COMPUTER SIMULATION MODEL FOR OPTIMUM SEAPORT PLANNING

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ABSTRACT

The optimum port size (which has the minimum total cost) can be determined by computer simulation model. The softwares HARSOL and HARCON which are developed in METU, Civil Engineering Department, Coastal and Harbor Engineering Research Center, determine the port size which gives the minimum total port cost by processing the phenomena such as random arrivals and sizes of the ships, queue discipline and service for loading/unloading which fits to a statistical distribution. HARSOL runs for the general cargo terminal and HARCON runs for container terminal. The optimization models are performed for a case study. The sensitivity of the model is investigated concerning the random number generation.

1. INTRODUCTION

Ports must be planned and developed to provide an optimum port capacity for the increasing volume of trade. The capacity of a port is the amount of cargo that is handled in the port during the operation period, usually taken as a year.

In the capacity computation of a port three principal factors has to be considered; the capability of the port to move cargo into and out of ships, the capability to transfer and store cargo with the port area and the capability to move cargo into and out of the port area (inland transport). The present work however, is confined to the situation at the point of contact between ship and the port. Hence computations are carried out considering only the capability of the port to move cargo into and out of ships.

Capacity of a port depends upon many operational parameters of fluctuating values such as the type of cargo, the randomness of ship arrivals and sizes, queue discipline, the service time distribution, adequacy of cargo handling equipment (cranes). The most economical transfer of cargo between ships and shore can only be achieved by considering all of these principal parameters. The diagram of port parameters are seen in Fig. 1.

In any port, total cost (usually given in annual base) considered consists of the cost of the port which is the cost of quay plus cost of the cargo handling equipment (including the economic life, interest rate, depreciation, maintenance) and the cost of the waiting time of the ships which depends on the insufficient number of berths.

