$

Consequently, from Eqs. (17) and (19), the following formula can be obtained :

$$L_q''(N^*,N^*+1, \lambda_c) \leqq (R_p+R_b+R_{cm} \cdot AC)/(1+R_{cg}) \leqq L_q'(N^*-1,N^*, \lambda_B) \quad (20)$$

where $L_q''(N^*,N^*+1, \lambda_c)=L_q(N^*, \lambda_c)-L_q(N^*+1, \lambda_c)$ and

$L_q'(N^*-1,N^*, \lambda_B)=L_q(N^*-1, \lambda_B)-L_q(N^*, \lambda_B)$

Using the preceding information, the optimal berth can be obtained as in Table 6. It can be standardized as follows, when the data of the port system are given, and $(R_p+R_b+R_{cm} \cdot AC)/(1+R_{cg})$ is defined as "cost index"(CI).

Step 1: Compute the CI from the given data of R_{cg},R_p,R_b,R_{cm} and AC.
Step 2: Compute the service rate μ.
Step 3: Determine the traffic intensity $A=\lambda/\mu$.
Step 4: Based on the CI, A and k, the optimal numbers of berth can be determined by Table 6.

For example, λ =2(ships/day), V=727TEU, γ =24TEU/hr, AC=2.0, f=0.75, DT=6hr, R_{cg}=0.5, R_p=0.30, R_b=0.30 and R_{cm}=0.1. Then, we can calculate as follows:

Step 1: $CI=(R_p+R_b+R_{cm} \cdot AC)/(1+R_{cg})=(0.30+0.30+0.1 \cdot 2.0)/(1+0.5)=0.533$
Step 2: $1/\mu=727/(2^{0.75} \cdot 24)+6=24$ (hrs)
Step 3: $A=\lambda/\mu=2.0$
Step 4: If k=3 with the help of Cosmetatos approximate formula, the optimal number of berths is 3。

If the cost funtion is considered as the cost related to the construction & operation expenses of the pier and ships staying in port only, then CI=(0.3÷1)=0.3 and the optimal number of berths is 4. Similarly, if the phase(k) of Erlang distribution for service rate (μ) is 1.0, then the optimal number of berths is 4, whenever CI is 0.533 or 0.3.

In order to describe the container port planning by using Eg.(20), we can get the relevant 3-Dimensional graph as shown in Fig.5～Fig.10. Fig.5 shows the relationships among optimum berths N, λ and CI which gives the relevant optimum berths(N) based on $M/E_3/N$ model. When N=6, with the change of the phase(k) of Erlang distribution, relevant relationships among λ ,k and CI based on $M/E_K/6$ model is shown as in Fig.6. Owing to N=6 and $M/E_3/6$ model, we can also get the optimum cranes in container port (see Fig.7). Simultaneously, the corresponding relationships among A, γ and CI under a certain number of cranes are shown as in Fig.8. And also, when the number of optimum cranes based on N=6 and AC=2 is determined, the interference exponent among cranes is related to A and CI, and Fig.9 shows the mutual relationships among A, f and CI. Moreover, under the basis that the optimum berths (N=6) and cranes (AC=2) are decided, we can find out the relationships among A, DT and CI as shown in Fig.10.

All of those graphs as mentioned-above show that the container port planning is the procedure of system analysis with various factors.

6. CONCLUSIONS

Queueing theory and cost function are applied to establish theoretical model of port system.It is suggested that each of the cost items of the port system be taken into the consideration of cost function. As for waiting cost(the shipowner side), there are the aspects of vessel and cargo; and for service cost, there are the aspects of port facilities rather than the pier, pier facilities, breakwater, handling cost, and expense for the storage yard.

