CRANES ALLOCATION AND INTEGRATED EFFECTIVENESS STUDY IN A CONTAINER TERMINAL

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Abstract: There were studies mentioned that the calculation of berth handling should take into account mutual interference factors. Such as truck movement under the cranes, the unevenly distributed of containers in the ship, and the delay caused by the marshalling yard, etc. However, the value of mutual interference exponent has not identified. And the relationship between the number of cranes allocated and interference exponent has not been explored. In this paper, the authors took two stages to envisage these issues. Firstly, obtained the gross integrated handling effectiveness that various numbers of cranes ever used while ship tied up at the berth. Secondly, further distilled the gross integrated handling effectiveness that multiple cranes worked simultaneously from the observations of the first stage. Then, calculated mutual interference exponent under above two circumstances. Consequently, the relationship between interference exponent and the number of cranes used (worked) has developed.

Key Words: crane allocation, integrated handling effectiveness, mutual interference.

1. INTRODUCTION

One of the major tasks of port planners is to determine the numbers of berth that a port should construct to serve arrival vessels. The optimal numbers of berth are determined by the optimal degree of occupancy of the berth. Plumlee (1966), Nicolaou (1967), Griffiths (1976), Noritake Michihiko *et al*. (1983) had proposed the criterion chosen for optimizing the degree of occupancy of the berth is that of minimizing the total cost of operation of the berth. This cost consists of two main sub-costs: the shipping cost incurred because of waiting for and using the berth, and the cost of providing the handling facilities (e.g. number and size of berths, number of cranes, number of ground transportation equipment, storage capacity, etc.)

For the cost of shipping company, it is a matter of ship turnaround time, which includes waiting time and working time of berths. The period of time a ship spends at port is closely related with the berths handling capacity a port can supply. Traditionally, optimal handling capacity of a berth was obtained by multiplying the volume of containers each crane handled per hour, number of cranes equipped on the berth, work hours per day, work days per year and the optimal degree of berth occupancy. Without taking into account the mutual interference of cranes, like unevenly distributed of cargo at ship and the movement of transportation between quayside and container yard, number of cranes available, etc. Thus, the results of berth capacity calculation could be overestimated.

Edmond E.D. *et al.* (1976) mentioned that the effect of increasing the number of cranes working at a ship was subject to rapidly diminishing returns because cranes could not work closer than 120 ft from each other. Griffiths (1976) in calculating the optimal handling capacity at an iron ore terminal found that the total handling capacity of a single berth working with two unloaders should account for mutual interference of equipment. Paul Schonfeld *et al.* (1985) and Huang W.C. *et al.* (1995) proposed a similar form of equation to measure the transfer time a ship spends at the terminal. In the equations, a mutual interference exponent was introduced. Huang W.C. *et al.* (1995) further presented the range of the mutual interference exponent. However, neither the real value of mutual interference exponent nor the relationship between mutual interference exponent and the number of cranes working at a ship has clearly identified yet.

In this study, we took one of the fabulous container terminals of Port of Kaohsiung for example. Using actual 1998 harbor logs and operating procedures to develop all data. The terminal was leased from Port Authority of Kaohsiung to a container line, with a linear quay of 916m in length, equipped with seven gantry-cranes on the quayside, capable of accommodating vessels of draught up to 14 m and used rubber-tired yard crane system. The terminal handled around 917 760 containers (1 375 200 TEUs) and served about 1440 vessels in 1998, of which 424 200 containers (about 47% of the year) were transshipment cargo.

We envisaged the ship sizes, volume of containers loaded and unloaded, number of quay cranes used, number of containers handled per unit time of ship working time, etc. Then calculate (1) total handling volume of containers under various number of cranes a ship ever used while along side the berth and (2) integrated handling capacity while multiple cranes worked together. Consequently, figured out the interference exponent and its relation with numbers of cranes applied. The results of this paper will be better understanding for port planners of the reduction in berth handling capacity while more than two gantry-cranes are operating at a single ship, and helpful to the determination of berth handling capacity.

