SIMULATION AND ANALYSIS OF CONTAINER TERMINALS OPERATIONS – CASE STUDY: KOREAN PORTS

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Abstract: This paper aims to determine terminal performance and to calculate optimal throughput of a quay by port type. To this end, we have collected data, processed them, and inputted to the developed simulation model. The three port types of new port are considered to be typical of the future ports under construction or to be construction soon. The optimal throughput calculation of quay, the required number of cranes, and optimal berth occupancy can be given by using the simulation models of this study. The existing calculation methods of optimal throughput of a container terminal have mainly been based the berth capacity alone. Because of this, the container handling volume over the design capacity has rapidly worsened the traffic congestion of CY. The high density of CY worsens not only the productivity of a container terminal, but also increases sharply its logistics costs by forcing some cargoes into the ODCY. According to the questionnaire survey centring on the opinions of veteran terminal operators, the CY occupancy ratio of 60% is suitable for smooth workflow of the whole container terminal. Based on this idea, if the logistics volume is generally maintained at the level of CY occupancy of 60%, it will be reasonable and productive.

1. INTRODUCTION

This paper is based on the data provided from the following Korean container terminals: Shinsundae, Jasungdae-Hutchison, Gamman-Korea Express, Gamcheon-Hanjin, Kwangyang-Korea Express, and Incheon-Sunkwang. Based on these data, this study has calculated the ship arrival time interval, LPC (lift per call), the number of assigned cranes, and handling time per container (based on the total working hours and net working hours of a crane), making an estimation of distribution, so that it may be used in the queue simulation analysis. The data provided by six container terminals have been summarized in the following (Table 1).

As illustrated in the Table 1, the three container terminals – Shinsundae, Jasungdae-Hutchison, and Gamcheon-Hanjin - have provided all the data, but the other three terminals – Gamman-Korea Express, Kwangyang-Korea Express, and Incheon-Sunkwang – lack some parts of data. Meanwhile, in case of Jasungdae-Hutchison, the period of data collection is from Dec. 31, 2004 to Dec. 31, 2005 and the data period of both Gamman-Korea Express and Incheon-Sunkwang is six months and 2 months respectively instead of a full year period like all the other terminals.

A simulation model of a container terminal is basically a computer program written in a general purpose language or in a special simulation-oriented language. The different types of simulation languages that have been used for modeling of the processes at the ship-berth link include MODSIM III, AweSim, Arena, Extend, Witness, GPSS/H. The simulation models are used to analyze queuing and bottleneck problems, container handling techniques, truck and vessel scheduling (departure and arrival rates), equipment utilization, and port throughput and operational efficiency (yard, gate and berth). So, a simulation implements the most important aspects of the processes at the container terminal, often in a simplified manner [1 – 6, 8 – 14].

2. ANALYSIS PROCEDURE OF BASIC DATA

According to the procedure as illustrated in the Figure 1, this research has generated the distribution estimation and empirical distribution based on the basic data.

