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COMPUTER SIMULATION MODEL FOR AN OPTIMUM SEAPORT SIZE

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ABSTRACT

COMPUTER SIMULATION MODEL
FOR AN OPTIMUM SEAPORT SIZE

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The study is concerned creating a simulation model to optimize the design and operation of a port by seeking optimal balance between the cost of ships and the cost of size of a port.

In the computer simulation model, arrival rate of ships, queuing system and service rate are created in the form of mathematical statements.

The simulation model minimizes the total annual cost of the port mainly with the optimal combination of quay length and handling equipment which can vary both in size and number at the same moment.

In the study, the traffic and cargo handling operations in the port are confined to the quay apron, hence the warehousing and transfer activities are not considered.

Based on the simulation model, a case study is carried out for the General Cargo Terminal in İzmir Port.

Keywords: Port Planning, Port Computer Simulation, Optimum Port Size

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ÖZ

OPTİMUM LİMAN BOYUTUNU SAPTAMADA BİLGİSAYAR BENZEŞİM MODELİ

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Bu çalışma, liman planlamasını ve işletmesini gemi maliyetleri ile liman büyüklüğündeki dengeyi optimize eden bir bilgisayar benzetim modelinin yaratılmasını içerir.

Bilgisayar benzetim modelinde, gemilerin geliş aralıkları, kuyruk sistemi ve servis zamanları matematiksel ifadeler olarak yaratılır.

Bilgisayar benzetim modeli optimum rıhtım uzunluğunda gerekli olan kapasite ve sayıları aynı anda değişebilen yükleme ve boşaltma teçhizatı ile toplam yıllık liman fiyatını en aza indirger.

Çalışmada, limandaki yükleme/boşaltma işlemleri rıhtım apronu ile sınırlandırılmıştır, ambarlama ve yükün liman içinde nakledilmesi gibi faaliyetler dikkate alınmamıştır.

Yapılan bilgisayar benzetim modeline dayanılarak, İzmir Limanında Genel Kargo Terminaline yönelik bir uygulama yapılmıştır.

Anahtar sözcükler: Liman Planlaması, Liman Bilgisayar Benzetimi, Optimum Liman Büyüklüğü

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LIST OF SYMBOLS

A	Mean interval between ship arrivals (hr/ship)
ACTM1	Number of hatches of each ship
a	Arrival rate (ships/hour)
B	Service rate (number of ships served per unit time)
DWT	Deadweight or ship size in metric tons
DWT_{max}	Maximum ship size
DWT_{mean}	Mean ship size
DWT_{min}	Minimum ship size
loa	Overall length of the ship from stern to bow in meters
M	Number of quay cranes
$M/E_k/S$	Average number of ships staying in port
N	Number of berths
n	Total number of ships
P_{actual}	Actual mean crane capacity (ton/hr)
P_{gear}	Mean crane capacity of ship's gear (ton/hr)
P_{mean}	Mean crane capacity (ton/hr)
Q	Annual port capacity (yearly throughput) ton/year
q	Queue length (ships)

q_l	Quay length (m)
q_{max}	Maximum queue length during the simulation
T	The time period concerned in the simulation
T_a	Ship turn-around time
T_s	Service time of ship
T_w	Waiting time of ship
t_s	Mean service time
t_w	Mean waiting time
TEU	Twenty feet equivalent unit
β	Actual cargo carrying coefficient of ships
$\varnothing$	Berth utilization ratio or berth occupancy
γ	Ships' gear utilization parameter

CHAPTER I

INTRODUCTION

1.1 General Description

"Is marine transportation important in the world trade?" The answer to such a question will surely be "Yes". Since it is the most economical way of transportation (where applicable) with the huge carrying capacity and cheapness. Hence, marine transportation takes the biggest share in the world trade.

Especially the developing countries need more improvement in terms of port facilities as it is known that the expansion on sea port facilities has an important role on the economic growth of developing countries.

As the port is a vital link in the chain of transport, there should no longer be an obstacle which slows down the flow of cargo through the port due to inadequate service capacity.

In the modern world, the ports should be organized and modernized in such a way that, they should easily meet the increasing port capacity demand of national economy and should cope with the technological changes in shipping.

Türkiye with its 8300 km. of coastline, has many ports and berthing facilities with about 80 ports on four seas including 12 major public ports [1].

Although there have been several port development programmes undertaken in the past, Türkiye as a developing country, needs more improvement supported by the government or by the private sector which has an influential trend towards the development of the sea trade.