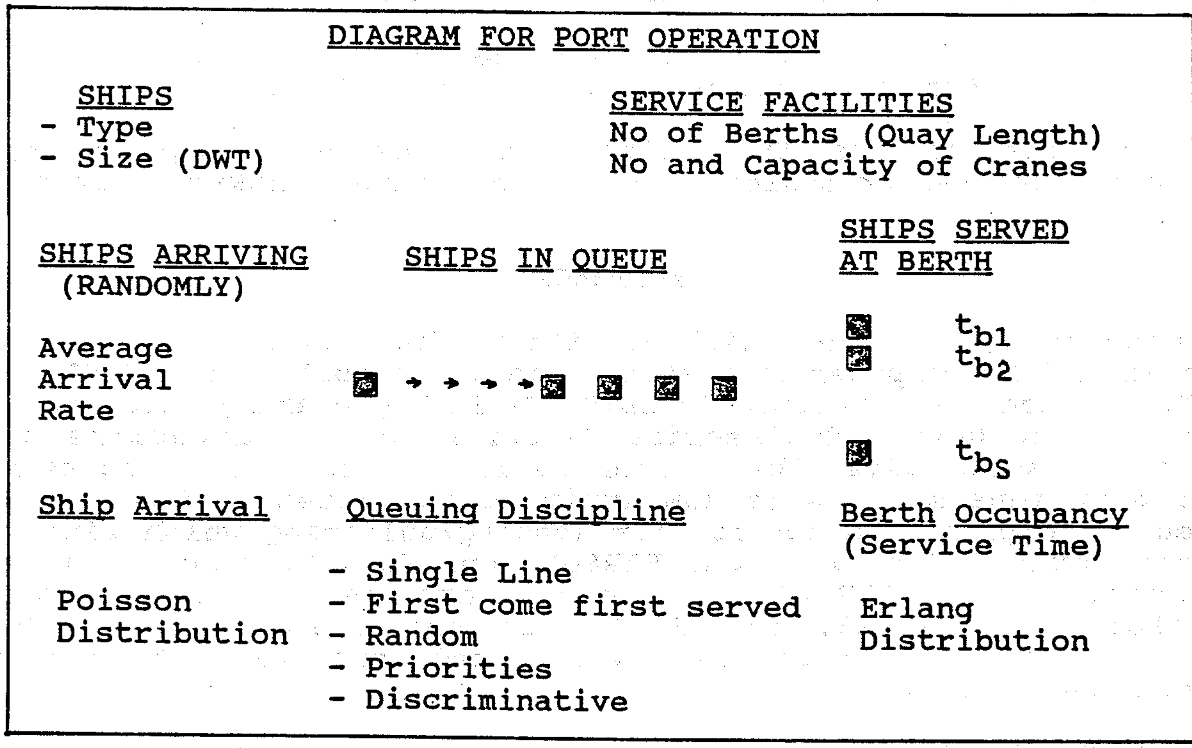

Figure. 1. The diagram of port parameters

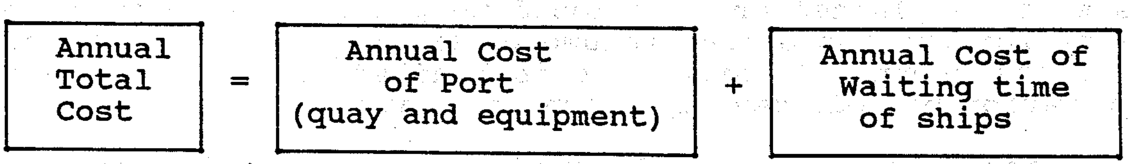

Figure 2. Annual Total Cost Parameters

Between the opposing cost objectives each port must reach a compromise that will provide an optimum port size (optimum quay length and optimum number of cranes used along the quay) which yields the minimum annual total cost hence achieves the most economical transfer of cargo.

2. PORT SIMULATION MODEL

The port simulation model consists of creating an arrival rate of ships, queuing system and a service rate in the form of mathematical statements.

In this study, the numerical simulation softwares HARSOL (Hansen 1976, Ergin and Yalciner 1990, Ergin and Yalciner 1990a). and HARCON written in Fortran Language are utilized (Ergin and Yalciner 1990, Ergin and Yalciner 1990a). They simulate any port with variable number of berths along a given length of quay and number of loading and unloading equipment (Cantekin 1984, Ozkan 1989)

Some basic parameters and events of the simulation programs are as follows.

a) Ship Arrival Distribution
The number of ships arriving in the port is considered to be unlimited, hence it is assumed that arrivals are not affected by the number of ships in the queue system.

Ship arrival distribution conforms the pattern of random occurrences which fit Poisson's distribution (Noritake and Kimura 1983, Ergin, Sendil, Altan 1983, Ergin and Yucel, 1983, Ergin and Cantekin 1988, Hansen 1972).

$$P(n) = \frac{(n)^{\bar{n}} e^{-\bar{n}}}{n!} \quad \text{.................................}(1)$$

in which P(n) is the probability of n vessels arriving in the port and $\bar{n}$ is the average number of vessels arriving in a given time during the port operation period (a year).

b) Berth Occupancy (Service Time Distribution)
Berth occupancy time t_b is the time ships spend at berth whether loading/unloading operation being performed or not. It is the time berths are occupied by ships.

Probability of time spent at berth $S(>t_b)$ is commonly described by Erlang distribution;

$$S(>t_b) = e^{-Kbt_b} \sum_{i=0}^{K-1} (Kbt_b)^i \frac{1}{i!} \quad \text{.......................}(2)$$

where K is the Erlang number (K=1, 2, 3, ...), t_b is the berth occupancy time, b is the average service rate (ship/hr).

c) Arrival Interval Distribution
Assuming the arrival of ships to the port is random and follows "Poisson's law of random occurrences"ship arrival interval is transformed to a negative exponential distribution of arrival interval. The equation is as follows;

$$\Delta t = -A \log(\text{random}) \quad \text{................................}(3)$$

where Δt is the time interval between two successive ship arrivals, A is the actual mean time interval between ship arrivals (arrival rate) and it is taken constant through the simulation. The random number which lies in between 0 and 1 is generated by a subprogram during simulation.