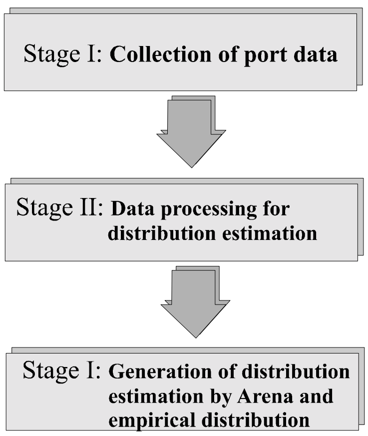

Fig. 1: Analysis procedure

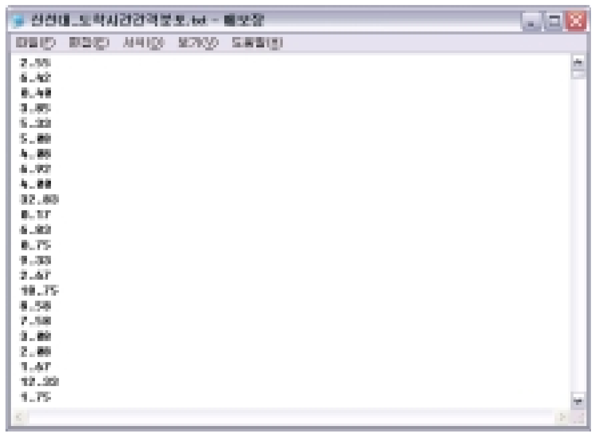

Fig. 2: Text file containing the data related to distribution estimate

Specifically, all the data from the container terminals are collected in the stage 1 as illustrated in the Table 1. The items for distribution estimation based on the collected data are: ship's arrival time interval, LPC, number of assigned crane, and handling time per container. But these data can be generated by way of separate calculation process based on the primary data. And then these data is to be converted and stored in the text file as illustrated in the Figure 2 [11].

Data summary of six container terminals. Table 1.

Item \ Terminal	Shinsundae	Jasungdae Hutchison	Gamman Korea Exp	Gamcheon Hanjin	Kwangyang Korea Exp	Incheon Sunkwang
Period of data collection	Dec/28, '04 – Dec/ 31, '05	Dec/31 '03 – Dec/31 '04	Jun/1 '05 – Nov/30 '05	Dec/31 '04 – Dec/31 '05	Dec/31 '04- Nov/30 '05	Sep/12 '05- Nov/29 '05
Number of ship	1477	1531	318	420	416	28
Estimated berthingtTime	O	O	O	O	X	X
Estimated unberthing time	O	O	O	O	X	X
Actual berthing time	O	O	O	O	O	O
Actual unberthing time	O	O	X	O	O	O
Length of ship (m)	O	O	O	O	X	O
Carrying capacity (TEU)	O	O	X	O	X	O
40 ft unloading	O	O	O	O	O	O
40 ft loading	O	O	O	O	O	O
20 ft unloading	O	O	O	O	O	O
20 ft loading	O	O	O	O	O	O
Number of assigned crane (average)	O	O	O	O	O	O
Total working hours per QC	O	O	O	O	O	O
Net working hours per crane	O	O	X	O	O	O

(O: data provided, X: data unprovided)

By using the Arena data file, which is a simulation analysis program, the distribution is to be estimated based on the data stored in the text file. Figure 3 illustrates the distribution estimation of ship's arrival time interval at the Shinsundae terminal [11].

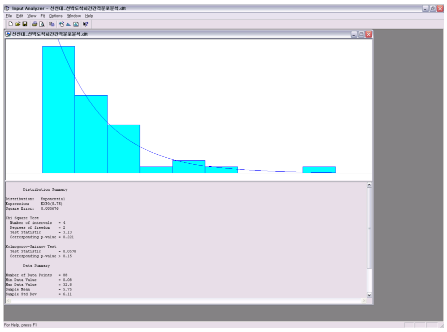

Fig. 3: Example of distribution estimation by Arena

3. SUMMARY OF ANALYSIS RESULTS

As mentioned above, based on the primary data collected from the 6 container terminals, and by using Arena, this study has made a survey of the distribution estimation of the four items: ship's arrival time interval (based on actual berthing time), LPC (including the unloading and loading of both 40 ft and 20 ft containers), number of assigned crane, and handling time per container. Meanwhile, in case of LPC, it has been divided into four sections: 1) from 0 to less than 500, 2) from 500 to less than 1,000, 3) from 1,000 to less than 1,500, 4) more than 1,500. And then the distribution of both LPC and assigned crane's number in each LPC sections have been estimated separately.

Results of distribution estimation by terminal type. Table 2.