Geographically, Türkiye is a natural land-bridge between Europe and the Middle East, so, it has a vital role in linking the sea and the land routes of the eastern and western markets.

The focal points of Türkiye's foreign trade and transit traffic are the ports. Altogether Turkish ports handled 184 million tons of cargo in 1989 [1].

Parallel to the steady growth and diversity in traffic and developments, the ports have to come to a level which can operate with modern management

techniques. The studies and development projects are on the way to improve the existing infrastructure, handling equipment, and to train the manpower at ports.

1.2 Scope of the Study

The main questions which the planners have to seek answers in port planning are :

1) for an existing port facility, what is the optimum capacity and

2) for a given demand what should be the optimum port size in order to minimize the cost at ports.

Since both ships and ports are very expensive it is desired to utilize them as intensive as possible. It is quite difficult to maximize ship utilization without providing excessive port facilities. Also, the waiting of ships in the port longer than some reasonable duration will cost either to the shipowner or to the port, so, a rational solution can be made only by balancing the benefit of both sides.

When the cost of a vacant berth and ships' waiting cost is considered as well as the great dimensions of investment of construction, the determination of the optimum seaport size for the

existing situation and future demand should be made with a complete evaluation of all the cost parameters involved with some methods such as queuing analysis, optimum port capacity and port simulation techniques.

In this study, the port simulation technique is used to make the best combination of quay length and loading/unloading equipment for any given arrival rate and cost combinations.

Ideally, a seaport must be planned so as to ensure that all berths are occupied at all available time and no ships are ever kept waiting for a vacant berth. This is unfortunately impossible in practice because of the randomness of ship arrival times, change of the number of ships arriving at a port in different seasons and months, bad weather conditions, different servicing time, different ship size and probable labor strikes.

The principal factors affecting the size of a seaport are :

a) the availability of berths or the length of quay open to ship traffic,

b) the capacity of the port to move cargo into and out of ships,

c) the capability of the port to move cargo into and out of the port area,

d) the capability of the port to store cargo within the port area.

So, the problem is how to relate these factors in a plan in order to minimize the total cost of shipping through the port.

In this study, simulation programme "SERCG" is developed for container and general cargo terminals to create:

i) an arrival rate of ships

ii) queuing system

iii) a service rate

with usage of variable number and capacity of quay cranes and ship's gear in the form of mathematical statements.

The simulation programme gives the optimum combination of quay length and, size and number of loading/unloading equipment by minimizing the summation of cost parameters.

The cost parameters are namely cost of structure, cost of loading/unloading equipment, cost of operation and cost of ship.

In the development of simulation programme only the capacity of port to move cargo into and out of ships at the quay is taken into consideration.

Finally as an application, a case study on İzmir Port is carried out for general cargo terminal. The optimum capacity of İzmir Port is obtained for the existing and for the future demand.

CHAPTER II

PORTS

2.1 Port and Its Functions

The port is the vital link in the long chain of transportation that binds the producer to the consumer. It marks the service station where adequate and proper infrastructure and equipment are available for the purpose of safe transferring of cargo and passengers between ships and other transportation modes.

The main function of a modern port is to serve as the gateway to an industrialized hinterland, to provide an outlet for its products and an inlet for the raw materials which are needed [2].

To obtain this modern port; the transfer and storage of cargo, marketing and/or processing of cargo, collection of customs, vessel servicing, land traffic service, and other naval operations gain importance [3].

2.2 What Ports are for

Almost every country with a sea coastline has a kind of port system, generally composed of one or more trading ports of different sizes. Today ports are the strong points of the economy of countries possessing a coastline and they constitute the lungs for their foreign trade. Port activities contribute to the economic independence of nations which is vital to their political independence and they perform a strategic role in their trade. There are different purposes of the port for different groups of people [4].

2.2.1 For Port Owners

Although there is currently a tendency towards privatization of entire ports or parts of ports, in most countries the port owner is still the governmental authority whether national, regional or local. Its representative is the port authority or administration. Ports play an essential role not only for a country's foreign trade but for its entire economy and the standard of living of its inhabitants. Ensuring the lowest possible transit cost is a means of reducing the prices paid by the country's consumers.

There are other complementary purposes of ports as well as this basic purpose, such as: contributing to better land use, promoting the development of particular areas or of certain goods traffic, creating employment and earning foreign exchange.