The simulation starts at time t=0, when the first arrival is assumed to have taken place., then the next arrival is found by Eq.3.

d) Distribution of Ship Sizes
The ship size is given by the carrying capacity of the ship which is the Dead Weight Tonnage (DWT). The range of capacities of the expected ships (with minimum DWT, mean DWT and maximum DWT) are given as an input data which are used to obtain the random distribution of ship sizes by a negative exponential distribution function (Hansen 1976, Ergin and Yalciner 1990)

e) Quay Length and Arranging Berthing Sequences
The quay length required for each ship depends on the overall length and the breath of the ship which are obtained by using carrying capacities DWT (Hansen 1976, Ergin, Sendil, Altan 1983).

The programs use a longitudinal continuous quay length. It arranges the quay in such a way that if there is a vacant place along the quay at any time during the simulation the first ship in the queue or the first arriving ship can berth provided that the quay length available is sufficient. A hypothetical case study of berthing and servicing of ships calling at a port is given in schematic way in Fig. 3.

f) Working Hours
Working hours for the days of a week can be given as the input to the program, with changeable daily working hours.

g) Number and Capacity of Cargo Handling Equipment
The total number (M), the capacity (P) and the type of the loading and unloading equipment used along the quay affect the rate of service time hence results the congestion (extending queue length) in the port.

h) Distribution of Cranes
The maximum number of loading and unloading of equipment (cranes) assigned to a ship is the function of ship size and hence limited by the hatch number of the ship.

The cranes available in the port are distributed uniformly to the ships present at the quay. The ship at a berth which has the lowest berth number gets the first crane assigned and having bigger numbers get in turn the following cranes assigned when all ships at the quay have got one crane. The program assigns second, third etc. number of cranes (Fig. 3).

i) Programs HARSOL and HARCON
HARSOL is developed for general cargo terminals whereas HARCON is developed for container terminals. In respective programs the dimensions of the general cargo and container ships are obtained regarding the ship characteristics. HARSOL simulates the distribution of cranes to the general cargo ships depending on the number of hatches. However in HARCON which is developed for a container terminal at most two gantry cranes are assumed to be assigned for each container ship which is more adequate since gantry cranes have larger capacities. The proper values for the costs of quay, cranes and waiting time of ships are also inputted.

3. HYPOTHETICAL CASE STUDY FOR HARSOL AND HARCON

The main inputs of the programs HARSOL and HARCON are the yearly throughput Q (ton/year), initial quay length (m), the minimum, mean and maximum ship sizes (DWT_{min}, DWT_{mean}, DWT_{max}) which are expected to use the port, arrival rate λ (hr/ship), daily working hours (hr), capacity P (ton/hr) and total number of quay