Table-6 Lq"(N*,N*+1, λ_C) and Lq'(N*-1,N*, λ_B) by M/E_k/N Queueing Model

A	N	k=1		k=2				k=3				k≒∞			
		Cosm. &Lee-Long.		Cosmetatos		Lee-Longton		Cosmetatos		Lee-Longton		Cosmetatos		Lee-Longton	
		Lq"	Lq'	Lq"	Lq'	Lq"	Lq'	Lq"	Lq'	Lq"	Lq'	Lq"	Lq'	Lq"	Lq'
1	2	0.28788	∞	0.21933	∞	0.21591	∞	0.19648	∞	0.19192	∞	0.15079	∞	0.14395	∞
	3	0.03865	0.28788	0.03076	0.22275	0.02899	0.21591	0.02813	0.20104	0.02577	0.19192	0.02287	0.15763	0.01933	0.14395
	4	0.00584	0.03865	0.00496	0.03165	0.00438	0.02899	0.00466	0.02931	0.00390	0.02577	0.00407	0.02464	0.00292	0.01933
2	3	0.71498	∞	0.54420	∞	0.53623	∞	0.48727	∞	0.47665	∞	0.37346	∞	0.35752	∞
	4	0.13411	0.71498	0.10481	0.55217	0.10058	0.53623	0.09504	0.49790	0.08941	0.47665	0.07551	0.38939	0.06706	0.35752
	5	0.03079	0.13411	0.02495	0.10692	0.02309	0.10058	0.02300	0.09786	0.02053	0.08941	0.01910	0.07973	0.01540	0.06706
	6	0.00708	0.03079	0.00599	0.02556	0.00531	0.02309	0.00563	0.02382	0.00472	0.02053	0.00490	0.02034	0.00354	0.01540
3	4	1.17407	∞	0.89287	∞	0.88056	∞	0.79913	∞	0.78272	∞	0.61171	∞	0.58710	∞
	5	0.25508	1.17407	0.19801	0.90518	0.19131	0.88056	0.17898	0.81554	0.17006	0.78272	0.14094	0.63633	0.12755	0.58710
	6	0.07091	0.25508	0.05652	0.20136	0.05318	0.19131	0.05173	0.18345	0.04727	0.17006	0.04214	0.14764	0.03546	0.12755
	7	0.02046	0.07091	0.01683	0.05764	0.01535	0.05318	0.01562	0.05321	0.01364	0.04727	0.01320	0.04436	0.01023	0.03546
	8	0.00574	0.02046	0.00489	0.01720	0.00431	0.01535	0.00461	0.01612	0.00383	0.01364	0.00404	0.01394	0.00287	0.01023
	9	0.00153	0.00574	0.00135	0.00501	0.00115	0.00431	0.00129	0.00477	0.00102	0.00383	0.00118	0.00428	0.00076	0.00287
4	5	1.64693	∞	1.25154	∞	1.23520	∞	1.11795	∞	1.09795	∞	0.85623	∞	0.82355	∞
	6	0.38937	1.64693	0.30111	1.26789	0.29203	1.23520	0.27169	1.14154	0.25957	1.09795	0.21287	0.88892	0.19471	0.82355
	7	0.12110	0.38937	0.09570	0.30566	0.09083	0.29203	0.08724	0.27775	0.08074	0.25958	0.07031	0.22195	0.06056	0.19471
	8	0.04004	0.12110	0.03245	0.09733	0.03003	0.09083	0.02992	0.08940	0.02669	0.08074	0.02486	0.07356	0.02002	0.06056
	9	0.01313	0.04004	0.01094	0.03305	0.00985	0.03003	0.01022	0.03073	0.00875	0.02669	0.00876	0.02607	0.00657	0.02002
	10	0.00415	0.01313	0.00357	0.01116	0.00311	0.00985	0.00337	0.01051	0.00277	0.00875	0.00298	0.00920	0.00207	0.00657
	11	0.00125	0.00415	0.00111	0.00364	0.00094	0.00311	0.00106	0.00347	0.00083	0.00277	0.00097	0.00313	0.00062	0.00207
5	6	2.12721	∞	1.61550	∞	1.59541	∞	1.44493	∞	1.41814	∞	1.10389	∞	1.06371	∞
	7	0.53160	2.12721	0.41006	1.63559	0.39870	1.59541	0.36955	1.47172	0.35440	1.41814	0.28855	1.14407	0.26583	1.06371
	8	0.17814	0.53160	0.14001	0.41575	0.13360	0.39870	0.12730	0.37713	0.11876	0.35440	0.10188	0.29992	0.08908	0.26583

