DETERMINATION OF THE CAPACITY OF A HIGHLY SATULATED PORT
----A CASE STUDY IN BANGKOK PORT----

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1. BASIC CONCEPT OF THE CAPACITY OF THE PORT

The congestion at Bangkok Port is the biggest obstacle to Thailand's development.It is believed that there are many reasons: the small number of berths, shortage of handling equipment and trailers, an inadequate container yard area, traffic congestion in the port, inefficient operation, and so on. The handling of a container is considered to be part of the container flow sequence, which is divided into four procedures: the handling of a container between vessel and apron,(the so-called marshaling yard), transportation by trailer between apron and stacking yard,(the so called container yard), the handling of the container in the stacking yard, transportation of container to/from the hinterland. So, the real bottleneck should be at one point only and probably has two or three causes at most. With this sequence in mind, facilities and equipment for the port is planned and designed appropriately to ensure the most efficient handling and usage. The capacity of the port is considered to be approximately equivalent to the planned capacity since the port usually operates within its capacity.

In the case of Bangkok, however, the port is already very congested and operates in highly saturated conditions, since the number of containers handled in the port is much higher than its planned capacity. The capacity of any port under these conditions is automatically decided interms of capacity at a bottleneck with its handling and transportation procedures. Accordingly, the capacity under consideration in this paper is defined as the maximum number of containers to be handled in the port under the optimal operation of equipment, which does not mean the optimal operation of the port since an adequate level of operation has not already been considered. In particular, vessel waiting-time is not considered in this study.

A saturated point in a port cannot always be considered as a bottleneck, because a bottleneck influences all upstream activities. Both import and export containers are handled simultaneously in any port, and their flow moves in a reverse direction, affecting each other. Therefore, it is very difficult to identify a container flow bottleneck and to determine the capacity of the bottleneck. It seems a primitive way to check all the sequences of handling; however, it is the best way.

It is widely believed that urban traffic in Bangkok is the worst among the large capital cities of the world. The transportation of containers from/to the hinterland, which is fourth procedure, may constitute one of the bottlenecks in the sequence. However,the sequence is not discussed in this paper, since the problems cannot be solved through the efforts of the port authority alone.

The purpose of this paper is to locate the bottleneck at the port, to determine the capacity of it and to specify the main reasons for the congestion. In this paper, the capacity of the port is determined by considering the following:

- evaluation of the capacity of handling between vessels and apron
- evaluation of the stacking capacity of the container yards
- determination of the capacity in terms of the container movement from/to vessel to/from container yard

2. DETERMINATION OF THE CAPACITY AT THE BERTHS

The container handling capacity at the berths can be determined from a macroscopic point of view by equation (1).

$$V = (V_1 + V_2) \times NVA \times NB \quad \text{------------}(1)$$

where, V_1 is average number of import containers per vessel, V_2 is average number of export containers per vessel, NVA is number of vessels that can be accommodated per year, and NB is number of berths available for container.

NVA is very dependent on the operating conditions and can be determined by the equation (2):

$$NVA = OD \times OT \times BOR/AB \quad \text{------------}(2)$$

where, OD is number of days in operation per year, OT is operating hours per day, BOR is berth occupancy ratio, and AB is average berthing time per vessel.

V_1 and V_2 are the number of containers equired for loading and unloading, respectively and they vary according to the size and capacity of the vessels. Based on the data provided by PAT (the Port Authority of Thailand), handling volume per vessel ($v_1 + V_2$) is estimated at 650 TEU(Twenty feet container equivalent)

This figure can be considered stable in the long term since Bangkok Port is a feeder port and the waterway cannot be improved in the near future because it is the river port. There are 6 berths on the East Quay and one berth on the West Quay for container handling. However, the 6 berths in East Quay can be adapted into 8 berths for average-sized vessels, and another 2 or 3 conventional berths can also partially use for container vessels. Accordingly, 10 berths can be assumed as the number of berths available for container vessels. OD is usually 365 days. The Port Authority of Bangkok operates three shifts and there is a one hour break during each shift. So, 21 hours of operation time is used in the calculations. The berth occupancy ratio is very difficult to estimate. According to most of the reference, an appropriate estimation of the occupancy ratio is 60% to 65%, with a maximum of 70%. Table 1 shows the occupancy figures in 1989/1988.

Table 1 Berth Occupancy Ratio during Oct. 1987 and Apr. 1988 in the Port of Bangkok

Period ('87-'88)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Occupancy Ratio(%)	65	72	62	79	74	76	81

These figures are far from the standard level. However 80% can be used as the figure to estimate the maximum capacity of the 10 berths, and this is very probably a reasonable estimate because the Port of Bangkok is highly congested. the average berthing time per vessel is the forcus of attention in this paper. Table 2 shows the estimated berthing time per vessel, according to the JICA study team.