2. THE MODEL

Paul Schonfeld *et al.* (1985) and Huang W.C. *et al.* (1995) have derived expressions for measuring a ship's transfer time (the average operating time per ship). If the cranes could operate without mutual interference and if the workload was equally distributed among n cranes, Paul Schonfeld *et al.* (1985) defined the transfer time as:

$$T = x\,y / n \qquad (1)$$

Where T is a ship's transfer time (i.e. loading and unloading); x is the number of containers exchanged per ship at the terminal; y is container-handling rate (time/move); n is the number of cranes serving the ship. However, since interference may occur, due to truck movements under the cranes and in the container yard and the unevenly distributed of containers in the ship, the above equation should be modified as:

$$T = x\,y\,/\,(n^{f}) \tag{2}$$

In which the exponent f may be less than 1.0. An f value of 1.0 is equivalent to assume no mutual interference. The less of f value the more mutual interference among cranes occurred. Huang W.C. *et al.* (1995) defined the average operating time per ship T as follow:

$$T = V\,/\,(AC^{f} \times \gamma) \tag{3}$$

Where V is the average exchanged volume (tons or TEUs/ship) per ship; γ is the operation efficiency of a single crane (tons or TEUs/hr); f is the crane interference exponent; AC is the number of cranes per berth. Equation (2) and (3) actually has the same form of calculation, if we transform equation (2) into

$$T = x\,/(1/y \times n^{f}). \tag{4}$$

γ has the same measurement unit with (1/y). The denominator of equation (3) and (4), in practice, is the integrated handling effectiveness while more than two sets of crane work at a ship.

Huang *et al.* (1995) further identified the range of the value of crane interference exponent f =0.5 ~ 1.0. However, the real value of f is still not precisely known, and the degree of relationship of interference exponent f and the number of cranes allocated at a ship remains undeveloped. In this study we would take the form of the denominator of equation (3) as a basis to calculate interference exponent f.

The computation of mutual interference under multiple cranes in above equations implies that cranes should work simultaneously, that means every crane start and stop working at the same time. However, from a practical point of view, this kind of situation was not happened frequently because of unevenly distributed containers in a ship. Each crane handled different volume of containers. As a result, cranes even start working at the same point of time still seldom stop at same time. So, to collect enough handling sample that related to various numbers of cranes operate completely at the same period of time is almost impossible.

In order to figure out the value of interference exponent f. we divide the calculation of integrated handling capacity under various numbers of cranes into two stages. One is the number of cranes a ship has ever used during its work hours. The other is the number of cranes worked simultaneously. The number of cranes a ship ever used is according to the records of harbor logs. Which was the truly data collation described every operation step during ship working time. This means that all of the allocated cranes did not exactly operate simultaneously through out the ship working time. While the numbers of cranes worked simultaneously were those cranes, distilled from the harbor logs, which starts at about the same time (less than 30 minutes) and more than 90% of the ship handling-time work together. Then computes integrate handling rates under various numbers of cranes. Finally came up with the interference exponent. The relationship between the ship working time and the crane work time can be seen from figure 1.

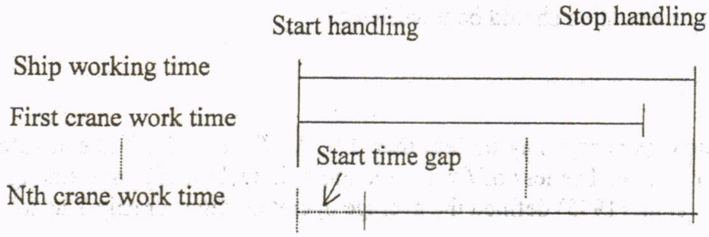

Figure 1. Ship operation time depiction

3.THE NUMBER OF CRANES ALLOCATED

The number of cranes allocated is defined as the number of gantry cranes has ever been used, no matter how long the crane worked, during the period of handling while a container ship tied up at a berth. These cranes do not always start and stop handling at the same time. It was a real record that the number of cranes a ship ever applied no matter what its sequence was.