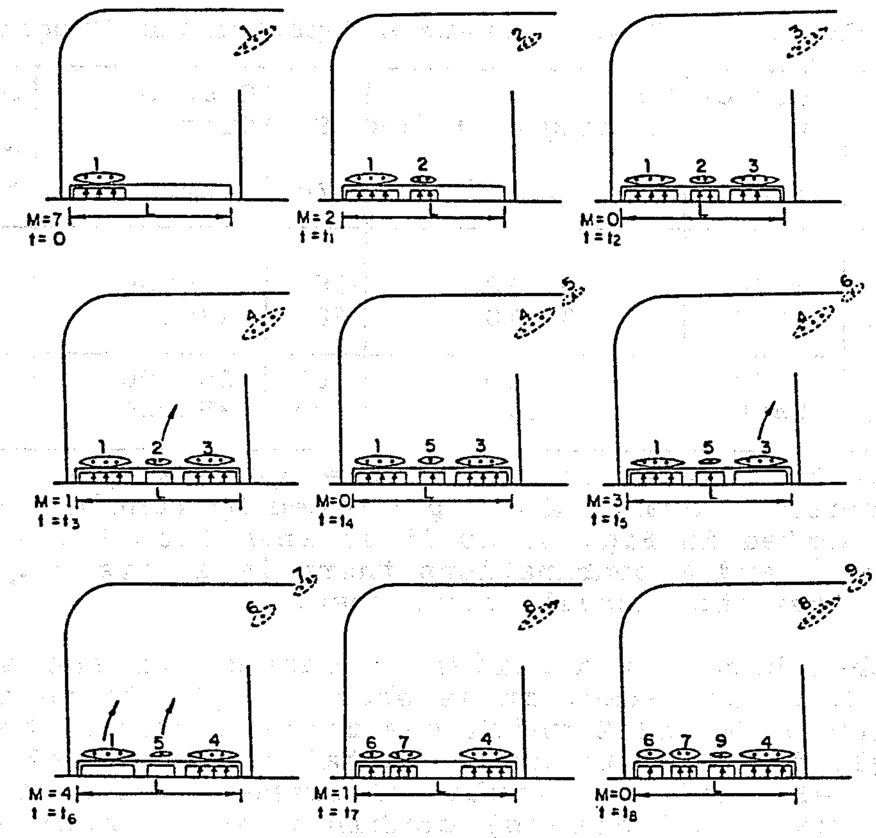

Figure 3. A Hypothetical Case Study of the Operations in a Port

cranes M, yearly cost of quay ($/m), yearly cost of cranes ($/unit), operation cost of cranes ($/unit/hour) and cost of the ship ($/DWT/hr). Daily working hours were chosen as 15 hr/day including weekends. The input data and cost parameters are tabulated in Table 1 and 2 respectively.

Table 1. The Input Data for the Programs HARSOL and HARCON

	Q (t/yr)	DWT min	DWT mean	DWT max	A (hr/shp)	P t/h	M	L_{quay} (m)
General Cargo Terminal	$8x10^6$	14000	20000	30000	15.33	36	15-45	600-1400
	$8x10^6$	14000	20000	30000	15.33	60	10-40	600-1400
Container Terminal	$8x10^6$	14000	20000	30000	15.33	200	4-12	300-1200
	$8x10^6$	14000	20000	30000	15.33	400	2-10	300-1200

The total annual costs due to the different quay lengths, number of cranes for assigned capacities are the main output of the programs. In order to check the reliability of the optimization results, for comparison with the inputted ship characteristics, the variation of the mean ship sizes and arrival rates simulated during process of the programs are also written on the output.

Table 2. The Cost Parameters Inputted the Programs

	Cost of Quay $/m	Cost of Waiting of Ships $/DWT/hr	P t/hr	Cost of Crane $/yr/crane	Operation Cost of Crane $/hr/crane
General Cargo Terminal	1200 1200	0.010 0 010	36 60	85000 120000	3.3 4.1
Container Terminal	2400 2400	0.010 0.010	200 400	200000 350000	4.3 4.5

Results of the investigation on the optimum quay length and optimum number of cranes M are performed by running the program HARSOL presented in Fig. 4. As it is seen from the figure that for a given P and M combinations there is always a quay length which minimizes the annual total cost.

On the other hand, if a series of curves for the same P but different M is compared, it is seen that there is an optimum combination of P and M which the minimum annual total cost. Accordingly the minimum annual total costs are obtained for P=36t/hr, M=30 (optimum number of cranes) and P=60t/hr, M=25 (optimum number of cranes) combinations corresponding to L_{quay}=1000m. and L_{quay}=900m. respectively.

In Fig. 5. the results of HARCON by inputting the data of container terminal (given in Table 1 and 2) is shown. These results show the similar trend as seen in Fig. 4. The minimum annual total costs as obtained for P=200t/hr, M=8 (optimum total number of cranes) and P=400t/hr, M=6 (optimum number of cranes) combinations corresponding to L_{quay}=600m. and L_{quay}=600m. respectively.

In general, Fig. 4 and 5 show that for a given crane capacity, increasing the crane numbers, the service rate increases which decreases the ships waiting cost. However, as it is seen that, there is an optimum number of cranes which minimizes the total annual cost.

Increasing the crane number further only increase the total annual cost, which means that after obtaining the optimum number of cranes the additional ones can not be utilized even if all the berths are occupied, hence the total annual cost increases due to these additional cranes.

Therefore, in the port planning in order to obtain minimum annual total cost, the optimum number of cranes should be utilized.
It is seen from Figs. 4 and 5 that increasing crane capacity results in shorter quay length and less total annual port cost. Therefore, utilizing cranes with higher capacity which results in lower total port cost and a shorter quay length should be a planning objective.