Terminal / Type Variable	Shinsundae	Jasungdae-Huthcison	Gamman-Korea Exp	Gamcheon-Hanjin	Kwangyang-Korea Exp	Incheon – Sunkwang
Ship's arrival time interval	Exponential distribution	Beta distribution	Beta distribution	Weibull distribution	Gamma distribution	Beta distribution
LPC	Weibull distribution	Weibull Distribution	Weibull distribution	Normal distribution*	Beta distribution*	Beta distribution
Gross crane productivity **	Lognormal distribution*	Lognormal Distribution	Lognormal Distribution *	Gamma distribution	Lognormal Distribution*	Lognormal Distribution*
Net crane productivity**	Lognormal distribution*	Lognormal distribution	N/A***	Lognormal Distribution*	Lognormal distribution*	Exponential distribution*

*) It has the least error among many distribution estimations, but is not statistically significant; **) Gross (net) working hours/ LPC)/ number of assigned crane
***) Data not provided; In case of Kwangyang-Korea Express, LPC distribution is divided into two – (export VAN + import VAN) and (export TEU + import TEU) – and then analyzed. It has been similar to Beta distribution, but not statistically significant.

Estimated distribution function by port type. Table 3

Type Variable / Terminal	**Ship's arrival time interval**	**LPC**	**Handling time per Container (based on gross working hours)**	**Handling time per container (based on net working hours)**
Shinsundae	EXPO (5.75)	-0.001 + WEIB (1.02e+003, 1.69)	LOGN (2.78, 2.22)	LOGN (2.61, 1.99)
Jasungdae Hutchison	-0.001 + 35*BETA (0.931, 4.75)	20 + WEIB (797, 1.58)	LOGN (1.07, 0.435)	LOGN (0.852, 0.338)
Gamman Korea Express	54*BETA (7.29, 20.9)	104 + WEIB (982, 1.96)	LOGN (0.914, 0.34)	
Gamcheon Hanjin	WEIB (22.2,1.22)	NORM (802, 411)	0.32 + GAMM (0.147, 6.37)	0.3 + LOGN (0.764, 0.346)
Kwangyang Korea Express	GAMM (112,1.73)	10 + 2.49e+003*BETA (0.718, 2.58)	LOGN (1.01, 0.43)	LOGN (0.929, 0.416)
Incheon Sunkwang	19 + 81*BETA (1.21, 0.734)	20 + 736*BETA (1.91, 0.8222)	0.999 + LOGN (0.719, 1.52)	0.72 + EXPO (0.485)

As shown in the Table 2, the distribution estimations of ship's arrival time interval, LPC, and crane productivity have different distribution types, and even if they have identical distribution estimation, their concrete distribution functions are different. As explained their types and traits can be quite different according to the probability distribution. Because of this, if simulation analyses are conducted in a lump without taking into consideration the traits of each port, they can cause a serious error. Therefore, this means that those preceding researches that have not considered the traits of each port may carry a statistical error. Accordingly, this study has divided domestic ports by type, and conducted a simulation analysis (distribution estimation) by port type in order to calculate an optimal throughput of each port.

Table 3 has summarized by port type the functions of the distribution patterns, which have been estimated in the Table 2, and these functions will be used for the queue simulation analysis.

4. BASIC DATA ANALYSIS RESULTS OF SHINSUNDAE TERMINAL

4.1. SHIP'S ARRIVAL TIME INTERVAL DISTRIBUTION (BASED ON ACTUAL BERTHING TIME)

Based on actual berthing time, ship's arrival time interval distribution has been generated, and non-parametric tests have been conducted for this. The results of the non-parametric tests are summarized in the Table 4.

Ship's arrival time interval distribution and test results. Table 4.