How many gantry cranes should be allocated at a ship when it was alongside a berth? This answer can be roughly seen in table 1. To a large extent, if we don't divide ship sizes and cargo handled further, two cranes were most frequently ever used (about 60% of the vessels), then came three cranes (about 25 % of the vessels) and four cranes (about 10 % of the vessels). For those ships ever used more than four cranes (i.e. five, six, seven, eight cranes) only account about 2 % of the vessels. The reasons are worthy of further analysis. There are four truck lanes under the modern gantry crane at the container terminal, thus uses more than four cranes, with so many tractors movement, and would undoubtedly cause transportation disturbance. The average number of cranes used was 2.44 cranes/ship and the standard deviation was 0.87 cranes/ship. Compared this result with Edmond E.D. *et al.*'s (1976) finding, one would surprise to find that the difference of the number of crane work at a ship is insignificant even more than 20 years has passed.

Table 1. Number of Cranes Ever Used at a Ship

Number of cranes ever used	Number of ships	%
1	98	6.84%
2	817	57.05%
3	365	25.49%
4	129	9.01%
5	15	1.05%
6	5	0.35%
7	2	0.14%
8	1	0.07%
Mean=2.44 cranes/ship, Std.=0.87 cranes/ship		

One would argue that the number of cranes ever used has strong relationship with the size of ship and the volume of containers handled. Therefore we further divide ship sizes by length, and the volume of containers handled into four groups to look into this problem more deeply. The distributions are shown in table 2 and 3.

Table 2 indicates for those ships which lengths less than 150 meters, 82 % used two cranes, 14 % used one crane, and 4 % used three to four cranes. For ship lengths in the range 150-200 meters, 83 % used two cranes, 10 % used one crane, and 8 % used three to four cranes, the proportion of using more than two cranes is slightly larger than the preceded range. There was no indication of using more than four sets of crane in these two size groups. For ship lengths in the range of 200-250 meters, 56 % used three cranes, 30 % used two cranes, 10 % used four cranes and 2 % used up to seven cranes. For ship lengths in the range of 250-300 meters, 53 % used three cranes, 35 % used four cranes, 5 % used five cranes, and 3 % used up to eight cranes.

The most frequently number of cranes used shift from two to three when ship size longer than 200 meters. The proportion of using four cranes was around four times in the range of 250-300 meters than in the range of 200-250 meters (35% compared with 10%). All of the analysis shows that the number of cranes ever used increased while the ship length became longer.

Table 2. Number of Cranes Ever Used for Different Ship Length Groups

Ship length	L≦150m		150m<L≦200m		200m<L≦250m		250m<L≦300m	
No. of cranes	No. of ships	%	No. of ships	%	No. of ships	%	No. of ships	%
1	40	14%	57	10%	10	3%	1	
2	242	82%	469	82%	96	30%	10	4%
3	8	3%	43	8%	180	56%	134	53%
4	4	1%	2	0%	33	10%	90	35%
5					2		13	5%
6					1		4	2%
7					1		1	
8							1	
Total	294		571		323		254	

From table 3, for containers handled less than 500 moves, about 98 % used less than two cranes, and about 2 % used up to three cranes. For containers handled in the range of 500-1000 moves, the probability used two cranes reduced to about 50 %, about 45 % of probability used three cranes, and not a single ship used one crane in this range. For container traffic in the 1000-2000 moves range, about 70 % used three cranes, around 20 % used four cranes, and only one ship used two cranes (nearly 0 %). For container traffic more than 2000 moves range, the opportunity to use three cranes was 50%, about 47 % used four, and no ships used less than two cranes.

It is obvious that ships handled larger amount of containers used more gantry-cranes. For those ships handled more than 500 containers, no chance of using one crane, whereas for ships handled more than 1000 containers, almost more than two cranes were used (mostly used three or four cranes) and sometimes more than four cranes.

Table 3. Number of Cranes Ever Used for Different Container Traffic Groups (moves)

Container handled	V≦500		500<V≦1000		1000<V≦2000		2000<V	
No. of cranes	No. of ships	%	No. of ships	%	No. of ships	%	No. of ships	%
1	98	12%						
2	713	86%	103	51%	1			
3	14	2%	91	45%	185	73%	75	50%
4	1		7	3%	51	20%	70	47%
5			2	1%	13	5%	0	
6					2	1%	3	2%
7					1		1	
8							1	
Total	826		203		253		150	

4. MUTUAL INTERFERENCE EXPONENT

4.1 Integrated Handling Effectiveness (number of cranes ever used)

Integrated handling effectiveness in this section is defined as the total handling gross capacity under the various numbers of cranes ever used. From table 4, One can clearly see that cranes were not operated together all the way through the ship working time. That means crane did not start handling and stops handling at the same point of time.