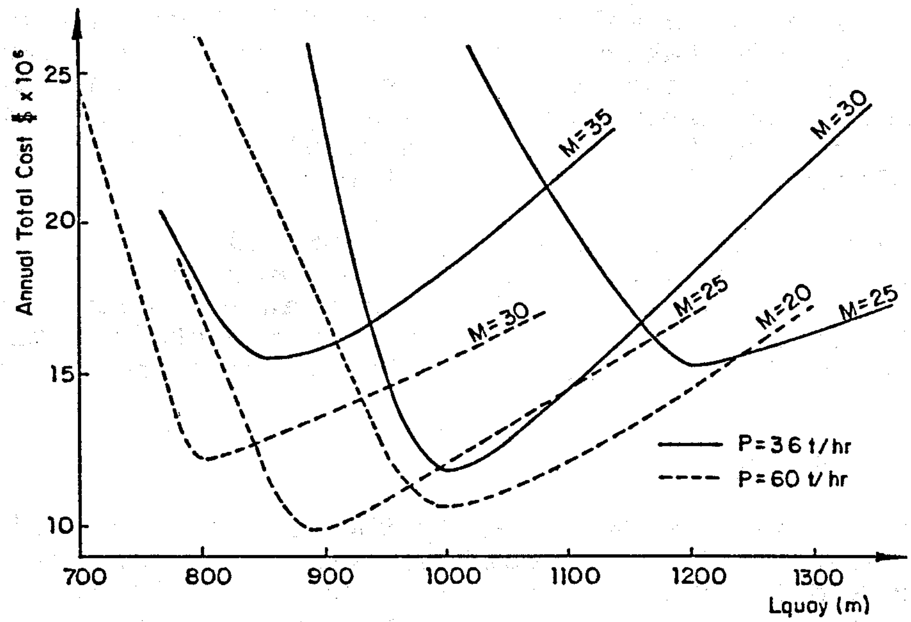

Fig. 4. Variation of Annual Total Cost of a General Cargo Terminal due to the Variation of Quay Length and Total Number of Cranes (DWT_{max}=30000, DWT_{mean}=20000, DWT_{min}=14000, Q=8000000t/yr, A=15.33 hr/ship)

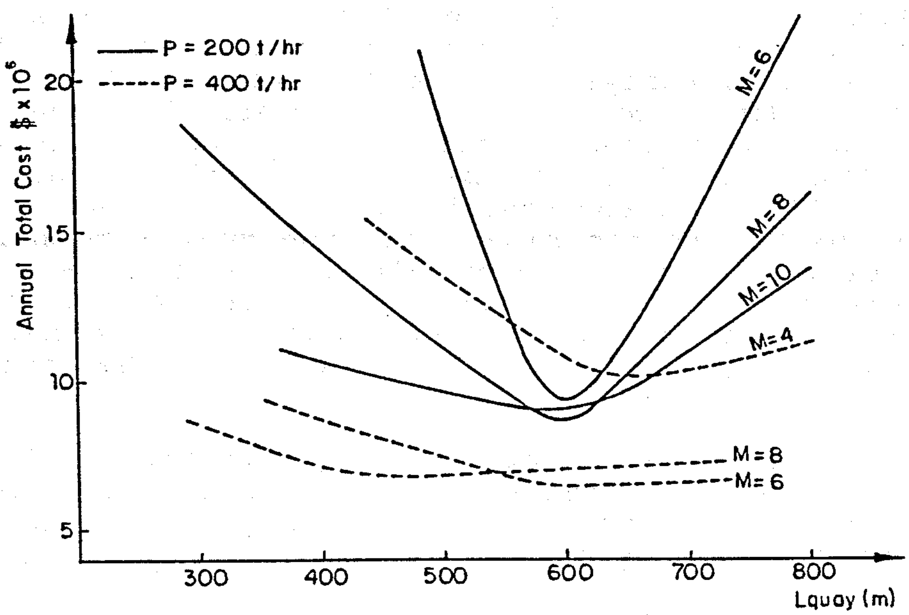

Fig. 5. Variation of Annual Total Cost of a Container Terminal due to the Variation of Quay Length and Total Number of Cranes (DWT_{max}=30000, DWT_{mean}=20000, DWT_{min}=14000, Q=8000000t/yr, A=15.33 hr/ship)