Distribution name	Expression	Non-Parametric (P-value)	
		X^2	Kolmogorov - Smirnov
Exponential distribution	EXPO (5.75)	0.221	0.15

As illustrated in the Table 4, the ship's arrival time interval in the Shinsundae terminal generates an exponential distribution. Specifically, the non-parametric tests for this distribution have been conducted. As a result of the following two tests - chi-square (X^2) test and Kolmogorov-Smirnov test, the null hypothesis that all are an exponential distribution, has not been rejected. Accordingly, it can be said from the tests that the ship's arrival time distribution is approximate to an exponential distribution. The histogram and distribution pattern of the data is illustrated in the Figure 4.

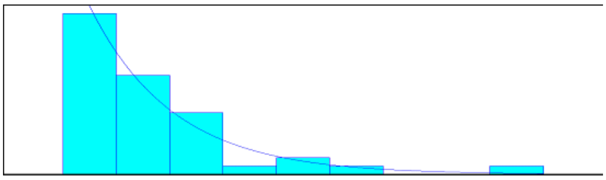

Fig. 4: Ship's arrival time interval distribution of Shinsundae Terminal

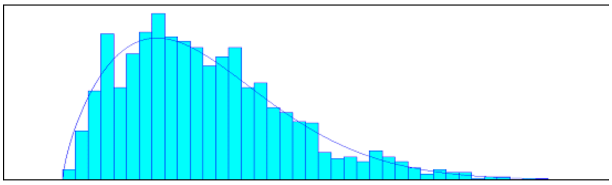

Fig. 5: LPC distribution of Shinsundae Terminal

4.2. LPC DISTRIBUTION (UNLOADING/LOADING OF 40 FT CONTAINER + UNLOADING/ LOADING OF 20 FT CONTAINER)

The LPC distribution (unloading/ loading of 40 ft container + unloading/loading of 20 ft container) of Shinsundae Terminal has been generated, and the results of its non-parametric tests are summarized in the below Table 5.

LPC distribution and results of non-parametric tests. **Table 5**

Distribution name	Expression	Non-Parametric (P-value)	
		X^2	Kolmogorov -Smirnov
Weibull distribution	-0.001 + WEIB (1.02e+003, 1.69)	0.221	0.15

As illustrated in the Table 5, the LPC of Shinsundae terminal generates a Weibull distribution. Specifically, the non-parametric tests for this LPC distribution have been conducted, and as a result of these two tests – chi-square test and Kolmogorov-Smirnov test, the null hypothesis that all are a Weibull distribution has not been rejected. Accordingly, it can be said that the LPC distribution is close to the Weibull distribution. The histogram and distribution pattern of the data is illustrated in the Figure 5.

Meanwhile, in order to effectively make a queue simulation analysis that will be dealt in next section, this study has divided the LPC data into four sections: 1) from 0 to less than 500, 2) from 500 to less than 1,000, 3) from 1,000 to less than 1,500, 4) more than 1,500. And then, LPC distribution by each section has been generated, while conducting non-parametric tests for them. The number of ships, its ratio, and distribution estimation by section are summarized in the following Table 6.

Number of ships, distribution estimation, and function by LPC section. Table 6

Section	Number of ship	Ratio	Distribution estimation	Function
Less than 500	339	23%	Beta distribution	18 + 481*BETA (2.09, 1.36)
500~ less than 1000	564	38%	Beta distribution	500 + 499*BETA (0.977, 1.11)
1000~less than 1,500	377	26%	Beta distribution	1e+003 + 498*BETA (0.846, 1.09)
More than 1,500	196	13%	Beta distribution	1.5e+003 + 1.6e+003*BETA (0.725, 1.84)

4.3. NUMBER OF ASSIGNED CRANE DISTRIBUTION BY LPC SECTION

The empirical distribution of the number of assigned cranes by LPC section is illustrated in the following Table 7.