If we define start-time gap equals 0 hr., there were 370 ships, 79 ships, and 7 ships started at the same time for those ships that ever used two cranes, three cranes and four cranes. If we enlarge start-time gap from 0 hr to 0.5 hr. then there were 622 ships, 203 ships and 32 ship for ships that ever allocated two cranes, three cranes and four cranes while ships had been handling containers. Average start-time gap for the second crane was about 0.5 hr., whereas for the third or the fourth crane was much larger, up to 15 minutes and 35 minutes, in the three and four cranes ever used group.

Average gross crane-work-time ratio decreasing as the number of cranes increasing. Its account from 88% for ships ever used two cranes to 72% for ships ever used four cranes. The difference of the ratio for the first and the second crane in each group was not obvious, only about 1 % to 3 %. While the ratio of the third or the fourth crane had a clear diminishing, about 10% to 35 % in the four cranes ever used group. After subtracted the non-operation hour from crane work time, the net crane work time ratio showed the same tendency as the gross crane-work-time ratio did. The ratio in each group was 66%, 62% , and 72% respectively.

Under the operation circumstance as described in table 4. Average integrated handling effectiveness for ships ever used two cranes was 37.03 moves/hr and the standard deviation was 7.20 moves/hr. Average integrated handling effectiveness for ships ever used three and four cranes were 50.49 moves/hr and 57.78 moves/hr and their standard deviation were 10.22 moves/hr and 12.46 moves/hr respectively. The amount of integrated handling effectiveness increased as the number of cranes ever used increased. The degrees of dispersion (standard deviation/mean) were about 20% for all these cases.

Table 4. Cranes Operation Analysis for Numbers of Cranes Ever Used

Cranes ever used	1	2	3	4
Number of ships	98	817	365	129
Start-time gap=0 hr. (ships)	0	370	79	7
Start-time gap=0.5 hr (ships)	0	622	203	32
Average start-time-gap (hour)	0	0.7	0.5(2nd. crane) 2.6(3rd. crane)	0.3(2nd. crane) 1.4(3rd. crane) 6.2(4th crane)
Average gross crane-work-time ratio (%)	100%	88% 87%(1st crane) 90%(2nd crane)	82% 85%(1st crane) 87%(2nd crane) 75%(3rd crane)	72% 82%(1st crane) 83%(2nd crane) 76%(3rd crane) 49%(4th crane)
Average net crane-work-time ratio (%)	100%	66% 66%(1st crane) 67%(2nd crane)	62% 64%(1st crane) 65%(2nd crane) 56%(3rd crane)	53% 61%(1st crane) 61%(2nd crane) 57%(3rd crane) 37%(4th crane)
Integrated handling effectiveness (moves/hr/ship)	21.35 (3.45)	37.03 (7.20)	50.49 (10.22)	57.78 (12.46)

Note:
1. gross crane-work- time ratio = crane work time / ship working time
2. net crane-work-time ratio = net crane work time / ship working time
3. start-time gap is the time gap between n^{th} crane and the 1^{st} crane start handling time.
4. net crane-work-time is the gross crane work time deducted crane non-operation time
5. Ship working time is the period of time between the fist crane start handling and the last crane stop handling.
6. Ships ever used more than four cranes were ignored because of limited observations.
7. The value in the ( ) is the standard deviation.

4.2 Mutual Interference Exponent (number of cranes ever used)

Although there were container ships ever used up to eight cranes, however, this occurrence was very rare. In this study we consider only ships allocated one to six cranes while berthing. Average integrated handling effectiveness and standard deviation for ships ever used one crane to six cranes were 21.35 moves/hr, 3.45 moves/hr (one crane); 37.03 moves/hr, 7.21 moves/hr (two cranes); 50.49 moves/hr, 10.22 moves/hr (three cranes); 57.78 moves/hr, 12.46 moves/hr (four cranes); 59.38 moves/hr, 13.45 moves/hr (five cranes) and 61.17 moves/hr, 10.24 moves/hr (six cranes) respectively. One would expect ships ever used more cranes have a higher integrated handling effectiveness, this is quite true. However, for those ships used more than four cranes the difference is not too big. If we compare 61.17 moves/hr (six cranes) and 59.38 moves/hr (five cranes) to 57.78 moves/hr (four cranes). This was because of limited truck lanes under the gantry-crane and the traffic interference undoubtedly caused.