Comparison of the General Cargo Terminal and Container Terminal
In order to compare the general cargo terminal and container terminal the results of simulation presented in Figs. 4 and 5 are replotted in Fig. 6 by taking only those resulted in optimum quay length and the optimum number of cranes. As it is seen from this figure, to handle the same amount of yearly throughput with the same ship size ranges, the container terminal results in the most economical solutions which yield the optimum port size.

In that respect among the alternatives considered a container terminal with crane capacities P=400 t/hr and M=6, results in optimum quay length of 600m. with minimum annual total cost of $\$6.09x10^6$. Hence designing the terminal as a container terminal should be one of the major planning objectives parallel to the trend all over the world.

4. SENSITIVITY ANALYSIS

Since the random number affects mainly the ship size distribution and ship interarrival distribution, set of simulations are performed for 3 different random number sequences to investigate the effect of generation of random number on the optimum size of the port.

Sensitivity analysis concerning the random number generator is performed for HARSOL with P=60 t/hr and quay length ranging between 600 m. and 1400 m. and number of cranes M ranging between 10 and 40 under identical input data.

From 105 different runs for each random number sequence, the curve for the combination of P and M which yields the optimum quay length and the optimum number of cranes is selected and presented in Fig. 7. Analyzing these 3 curves I, II and III, it is found that random number sequence has no effect on the optimum total number of cranes but has slight influence on the optimum port size. From Fig. 7. it is seen that optimum quay length ranges between 850-900m, and annual total cost fluctuates between $\$10.x10^6$-$\$12.5x10^6$. In the final decision quay length has the primary importance and the cost element is only a relative measure among the alternatives. Therefore even though the program is sensitive to random number sequences, the results on the optimum port size can be confidently used for the decision.

5. CONCLUSIONS

A port is an extremely complicated center, even when dealing with the loading/unloading of ships. Many parameters influence the traffic features of the terminal such as ship arrival rate, ship sizes and service capacity of the port.

The simulation model can be performed to analyze the importance of influential parameters on the economic optimum size of a port.

The programs HARSOL and HARCON developed for general cargo and container terminals, performed for a hypothetical case study and the following general conclusions are drawn.

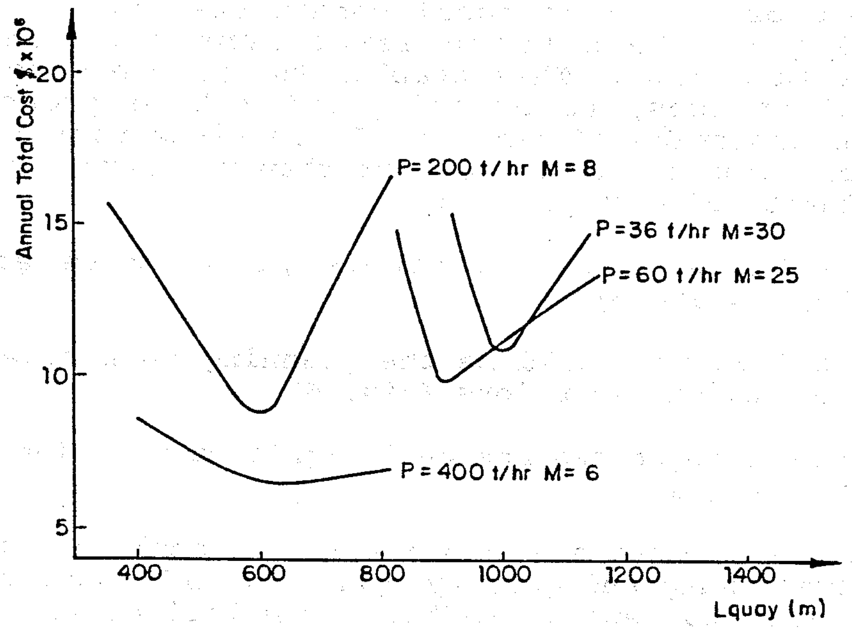

Fig. 6. Comparison of the Annual Total Costs of General Cargo Terminal and Container Terminal due to the Variation of Quay Lengths (DWT_{max}=30000, DWT_{mean}=20000, DWT_{min}=14000, Q=8000000t/yr, A=15.33 hr/ship)