It is worth noting that in medium-sized and small countries (those of which generally have one or only a few ports) the port plays a vital role and it is one of the major elements of the national system of production. Countries such Singapore, Netherlands and Belgium provided examples of port efficiency, dynamism and innovation which are the major concerns of the public authority.

In many developing countries, the purpose of the port should be to play a key role in national development. In some countries, the trade handled by the ports is not always sufficient to make heavy capital investment economically worthwhile. This is sometimes the case in island countries where ports must also play a social role by ensuring communication that will prevent isolation.

To secure the lowest possible port transit cost, the Government may impose further port purposes, by:

a) requiring the port to contribute directly to the financing of the State budget,

b) imposing on the port a policy of over-recruitment of personnel.

In the case of developing countries, where resources are limited and the private sector has not reached maturity, it seems unlikely that the State can rely only on market forces to guide the development of its ports.

2.2.2 For Port Operators

In many ports, the operators (cargo handling and stevedoring firms, etc.) are often private firms which are sometimes wholly or partly publicly owned. For all these operators, the main purpose is generally that of covering their costs and making a profit.

The operators seek to make a reasonable profit that is justified by the improved services they offer to the traffic, by attractive pricing, by increasing their production through more active promotion and offering a better quality, price ratio or by reducing their operating costs by such measures as improving their organization, management and productivity, by personnel

training, by wise investment, by using efficient methods and by introducing new technologies.

Consequently, all the industrial and commercial activities necessary for, or induced by, the transiting of traffic through a port are linked by the behavior of each of the parties involved, as they influence the port's competitivity.

In addition to traditional activities, the most efficient ports also have such operations as warehousing, packaging and even processing of products which adds considerably to product value.

2.2.3 For Port Users

There are direct and indirect users of port, intermediate users, and there are final users who really pay the port services: the country's producers and consumers. What they seek from the ports is service of the best possible quality at the lowest possible cost. The port that is expensive for the users is not necessarily the port with the highest tariffs, it is rather always the port where the services are poor because of delays, inefficiency and damage.

2.3 Importance of Ports

There is the general idea that a ship is earning money only when she is at sea.

The fact that ships are doing now, that is; spending more time in port and less at sea each year, is really deplorable. To recover this loss of efficiency, optimization of ports are inescapable [2].

By optimizing the ports, the speed, at which ships are turned round in the ports, will increase. Therefore;

a) the transportation costs of import and export commodities will decrease,

b) cost of living of a maritime country will decrease,

c) international and regional trade will develop and expand with the progress of industrialization,

d) and probably the most important result will be; with an increasing volume of trade the political and economical independence of a nation will be established.

2.4 Some Port Parameters

In a port the efficiency and the adequacy of the operations are assessed by evaluating the values of several parameters. Some of these parameters and their definitions which in the sense they are used in this study are as follows:

a) Annual port or terminal capacity (Q): The amount of cargo (throughput) that a port or part of it dedicated for loading and unloading of one type of cargo namely a terminal, is capable of manipulating in a year under optimum conditions.

b) Berth (N): Section of quay (pier, wharf or jetty) notionally designed to accommodate one vessel and including a section of the surface over which labor, equipment, and cargo move to and from the vessel. By transference, in shipowner's language, service to a port [5].

c) Ship size or deadweight (DWT): The weight of the load that a vessel carries. It is given in metric tons.

- Actual cargo carrying capacity of the ship : β * DWT (where actual cargo carrying coefficient β ranges between 0.70-0.85).

d) Queue length (q): A queue refers the ships waiting for service due to slow service rate and insufficient number of berths or quay length. The queue is characterized by its maximum permissible size, which may be finite or infinite.

- Maximum queue length (q_{max}): Maximum number of ships in queue.

e) Total number of ships (n): The number of ships arrived or being serviced in the port facility in total, within the period concerned (T) which is generally taken as one year.

f) Arrival rate (a): The average number of ships arriving at the port per unit time i.e. each day or hour.

$$a = n / T$$

- The mean interval between ship arrivals (A):

$$A = 1 / a$$

g) Waiting time (T_w): The time ships waiting for a vacant berth that is the time from the moment of ship arrival in the port to the moment when the ship berths.

- The mean waiting time (t_w) for all ships during period of stay is;

$$t_w = \frac{\sum_{i}^{n} (T_w \ DWT)}{(\sum_{i}^{n} DWT)\ n}$$

h) Service time (T_s): The time ships spend at berth whether loading/unloading operation being performed or not. The time berths are occupied by ships.