Empirical distribution of the number of assigned cranes by LPC section. Table 7

LPC: 0~ under 500			LPC: 500~1000			LPC: 1000~1500			LPC: 1500 or more		
Unit	Ratio	Cumulative	Unit	Ratio	Cum.	Unit	Ratio	Cum.	Unit	Ratio	Cum.
1	14%	14%	1	0%	0%	1	0%	0%	1	0%	0%
2	77%	91%	2	33%	33%	2	4%	4%	2	0%	0%
3	9%	100%	3	62%	95%	3	63%	67%	3	22%	22%
4	0%		4	5%	100%	4	32%	100%	4	68%	90%
5	0%		5	0%		5	0%		5	10%	100%
Total	100%		Total	100%		Total	100%		Total	100%	

As illustrated in the Table 7, we can find out that in case of LPC section of 0-under 500, two assigned cranes account for 77%, in case of LPC section of 500 to 1,000, three assigned cranes account for 62%, in case of LPC section of 1,000 through 1,500, three cranes account for 63%, and finally, in case of LPC section of over 1,500, four cranes account for 68%.

4.4. HANDLING TIME PER CONTAINER DISTRIBUTION

Handling time per container means how much time (unit: minute) one crane takes in handling one container. The formula for the calculation is as follows:

Crane productivity = (total (net) working hours / LPC) * 60 / number of assigned cranes

(1) *Total working hours basis*

On the basis of total working hours, the handling time per container distribution of Shinsundae terminal has been generated, and then the non-parametric tests for it have been conducted, and its results are summarized in the following Table 8.

Handling time per container distribution (total working hours basis) and test results. Table 8.

Distribution name	Expression	Non-Parametric (P-value)	
		X^2	Kolmogorov - Smirnov
Lognormal distribution	LOGN (2.78, 2.22)***	0.005**	0.01*

*) $p < 0.05$; **) $p < 0.01$; ***) The distribution has to be adjusted after testing simulation model showing optimal result rather than best result.

As illustrated in the Table 8, the handling time per container (based on total working hours) of Shinsundae terminal has generated a lognormal distribution. Also, two non-parametric tests, i.e. chi-square test and Kolmogorov-Smirnov test have been conducted for the lognormal distribution. But as a result of these tests, the null hypothesis that all are lognormal distribution has been rejected, consequently proving that the handling time per container (based on total working hours) distribution is close to a lognormal distribution, but not statistically significant. The histogram and distribution estimation of the data are illustrated in the following Figure 6.

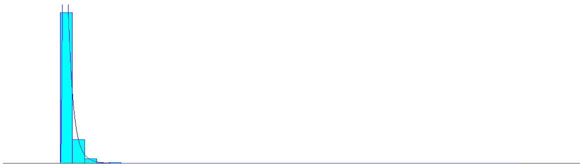

Fig. 6: Handling time per container distribution of Shinsundae terminal (based on total working hours)

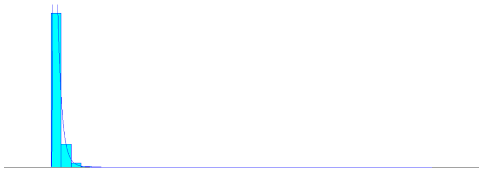

Fig. 7: Handling time per container distribution of Shinsundae terminal (based on net working hours)

(2) *Net working hours basis*
On the basis of net working hours, handling time per container distribution has been generated, and the non-parametric tests for it have been conducted. The results of these tests are illustrated in the below Table 9.

Handling time per container distribution and tests results (based on net working hours). Table 9

Distribution name	Expression	Non-Parametric (P-value)	
		X^2	Kolmogorov - Smirnov
Lognormal distribution	LOGN (2.78, 2.22)***	0.005**	0.01*

*) $p < 0.05$; **) $p < 0.01$

As illustrated in the Table 9, the handling time per container (based on net working hours) has been generated a lognormal distribution. In detail, the two non-parametric tests, that is, chi-square test and Kolmogorov-Smirnov test have been conducted, and as a result of these tests, the null hypothesis that all are lognormal distribution has been rejected. Accordingly, the handling time per container distribution (based on net working hours) is close to the lognormal distribution, but not statistically significant. The histogram and distribution estimation of the data are illustrated in the following Figure 7.