Table 2 Berth Occupancy Time in the Port of Bangkok

Berth Occupancy Time (hours)	14.0	22.4	30.7	39.1	47.4	Average 28.64
Proportion (%)	15	30	30	15	10	100

28.64 hours is the figure obtained, based on this data, and is discussed again in chapter 5.

As a result, the number of vessels that can be accommodated per berth is estimated at 214.1 (365 x 21.0 x 0.8/28.64). The berth capacity of the Port of Bangkok is 1.392 million (650 x 214.1 x 10) TEU maximum. However, the actual volume of containers handled at the Port in 1988 was around 0.75 million TEU, which is about 55% of maximum capacity. The discrepancy can be explained by comparing the number of berths and the estimated berthing time. In 1988, only six berths on the East Quay were available during the year, because of renovations, and only one berth was available on the West Quay. The berthing time at present is around 36 hours per vessel as mentioned before. By using these actual conditions, a real figure of 0.76 million TEU (1.392 x 7/10 x 28.64/36.6) is obtained.

3. DETERMINATION OF THE CAPACITY OF STORAGE AREA.

The stacking area capacity varies according to the system of operation. It is believed that the on- chassis system has the highest level of handling efficiency, but productivity per unit area is the lowest of the three typical systems. The straddle carrier system is considered to be the second most efficient, however, this system also requires a large stacking area because a straddle carrier can only pile up a maximum of 3 containers. By comparison, the handling speed of the transfer crane system is rather slow, but it has the highest productivity per unit area.

The maximum number of containers (MAXNC) that can be handled in a container yard is expressed by the equation (3):

$$MAXNC = ACY \times PUA \times H/FS \times 365 \text{ days}/DS \quad \text{---(3)}$$

where, ACY is the stacking yard area, PUA is the proportion of the area used for stacking containers to the whole area, H is number of containers to be stacked, FS is effective floor space of one container, and DS is average duration of storage

The port of Bangkok has 45.6 hectares of stacking yard at present and is going to have another 22.45 hectares in the near future. The PUA is varied according to port policy the planning and design of the port. Generally speaking, 60 % is very common around the world, and 70 % as the maximum where main roads for trailers are excluded. The transfer cranes in the Port of Bangkok can clear four stories of containers. However, a substantial level of piling up can be estimated at an average of 2.5 containers high. The floor space required for a twenty-foot long container is 14.85 square meters. It is assumed that the effective floor space for a container twenty feet long is 18 square meters, including clearance and redundant space. The actual storage time of storage could not be obtained for the Port of Bangkok, but it is widely believed to be an average of 14 days or more. Using the data mentioned above, a figure of 1.477 million TEU (0,991 million TEU at present) of capacity is estimated.

4. DETERMINATION OF THE CAPACITY OF THE FLOW BETWEEN VESSELS AND STACKING YARDS

Even if the capacity of both berths and stacking yards are known, the minimum volume is not equivalent of the capacity of the port. Because a bottleneck sometimes results during the handling from/to the vessels to/from the stacking yards, determination of the capacity of the flow in this sequence is carried out by using a simulation technique. Optimal allocation of equipment and facilities is required in advance in order to apply the simulation technique. Dynamic programming is used to find the optimal allocation, and the Lagrange Multiplier procedure is used to solve the multidimensional, dynamic programming problems. The normal Monte Carlo simulation with the event sequence technique is employed here.

The problems for dynamic programming can be written down as follows:

$$\text{Maximize } \left(\sum_{i=1}^{N} r_i(x_{i1}, x_{i2}, ---, x_{il})\right) - \sum_{j=1}^{k} \alpha_j \sum_{i=1}^{N} X_j$$

$$\text{subject to } \quad \sum_{i=1}^{N} x_{ij} = x_j$$

$$j = 1, 2, ---, k$$

$$x_{ij} = 0, 1, 2, ---, X_j$$

where, N is total number of vessels moored at berths, l is total number of types of cranes available, Xj is total number of cranes of type j (j= 1,2,---,l), x_{ij} is number of type j cranes allocated to vessel i (i= 1,2,---,N), $r_i(X_{i1}, X_{i2}, ---, x_{il})$ is the return obtainable (e.g. no. of containers moved per hour) by allocating x_{im} number of type m (m = 1,2,---,l) cranes to vessel i, α_j is Lagrange Multipliers, and k is number of Lagrange Multiplier to be introduced.