- t_s is the mean service time which can be expressed as;

$$t_s = \frac{\sum_{i}^{n} (T_s \ DWT)}{(\sum_{i}^{n} DWT)\ n}$$

- Service rate (b): $b = 1 / t_s$

i) Berth utilization (ø) or berth occupancy ratio: The ratio of time for which N berths of a port are occupied to the total number of berth time in period T.

$$ø = \frac{a}{b\ N} = \frac{n\ t_s}{T\ N}$$

j) Ship turn-around time (T_a): Total time that a ship spent in port from its arrival to its departure (waiting time + service time).

$$T_a = T_w + T_s$$

2.5 Port Planning and Development

Ports must be planned and developed to provide an optimum port capacity for the increasing volume of trade.

In the capacity studies of a port, ship arrival and berth occupancy distributions are the two basic necessary elements. When a historical survey is made in port planning, it may be noticed that the sequence of arrival of vessels are often described as a Poisson function and the service time distributions as one of the K-level of Erlang distribution (1),(2),(3),(4).

In the design of a port for an estimated yearly throughput (yearly amount of cargo Q:ton/year), the planning target is to determine the quay length and the capacity of cargo handling equipment which yield the optimum port capacity by minimizing the total cost of the port.

The ideal solution is achieved when all the berths are occupied and no ship is kept waiting. In practice, however, the number of ships in the port, exceeds the available number of berths, so; queuing of ships occur [6].

In any port, main cost elements are the cost of structure, cost of loading/unloading equipment, cost of

operation and cost of ships present in the port.

In order to make a sound evaluation of the optimum capacity of a port, all the cost elements appearing in the port activities have to be considered.

Cost of structure, cost of loading/unloading equipment which also covers the cost of operation can be named as cost of port. On the other hand, cost of ship is taken as the cost of ship turn-around time which is the summation of cost of waiting and cost of service time of ships.

In any port, total cost which can be considered on annual base is equal to annual cost of port plus annual cost of ships. The annual cost curves are shown in Figure 2.1.

As it is seen from Figure 2.1, for increasing quay length, annual cost of port (curve A) increases and annual cost of ships (curve B) decreases due to the fact that ship turn-around time decreases.

The annual total cost curve is drawn with the superposing of these two curves (A+B). And the minimum annual total cost and thus the optimum quay length is obtained where the slope is zero.

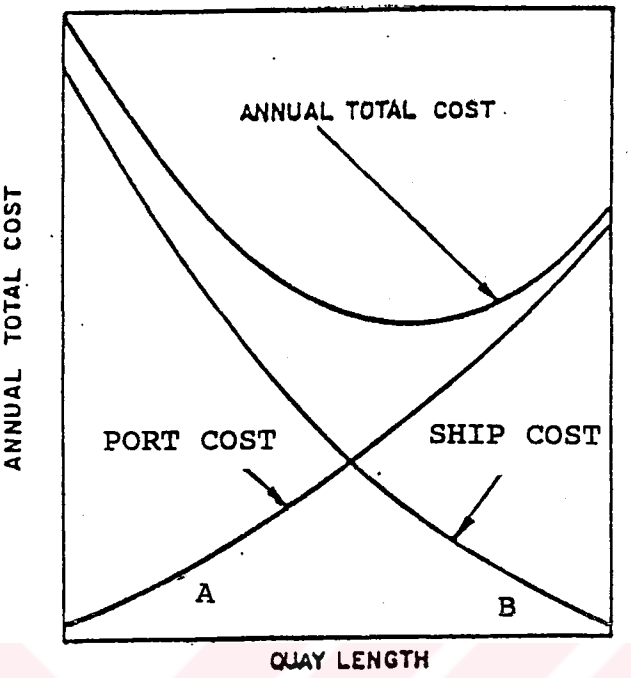

Figure 2.1 Annual Total Cost of a Hypothetical Port Situation

In port planning, the optimum quay length (equipped with optimum loading/unloading equipment) which leads to the minimum annual total cost will bring the most economical transfer of cargo.

But if, an existing port is to be developed, there are several ways: The improvement might be done by increasing the quay length and/or increasing the number and capacity of loading/unloading equipment [7].