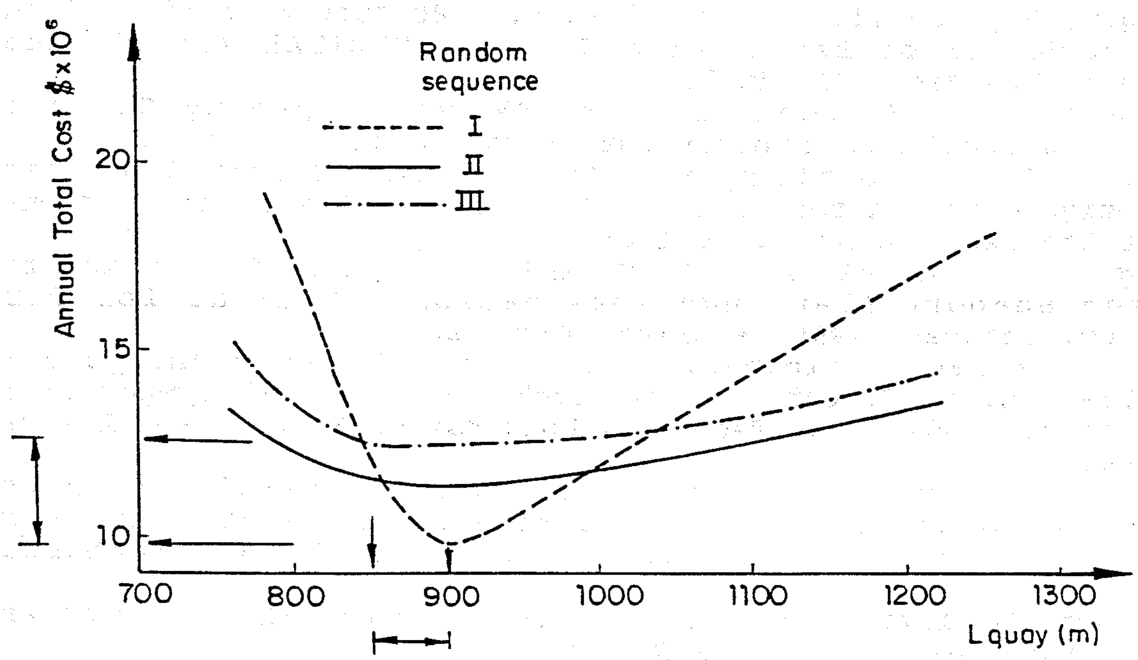

Fig. 7. Comparison of the Results of Three Different Random Number Sequences (P=60 t/hr, M=25, DWT_{max}=30000, DWT_{mean}=20000, DWT_{min}=14000, Q=8000000t/yr, A=15.33 hr/ship)

i. In a port simulation model it is easy to make rapid reproductions of the operational conditions and to vary the influential parameters where large number of repetitive calculations take place. This enables the planners to simulate the proposed changes, to existing and future processes, to evaluate the economies of various alternatives with sufficient advance information and hence prevent them to perform one to one model experiments of port planning.

ii. Usage of higher capacity cranes yields more economical solutions (Figs. 4 and 5).

iii. Containerization should be the planning objective since it gives more economical solutions (Fig. 6).

iv. Random number sequences has an insignificant influence on the optimum port size (Fig. 7)

v. The results presented are confined to the activity of transfer of cargo between ship and quay by operating only quay cranes. In order to be able to generalize these conclusions the remaining activities (such as usage of ship gear, transfer of cargo in and out of port area, storage policies etc.) should be considered in the future studies.

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