There were many factors for terminal operator to decide the allocation of number of cranes at the ship. Such as ship sizes, cranes available, management of container yard, movement of tractors, volume of cargo handled, expected ship departure time, pattern of ship arrival, etc. There was no single rule explained how terminal operator allocated cranes. It was not usual to find that all the cranes began and stop handling containers at the same time when work at a ship. Refer to the form of the denominator of equation (3) and (4), $AC^f \times \gamma$, to measure integrated handling effectiveness . From the definition:

$$AC^f \times \gamma_1 = \gamma_n \tag{5}$$

Where γ_1 is the handling rate used one crane, γ_n is the integrated handling effectiveness ever used n cranes. Take nature logarithm of both sides of equation (5),

$$f \ln(AC) = \ln(\gamma_n / \gamma_1) \tag{6}$$

Take the mean integrated handling effectiveness under the various numbers of cranes ever used as a calculation base. Then we got:

For ships ever used two cranes: $f \ln 2 = \ln(37.03/21.35) = 0.544, f = 0.784$;
For ships ever used three cranes: $f \ln 3 = \ln(50.49/21.35) = 0.855, f = 0.778$;
For ships ever used four cranes: $f \ln 4 = \ln(57.78/21.35) = 0.989, f = 0.713$;
For ships ever used five cranes: $f \ln 5 = \ln(59.38/21.35) = 1.016, f = 0.631$;
For ships ever used six cranes: $f \ln 6 = \ln(61.17/21.35) = 1.046, f = 0.583$.

As calculated, interference exponent f decrease as the number of cranes ever used increase. Decreasing value of f indicates increasing of interference. For those ships ever used two or three cranes, f equal 0.784 and 0.778, difference is very small. Number of cranes ever used more than three, difference become larger. Integrated handling effectiveness of two cranes equals $2^{0.784}$ =1.72 times the handling rate of one crane, three cranes do $3^{0.778}$ = 2.35 times of the work one crane done; four cranes do $4^{0.713}$ = 2.69 times of the work one crane done, etc.

The relationship between mutual interference exponent and the number of cranes used is shown in figure 2. The regression equation is $y = -0.2165 \ln(x) + 0.9858$, where y = interference exponent f, x = the number of cranes ever used. The R^2 value indicated more than 95 % of the variation explained.

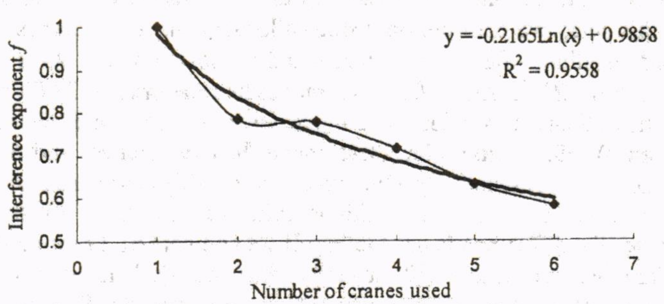

Figure 2. Relationship between interference exponent and number of cranes ever used

4.3 Mutual Interference Exponent (numbers of cranes worked simultaneously)

We further filter observations that multiple cranes almost worked together from the beginning to the end while ship berthing and handling containers. The numbers of cranes works simultaneously are those cranes which start-time gap less than 30 minutes and more than 90% of the ship working-time handling together. Table 5 is those operations that multiple cranes worked simultaneously. Observations correspond to the definition of cranes worked simultaneously rapidly reduced to 328 ships and 77ships for two and three cranes group. Compare to table 4, for ships ever used two and three cranes group, only about 40% and 20% of the ships obey the simultaneous-work definition. No single ship showed that four cranes were worked simultaneously.