CHAPTER III

HANDLING EQUIPMENT REQUIREMENTS OF PORTS

3.1 General

Since 1960's the shipping industry and cargo handling methods have experienced technological changes. Together with the introduction of ships carrying unitized cargo such as roll on/roll off vessels, container ships etc., the ports in the developed countries reacted immediately by providing the necessary facilities for handling unitized cargo [8].

The aim of having reduced ships turn-around time in ports and minimized cargo handling costs led to the appearance of the new concepts, namely, unitization of general cargo.

Cargo unitization term refers to various methods where a number of small items of cargo (general cargo) can be handled as a unit of standard size with the use of mechanical equipment; or where large items, difficult to handle can be packed as standard-sized units.

Among the methods of cargo unitization, containerization has attracted the biggest attention.

The equipment allocated for the transfer of cargo to and from the quay side is often insufficient to permit the transfer operation to keep up with the hoisting of loads in or out of the ship's hold. Careful equipping and planning of the transfer operation will thus often be the most effective single method of raising ship-handling productivity.

It is difficult to give clear economic justification for any specific level of equipment for the quay side operation, as can be done for the provision of berths and sheds; the estimate of equipment needs must be based on experience of the type of operation proposed. When the equipment needs have been estimated they must be included, together with the estimates for reserve equipment, spare parts and maintenance services as an integral part of the investment proposal. No attempt should be made to economize in this area, since without proper equipment the economic and financial success of the whole investment will be jeopardized.

In recent years the quantity of mechanical handling equipment needed per berth has increased owing to the greater variety of cargo classes, including a higher proportion of unitized cargo [9].

3.2 Quay Cranes versus Ships' Gear

A port is defined as a shore-based installation for the quick dispatch of cargo from land to sea and vice versa. There are two accepted methods by which general cargo can be so transferred: There is the ships' gear which is part of the ship and accompanies her from port to port. There are also quay cranes that normally belong to and are maintained by the port authority. So long as ships sail the seas, the controversy between using ships' gear or quay cranes for general cargo will continue [2].

With the exception of those ports where there is a large tidal range, the use of quay cranes usually offer little handling advantage over the use of ships' gear while entailing heavy expenditure and maintenance problems to port authority.

From time to time the obvious truth that turn-around would be quicker with shore cranes is pointed out. It is equally apparent that to equip the quays, many of which would need strengthening with modern quay cranes would be most costly business.

The strengthening of the quay edge necessary for quay cranes, and the installation of the requisite crane track and electrical equipment involve further heavy expenses which should be avoided where possible. At

least, an optimum case can be provided.

3.3 Ships' Gear

The most important means of loading and discharging ships is by their own gear. Ships' gear is given this pride of place for the following reasons;

a) it makes the loading and discharging of ships possible in ports where there are no quay cranes,

b) it provides the only practical means of discharging or loading ordinary general cargo over-side when ships are not able to come alongside berths,

c) it renders the ship, for cargo working purposes, independent of power failures on shore,

d) it is often superior in lifting capacity to the average quay crane, and last, but not least important,

e) it has to be carried by the ship wherever she goes and should be used, therefore, as often as is economically possible, to compensate the ship owners for,

i) the loss of freight space taken up by the ship's gear,

ii) the interest on the capital cost providing it and,

iii) the maintenance costs.

3.4 Quay Cranes

Quay cranes are provided for the purpose of loading and discharging ships in most modern ports in the world. The value of modern quay cranes may be summed up as follows:

a) They are independent of inboard power failures.

b) They may be used for loading/unloading land and water conveyances when there is no ship at the berth.

c) Their great outreach, luffing and travelling motions permit them to plumb many points with great accuracy both inboard and outboard, thus facilitating work in the hold and assisting to reduce congestion ashore.

d) The choice of pathways afforded to their sets by the slewing and luffing movements.

e) Each purchase requires only one driver.

3.5 Whether to Use Ships' Gear or Quay Cranes

The advantages claimed for the quay cranes are firstly, that, output can be as much as 70 per cent higher than when ship's gear is used. This is one of those statements that experienced port operators know to be true in some conditions only. It may well be as difficult to produce these favorable conditions as it is to say with certainty that they will obtain for specific berths [2].

But it is the flexibility of the quay crane that is its daily recommendation.

When no sorting to marks or sizes is required then the simple rhythm of the union purchase or the swinging derrick gives excellent results. Under favorable conditions it is true that, simpler the equipment greater the output.

The controversy over quay cranes and ships' gear is one more example that no general statement on port

operating will find complete and universal acceptance. Each side is sure that it is right and will stake its economy and its future prospects on its convictions [2].