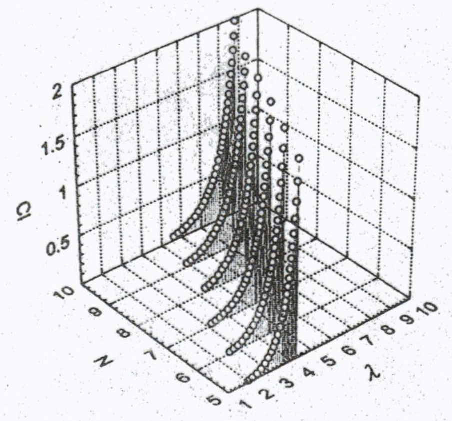

Fig.5 Optimum Berths in 3-Dimensions by $M/E_3/N$ Model

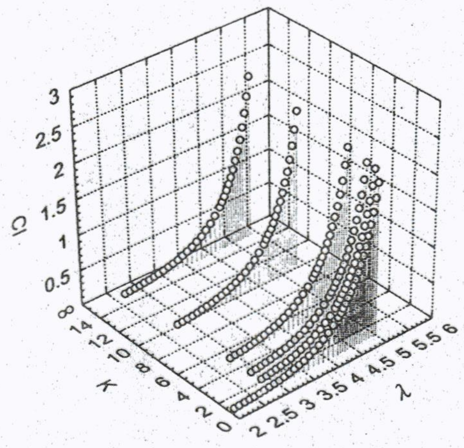

Fig.6 Relations among λ, K and CI based on Optimum Berths in $M/E_K/6$ Model

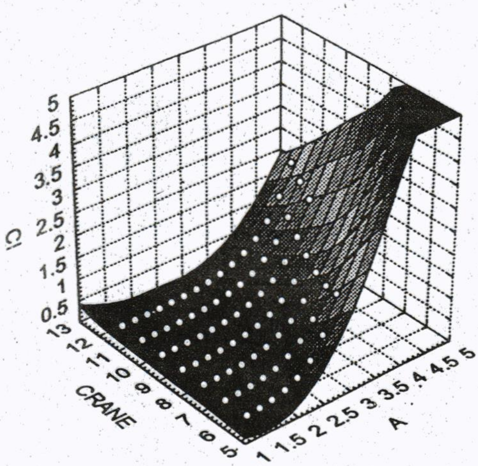

Fig.7 Optimum Cranes in 3-Dimensions by $M/E_3/6$ Model

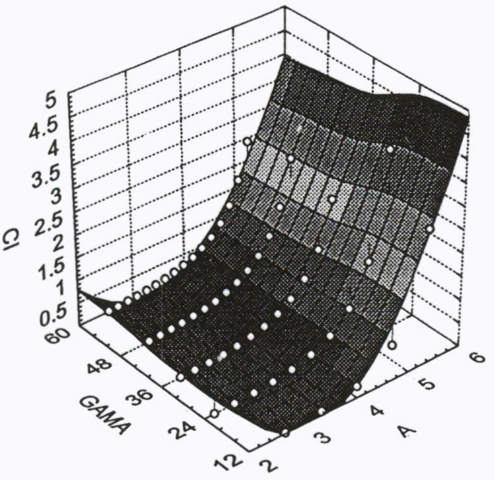

Fig.8 Relations among A, γ and CI under Optimum Cranes in M/E$_3$/6 Model

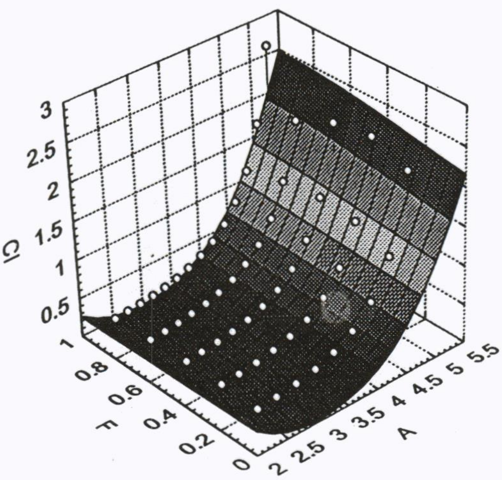

Fig.9 Interference Exponent of Optimum Cranes (AC=2) in M/E$_3$/6 Model

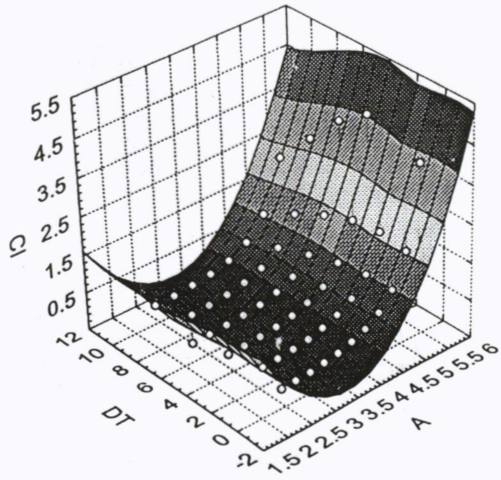

Fig.10 Dewelling Time of Optimum Crane (AC=2) based on M/E$_3$/6 Model

According to the port policy of the country and the planning objective of the port, planning or managment personnels can designate certain value for each item of cost. Meanwhile they can investigate the characteristics of the port system from the micro viewpoint by means of non-dimensional evaluation index(IND). This is concluded as follows:

1. In this study, non-dimensional evaluation index(IND) has been lead in order to allow the planning and managment personnels to judge whether the operation performance in a port is good or not . In addition, by using IND the comparison of performance evaluation at the different periods of the same port can not only be made but also be made in different ports (especially among international ports). And this kind of comparisons will decrease the effect caused by the changes of currency value (exchange rate) and inflation.

2. About the queueing models,it is found that there are considerable differences between $\rho*$ or IND* where are obtained separately from M/M/N and M/Ek/N models. Thus, most of the container terminals belonging to M/Ek/N queueing model should not be simplified and replaced by M/M/N model, especially when the terminal of small scale($N \leqq 6$) is studied.

3. There are Lee-Longton and Cosmetatos approximate solutions of W_q in M/Ek/N queueing system. Through the optimal analysis with cost function and the comparsion of two relevant solutions as mentioned-above, we know that the difference of value at $\rho*$ is 0.416% and at IND* is 0.246% in the case of N=6 and K=3. Therefore, it is seemed that the much more sophisticated Cosmetatos approximate solution are not absolutely necessary to be utilized.

4. The larger the berth scale (N) is, the more stable the port system will become. At the same time, when the optimal occupancy factor $\rho*$ of berth increases, the value of IND* decreases. Through the calculation of baseline values we can find out that $\rho*_{max} \fallingdotseq 82\%$, and $IND*_{min} \fallingdotseq 0.1$ in the case of N=1～30 are important numerals for the optimal process of container port.

5. From the illustrated calculation, the relationship between ρ_N^* / ρ_1^* and N, is shown in Eq.(12), and the extreme value of ρ_N^* / ρ_1^* is 2.27. Through the analysis of Eq.(12), we can get the economic berth scale within the domain of 6～15. By the way, Eq.(13) is one of the important discoveries in this study, which describes the relations among IND* of various berth scale .

6. Through the sensitivity analysis of each parameter which affects the $\rho*$ and IND* value, the parameters can be classified into three levels of categories according to the intensity of fluctuation.

7. The research on the different purposes of port planning can be done by means of the factors of A and B levels only. Taking the advantage of 3D graphs, the optimal number of berths and cranes on the terminal design of container port can be determined only by using the data of Rcg, Rp, Rb, Rcm, K and AC.

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List of Variables

Symbol	*Definition*	*Baseline Value*
ρ^*	**berth occupancy factor at criterion point**	**%**
IND^*	**non-dimension evaluation index at criterion point**	
N	**number of berth in port system**	**1~30**
λ	**average arrival rate of ship**	**(ship/hr)**
K	**phases of Erlang disdrubution**	**3**
μ	**average service rate per berth**	**(ship/hr)**
T	**cargo transfer time in berth**	**(hr/ship)**
V	**cargo exchange (container transfered) volume**	**727(TEU/ship)**
AC	**number of cranes per berth**	**2.0(crane/berth)**
f	**crane interference exponent**	**0.75**
γ	**crane handling rate**	**24(TEU/crane.hr)**
DT	**ship average dwelling time in berth**	**6(hrs/ship)**
Us	**ship cost in port per hour**	**($/hr.ship)**
Rcg	**ratio of the cost of container & cargo (Ucg) divided by Us**	**1.0**
X	**average payload of goods**	**(TEU/ship)**
Rpf	**ratio of the port facilities cost besides of the pier (Upf) divided by Us**	**0.15**
Rpo	**ratio of the operation expenses of port facilities besides of the pier (Upo) divided by Us**	**0.02**
Rbf	**ratio of the construction expenses of pier (Ubf) divided by Us**	**0.15**
bo	**ratio of the operation expenses of pier (Ubo) divided by Us**	**0.03**
Rcm	**ratio of the cost of handling machinery (Ucm) divided by Us**	**0.05**
Rco	**ratio of the labor cost of crane (Uco) divided by Us**	**0.08**
Ryd	**ratio of the storage yard cost (Uyd) divided by Us**	**0.00006**
H	**average deposit time**	**120hrs.**