5. SIMULATION RESULTS BY PORT TYPE

Here, a total of 9 ports types are presented based on container handling volume and capacity. Among 9 port types, 6 port types are representing typical domestic container terminals. The remaining 3 types are representing the future ports under construction. The new ports chosen in this paper are based on the Busan New Port and Kwangyang port under construction or to be constructed in the near future [9].

The new ports are to be divided three types: 4 berths for a 50,000-ton ship, 3 berths for a 50,000-ton ship, 2 berths for a 50,000-ton ship, and 2 berths for a 20,000-ton ship. These three types are to become typical of future domestic container terminals. Because of this, here we have defined types “New Port”. Acordinlly, the result value can be used as the decision-making materials for future port development policy. All considered ports can be separated as: Existing port I (LL1), Existing port II (LL2), Existing port III (SS), Existing port IV (MS1), Existing port V (MM), Existing port I (MS2) and New Port 1, 2, 3 with (LLN1, LLN2, LLN3), respectively.

The input values for simulation testing (Simulation model) was than carried out by using the Arena software (Arena 10.0) [7, 8 - 14], are shown in Table 10.
The LPC of the new ports is based on the “National Port Logistics Volume Estimation (2005)” MOMAF (Ministry of Maritime Affars and Fisheries). According to this estimation, the logistics volume for 2005 is

17,172,000 TEU (nationwide), and the estimated logistics volume for 2001 is 27,099,000 TEU, up 57,8% over the year of 2005.

Consquently, the reason that this study has used the estimation for 2011 is that the construction of three types of new port will be completed same year.

Simulation input values by port type. Table 10

Type	Ship's arrival time distribution	LPC	No. of container handling (based on total work hour)	No. of container handling (based on net work hour)	No. of berth	No. of crane per berth
LL1	EXPO (5.75)	-0.001 + WEIB (1.02e+0.003, 1.69)	LOGN (2.78, 2.22)	LOGN (2.61, 1.99)	4	3
LL2	-0.001+35 x BETA (0.931, 4.75)	20 + WEIB (797, 1.58)	LOGN (1.07, 0.435)	LOGN (0.852, 0.338)	4 (50,000 ton) 1 (10,000 ton)	3
SS1	54 x BETA (7.29, 20.09)	104 + WEIB (982, 1.96)	LOGN (0.914, 0.34)		1	4
MS1	WEIB (22.2, 1.22)	NORM (802, 411)	0.32 GAMM (0.147, 6.37)	0.3 + LOGN (0.764, 0.346)	2	3
MM	GAMM (112, 1.73)	10 + 2.49e + 0.003 x BETA (0.718, 2.58)	LOGN (1.01, 0.43)	LOGN (0.929, 0.416)	2	3
MS2	19 + 81 x BETA (1.21, 0.734)	20 + 736 x BETA (1.91, 0.8222)	0.999 + LOGN (0.719, 1.52)	0.72 + EXPO (0.485)	2 (50,000 ton) 1 (10,000 ton)	3
LLN1	EXPO (5.75)	-0.001 + WEIB (1.02e+0.003, 1.69)	TRI (2.2, 2.6, 3.0)	LOGN (2.61, 1.99)	4	3
LLN2	EXPO (5.75)	-0.001 + WEIB (1.02e+0.003, 1.69)	TRI (2.2, 2.6, 3.0)	LOGN (2.61, 1.99)	3	3
LLN3	EXPO (5.75)	-0.001 + WEIB (1.02e+0.003, 1.69)	TRI (2.2, 2.6, 3.0)	LOGN (2.61, 1.99)	2 (50,000 ton) 2 (10,000 ton)	3

Simulation model by port type have been made, and input parameter values for each model have been entered. The workdays and work hours of all the container terminal are 365 days and 24 hours respectively. There are only 2 days (New Year and Chuseok) for holiday. Also, 4 hours among 24 hours is off-duty, but in reality all the containers are in operation around the clock for effective container handling of the arriving ships.