Average start-time gap is small (less than 10 minutes); even at three cranes worked simultaneously group. The average start-time of the third crane was about 10 minutes. The average gross crane-work-time ratio showed that each crane was handling containers during 97% of the ship working time. The ratio was about the same for each crane. There was 3 % difference between this ratio to 100% which one crane could work. The result primary owing to the unevenly distributed of containers at a ship. The average net crane-work-time ratio was about 73%. The tendency of the ratio was similar to that of average gross crane-work-time ratio. Compare these two ratios to the figures in table 4; the difference increased as the number of cranes enlarged.

Since the gross crane-work- time ratio was very high, so the gross equivalent number of cranes worked is almost equal to the number of cranes worked simultaneously. We have more confidence that the observations met the defined requirements of cranes worked simultaneously. So the further mutual interference analysis based on these data are more reliable. Average gross handling rate and net handling rate of each crane revealed there was a slightly deduction as the number of cranes worked simultaneously increased.

If we multiple gross handling rate of one crane by the number of cranes worked simultaneously. It seems a little interference. For example $21.35 \times 2 = 42.70$ moves/hr, $21.35 \times 3 = 64.05$ moves/hr; compare to 40.86 moves/hr and 59.78 moves/hr which were the integrated handling effectiveness for two and three cranes worked simultaneously.

In stead, if we further multiple gross handling rate of one crane by the gross equivalent number of cranes worked. For example $21.35 \times 1.96 = 41.85$ moves/hr, $21.35 \times 2.90 = 61.92$ moves/hr. These two figures are very closed to 40.86 moves/hr and 59.78 moves/hr respectively. Interference among cranes was very small.

Again, from equation (6) we compute the interference exponent under the number of cranes worked simultaneously.

For ships two cranes worked simultaneously: $f \ln 2 = \ln(40.86/21.35) = 0.649, f = 0.936$;
For ships three cranes worked simultaneously: $f \ln 3 = \ln(59.78/21.35) = 1.030, f = 0.937$.

Integrated handling effectiveness of two cranes worked simultaneously equals $2^{0.936} = 1.91$ times the handling rate of one crane, three cranes do $3^{0.937} = 2.80$ times of the work one crane done. From the analysis of this section, one could find that interference among cranes is very limited. The mutual interference exponent is about 0.94 and irrelevant to the number of cranes worked. If we compute the mutual interference exponent by the gross equivalent number of cranes worked instead. The value is about 0.97 very closed to 1.0 and $2^{0.97}$ =1.96, $3^{0.97}$ = 2.90 times of the work one crane done (almost no interference among cranes).

Table 5. Cranes Operation Analysis for Numbers of Cranes Worked Simultaneously

Number of cranes worked simultaneously	1	2	3
Average start-time-gap (hour)	0	0.13	0.07(2nd. crane) 0.19(3rd. crane)
Average gross crane-work-time ratio (%)	100%	97%(3%) 97%(3%) (1st crane) 97%(3%) (2nd crane)	97%(3%) 97%(3%)(1st crane) 97%(3%)(2nd crane) 96%(3%)(3rd crane)
Average net crane-work-time ratio (%)	76%(7%)	73%(7%) 73%(7%) (1st crane) 73%(7%) (2nd crane)	73%(5%) 74%(5%)(1st crane) 73%(6%)(2nd crane) 73%(5%)(3rd crane)
Gross equivalent number of cranes worked	1	1.96	2.90
Net equivalent number of cranes worked	0.76	1.46	2.20
Gross handling rate (moves/hr/crane)	21.3 (3.5)	21.1 (3.2)	20.6 (2.4)
Net handling rate (moves/hr/crane)	28.2 (2.9)	27.9 (2.5)	27.2 (1.8)
Integrated handling effectiveness (moves/hr/ship)	21.35 (3.45)	40.86 (5.82)	59.78 (5.73)

Note:
1. Gross equivalent number of cranes worked simultaneously
= Number of cranes worked simultaneously × gross crane-work- time ratio
2. Net equivalent number of cranes worked simultaneously
= Number of cranes worked simultaneously × net crane-work- time ratio
3. The value in the ( ) is the standard deviation.