The following allocation of trailers was carried out after the optimal allocation of cranes to each berth. Total TEU handled per hour at berth i

$$TH = \left(\sum_{j=1}^{3} X_{ij} \times MR_{ij}\right) + SR_i$$

Number of trailers required at berth i

$$TR_i = {}^{1}/_{2}[\,CY_i \times (\sum_{j=1}^{3} X_{ij} \times MR_{ij} + SR_{ij})\,]/60$$

Total number of trailers required

$$TTR = \sum_{i=1}^{N} TR_i$$

where N is number of berths occupied by vessels, MR_{ij} is handling rate of mobile crane type j at berth i, SR_i is total handling rate of ship-gears at berth i, and CY_i is average cycle time in minutes of trailers at berth i.

$$X_{i1} + X_{i2} + X_{i3} \leq 3$$

Since three types of cranes are considered here, the maximum number of cranes to be allocated to a berth is assumed to be three. The following empirical relation is assumed between the cycle time of trailers and flow

$$NT \doteq 0.46\ (CY + 5.22)$$

where, NT is number of trailers allocated to a berth and CT is average cycle time of trailers at the same berth. For the simulation of crane rates the two regression models given below are used:

$$\text{Crane rate (mobile)} = 4.66 \exp\ (1.65\ RND)$$
$$\text{Crane rate (ship gear)} = 3.33 \exp\ (2.45\ RND)$$

where, RND is random number. For the simulation of cycle time of the trailers, the variation in the cycle time is assumed to be uniform and within the range of "average cycle time +/- 10 minutes". Table 3 shows average crane rates used in the study.

Table 3 Average Crane Rates Used

Crane Type	Type of Operation	Average Crane Rates
Moble	Loading	10 TEU/hr
	Unloading	14 TEU/hr
Ship Gear	Loading	14 TEU/hr
	Unloading	20 TEU/hr

Through this optimization process, the volume of the containers handled was estimated at 123 TEU per hour for seven berths. It means the Port of Bangkok can handle more than 1.35 million TEU. (1350000 = 123 x21hours x10 berth /7berths x365 days). Nevertheless, the efficiency level of the Port of Bangkok is 75 TEU per hours for seven berths and is equivalent to 0.81 TEU per year. This is almost the same level as the performance in 1988. See figure 1.

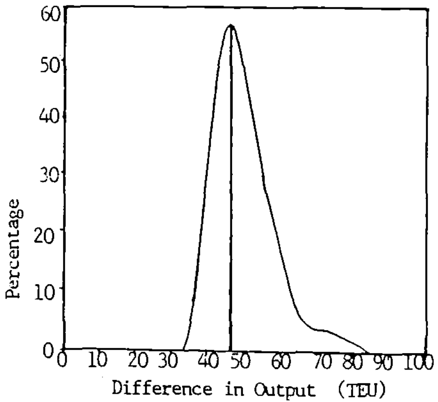

Fig. 1 Variation of Difference of Output (Total TEU can be handled-Actual TEU handled)

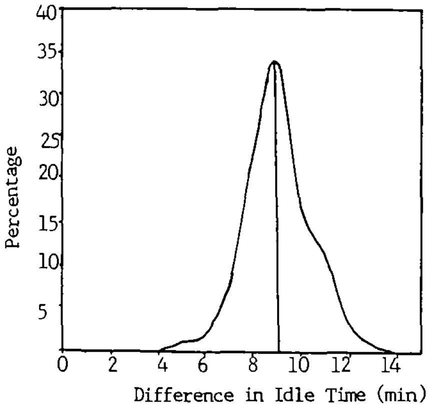

Fig. 2 Variation of Difference in Idle Times of Cranes

5. RESULTS AND CONCLUSIONS

The following results were obtained from the study

1. The handling Capacities both at the berths and in the stacking yards are estimated at 1.392 million and 1.477 million TEU, respectively.

2. The capacity in the sequence between vessels and stacking yards is a maximum of 1.35 million TEU. Then, it can be concluded that this sequence is where the bottleneck at the port exists, and the capacity is around 1.35 million TEU if all existing exists, port equipment is properly used. Otherwise, it might be less than 800,000 TEU.

3. It was found that the major reason for this inefficiency is the idling time of the cranes which is caused by inappropriate trailer allocation orinadequate operation of the trailers. The difference in idling time between the optimal operation and existing operation is estimated at an average of nine minutes per cycle. See Figure 2

As a result, the following conclusions may be drawn:

- to determine the capacity of a highly saturated port, all handling sequences should be checked;

- checking of each handling procedur is necessary and very helpful in finding the candidates for the bottleneck. However, it might be not enough to find a real bottleneck. To find the real bottleneck in the handling sequence, the simulation technique (assisted by dynamic programming) is very effective and suitable.

- through the case study of the Port of Bangkok, the capacity of the port was estimated 1.35 million TEU maximum, under the optimal operation of the existing facilities.

- to increase the capacity of the port, it is recommended the allocation and operation of trailers should be changed by introducing a computer-aided optimization system. It may also be necessary to purchase a significant number of additional/extra trailers.

A computer-aided optimization system might also be very useful in finding any new bottleneck in the handling and in proposing a new operation system, including changes in the container yard plan.

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