5.1. OUTPUTS BY PORT TYPES

The outputs derived from the quay simulation performance are shown in the Table 11. The average berth occupancy of LL1 port type closely approximates to the optimal berth occupancy of 60% meaning that these container terminals are well in operation. The average berth occupancy of SS1 type is 79% the highest of all types. This means that the current throughput of berth is far above the optimal throughput and that it is difficult to explain as common conception. The average berth occupancy of most of the other types is 10 to 12% below the optimal berth occupancy meaning that their logistics volume is not enough compared with their facility level.

Container terminal performance by port type. Table 11

	Current performance		Optimal capacity		Current performance				
Type	Average berth occupancy in %	Througput per berth in TEU	Optimal berth occupancy in %	Optimal througput	No. of crane per ship	Average service time in hr	Total time that ship spends in port in hr	Container handling per ship per hour	No. of berthing ship
LL1	61	510,000	60	500,000	2.88	14.8	16.8	97	1,388
LL2	50	430,000	62	530,000	3.09	15.1	16.6	84	1,441
SS1	79	890,000	35	380,000	3.78	12.6	14.0	126	554
MS1	33	270,000	45	360,000	2.85	13.3	14.7	93	435
MM	57	380,000	35	170,000	2.26	10.8	12.2	77	463
MS2	6	40,000	47.5	320,000	2.02	12.3	13.7	63	124
LLN1	65	540,000	60	500,000	2.89	15.9	17.3	95	1,432
LLN2	63	560,000	50	450,000	2.77	14.7	16.1	102	1,118
LLN3	52	430,000	55	470,000	2.79	15.4	16.8	93	1,178

There is no much difference between the average berth occupancy and optimal berth occupancy of LLN1, LLN2 and LLN3. This means that the port types suggested in this paper is satisfying the optimal berth occupancy required currently. The optimal throughput of LLN1 type, which has four berths of 50,000-ton level, is 570,000 TEU, and the optimal throughput of LLN3, which has two berths of 50,000-ton level and two berths of 20,000-ton level, is 460,000 TEU. The required number of cranes per ship ranges from 2.7 to 2.9. The container handling per ship per hour is 95 to 100 TEU.

6. CONTAINER YARD (CY) Simulation Results

The existing calculation methods of optimal throughput of a container terminal have mainly been based the berth capacity alone. Because of this, the container handling volume over the design capacity has rapidly worsened the traffic congestion of CY. The high density of CY worsens not only the productivity of a container terminal, but also increases sharply its logistics costs by forcing some cargoes into the ODCY. According to the questionnaire survey centring on the opinions of veteran terminal operators, the CY occupancy ratio of 60% is suitable for smooth workflow of the whole container terminal. Based on this idea, if the logistics volume is generally maintained at the level of CY occupancy of 60%, it will be reasonable and productive.

6.1. HEAVY TRAFFIC PROBLEM OF CY

Excessive container handling over the design capacity causes various problems including the additional costs for shuttle service. As shown in the Table 12, the heavy traffic congestion in the CY worsens not only the productivity of the container terminal, but also brings cost increase as well as lowered service level.
The values of input variables for CY simulation modeling are summarized as shown in the Table 13.

6.2. SIMULATION RESULTS

More accurate results will be revealed after CY-related data have been collected and analyzed, but in case of Shinsundae, the annual throughput per berth amounts to about 450,000-500,000 TEU, showing its CY occupancy of 70%. Reversely, if it tries to maintain its CY occupancy ratio at the level of 60%, its annual throughput per berth will be estimated to be 400,000-450,000 TEU.

The whole throughput of the container terminal depends on the lesser throughput of the two, i.e. quay and CY.