The distribution of integrated handling effectiveness under number of cranes ever used and number of cranes worked simultaneously were showed in figure 3 – 6. From the figures, one could find that the distribution pattern in figure 3 and 4 were more dispersed. Whereas the observations were much more centered in figure 5 and 6. Thus the results calculated with the number of cranes worked simultaneously are more correspondent to the definition of the model developed in this study.

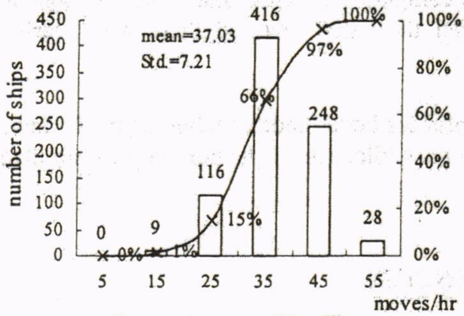

Figure 3. Integrated Handling Effectiveness(ever used 2 cranes)

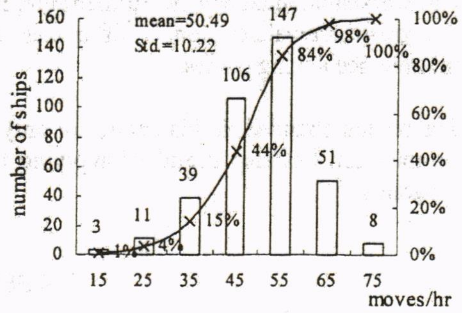

Figure 4. Integrated Handling Effectiveness(ever used 2 cranes)

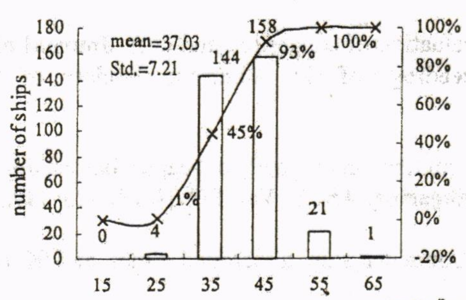

Figure 5. Integrated Handling Effectiveness(2 cranes worked)

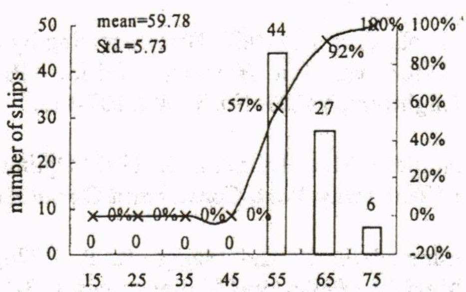

Figure 6. Integrated Handling Effectiveness(3 cranes worked)

5. CONCLUSION

The number of containers handled per unit of ship working time is a useful index to measure the berth service time. Many factors affect the integrated-handling rate. Among them, the number of gantry-crane available is one of the most important factors. In the case of this study, the most frequently used number of cranes was two cranes when a ship alongside a berth. Then came three cranes, four cranes, and one crane in order. The opportunity for ships used more than four cranes was very rare. Besides, ships handled larger amount of containers have a tendency to apply more gantry-cranes. However, this is not an unchangeable ruling policy for the allocation of cranes. For those ships handled less than 500 containers, there was probability used one crane. Whereas for ships handled more than 1000 containers, in principle, used more than two cranes (mostly used three or four cranes).

The integrated-handling effectiveness increased while the number of cranes ever used increased. However, the mutual interference among cranes augmenting as well. Interference exponent value ranged between 0.784 and 0.713 for ships ever used two to four cranes. The regression equation between interference exponent and the number of cranes ever used has obtained in this study.

If we selected those observations which multiple cranes worked simultaneously for further discussion. One could find that the interference among working cranes was very small. The mutual interference exponent is about 0.94 and irrelevant to the various numbers of cranes that worked simultaneously. Furthermore, if we compute the mutual interference exponent by the gross equivalent number of cranes worked the value revealed there was nearly no interference among cranes.

The results obtained in this study, not only helpful for better understanding of berth capacity computation but also useful of applying the cranes allocation behavior on port simulation programs.

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