Problems caused by CY congestion. Table 12

Problems of Congestion	**Remarks**
Productivity deterioration	Turnaround time lengthens Rehandling by Y/T increases Q/C's idle time extends (lower Q/C productivity) Terminal productivity worsens.
Lower customer service	Ship's waiting time lengthens Container storage period reduction and cargo transfer to ODCY Delayed schedule worsens the confidence of shipping companies.
Cost increase	Shuttle costs increases Cargo transfer to OCDY causes cost increase.
Others	Safety accident increases Facility failure (including machine trouble) takes place frequently.

Therefore, as illustrated in the Table 13, in case of Shinsundae alone, the throughput of quay determines the whole throughput of it, and in case of all the other terminals, the throughput of CY determines the whole throughput of their terminals. In the case of SS, the throughput of quay exceeds 500,000 TEU, but since its CY throughput is far below it, the whole throughput of it remains at 430,000 TEU, which is the throughput of its CY.

Optimal throughput calculation by port type. Table 13

Type	Quay		CY		Optimal Throughput of terminal	Number of berth	Length	Port name	TGS
	Occupancy ratio (%)	Throughput	Occupancy ratio (%)	Throughput					
	55	460,000							
LL1	60	500,000	60	320,000	320,000	Total: 4 berths 50,000 ton: 4	1,200m	Existing port	10,950
	65	540,000							
	40	150,000							
MM1	45	170,000	60	480,000	170,000	Total: 2 berths 50,000 ton: 2	700m	Existing port	5,252
	50	190,000							
	40	320,000							
MS1	45	360,000	60	220,000	220,000	Total: 2 berths 50,000: 2	600m	Existing port	2,238
	50	410,000							
	30	330,000							
SS	35	380,000	60	690,000	380,000	Total: 1 berth 50,000: 1	350m	Existing port	2,462
	40	440,000							
	57	490,000							
LL2	62	530,000	60	420,000	420,000	Total: 5 berths 50,000: 4 10,000: 1	1,477m	Existing port	10,484
	67	580,000							
	43	280,000							
MS2	48	320,000	60	92,000	92,000	Total: 3 berths 50,000: 2 10,000: 1	880m	Existing port	1,278
	53	350,000							
	55	460,000							
LLN1	60	500,000	60	370,000	370,000	Total: 4 berths 50,000: 4	1,440m	New port	12,500
	65	540,000							
	45	400,000							
LLN2	50	450,000	60	410,000	410,000	Total: 3 berths 50,000: 3	1,050m	New port	8,610
	55	500,000							
	50	420,000							
LLN3	55	470,000	60	410,000	410,000	Total: 4 berths 50,000: 2 20,000: 2	1,150m	New port	9,375
	60	510,000							

7. CONCLUSIONS

Some actual data collected from six port types has shown difference with the results value of simulation model. The reason is that those data has been based on several-month period, not one-year period. Therefore, these data has been converted into one-year basis. After this data conversion, there has been little difference between those actual data and the result values of the simulation model.

The three port types of new ports are considered to be typical of the future ports under construction on to be constructed soon. Their optimal throughputs are ranging from 0.44 to 0.50 million TEU, and the required number of cranes per berth is from 2.7 to 2.9. These results are quite approximate to those results contained in the port construction and operation plan of the government. The fact that the outputs derived from the simulation model are similar with actual data means that simulation model is well reflecting the reality.

A simulation model employing the Arena has been developed to container terminal performance evaluation of Korean port. It is shown to provide good results in predicting the actual terminal operations system of the Korean container port. The attained agreement of the results obtained by using simulation model with real parameters has been used, also, for validation and verification of applied model. In accordance with that, the correspondence between simulation results and real Korean terminal parameters gives, in full, the validity to the applied simulation model to be used for optimization of processes of servicing ships at existing and new Korean port. Finally, this model also addresses issues such as the performance criteria and the model parameters to propose an operational method that reduces average time that ship spends in port and increases the terminal throughput.

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