Most general cargo handling between ship and apron is accomplished by quay cranes. In many cases, the use of ship's handling gear would provide additional productivity. Most container cargo handling, on the other hand, is accomplished by special quay cranes (container gantry cranes) of higher capacity.

3.6 Combination of Ships' Gear and Quay Cranes

Sometimes a combination of ships' gear and quay cranes is used, thinking that it is quicker and productive but, it must be noted that; in this case, two drivers (one for the ship gear and one for the quay crane) will be needed and therefore the increased cost of manpower will be added to the total cost which will be far from the optimum total cost. But where there are clear pathways for the sets and the hatches are not too small, it is usual to work as two separate gangs when both cranes and ships' gear have to be used [10].

3.7 In Terms of Overall Cost

Ships' gear and quay cranes should not be taken as competitive but as complementary. In deciding whether to use ships' gear or quay cranes or both, each case must be considered on its merits in terms of efficiency of cargo handling, ships' turn-around and overall cost [11].

In considering cost it must be borne in mind that both ships' gear and quay cranes represent a heavy capital charge and although the direct cost is borne, in one case by the shipowner and in the other, usually by the port, undertaking the aggregate cost, both is ultimately included in the total cost of transport from the producer to consumer.

CHAPTER IV

LITERATURE SURVEY

The determination of the optimum seaport size can be evaluated by the analytical methods (queuing analysis) or by the computational methods (simulation techniques). In this study, the port simulation technique is used to obtain the best combination of quay length and loading/unloading equipment for any given arrival rate and terminal capacity.

4.1 Past Studies on Port Planning

Fratar, Goodman and Brant (1961) have studied the data on berth occupancy at general cargo terminals and the data on the arrival and departures of general cargo vessels during a six months period. When a detailed statistical analysis was made, it is found that Poisson Law meets the conditions of asymmetry and flatness imposed by the observed berth occupancy patterns and the theoretical functions had the highest level of agreement with the observed data [12].

Plumlee (1966) has worked out on the ship distribution pattern which was important for the logical solution of the port size problem. The actual pattern of ship distribution have been compared with the theoretical distribution predicted mathematically by the Poisson Distribution of Random Occurrences. He also studied on the optimum number of berths. He found the optimum size of a port with a number of berths where the total cost of vacant berths and waiting ships are minimum. He also examined the optimum berth usage for different cost combinations and berth numbers [13].

Jones and Blunden (1968), as a result of their analysis, decided that the ship arrivals were bestly described by an exponential function and service time was described as an Erlangian function having K=3 level [14].

Miller (1971) concluded that ships arrive at random. That is, the probability of a ship arriving in any interval of time is a constant irrespective of when other ships have arrived or of how many are in the queue. And times taken to service ships, that is, to berth, unload or load, and deberth, vary from ship to ship, but are independent of each other and of the number of ships waiting [15].

Noritake, and Kimura (1983) have worked on approximate solution of $M/E_k/S$ systems and compared the results of Cosmetatos and Lee-Langton approaches,

reaching a conclusion that Cosmetatos approach is more satisfactory especially for heavy traffic case. Then the optimum number of berths in wharf are found by the use of the average number of ships waiting for berths. They studied berth capacity considering available information on traffic intensity [16].

4.2 Past Studies on Simulation Models

Oymak (1971), studied the economical design criteria on the optimization process by the computer simulation programme. He considered the cost elements for the transfer of cargo and the construction of apron parts of the port. He used the data of Mersin and İskenderun Harbors. He carried out applications on the optimum harbor planning on Mersin and İskenderun [17].

United Nations Conference on Trade and Development (UNCTAD) developed a computer simulation model to analyze the general cargo operations of the two case study ports. According to UNCTAD, since the activities simulated including planning of work and use of facilities which vary from port to port, the model could not be applied to any other port without extension of the logic to incorporate the special characteristics of that port (Morse, P.M. 1958,UNCTAD, TD/B/C.4/109 and Add. 1, 1973).

The World Bank (1974) developed a simulation model called Port Simulation Model (PORTSIM) which can represent the operations of any port configuration [18].

J. Buhr Hansen (1976) developed two computer simulation models to investigate economic optimum size of a seaport, one model for variable number of berths (HARSOL) and the other for a fixed number of berths. He simulated the cargo movement between the ship and the quay apron. He also analyzed the influence of some parameters on the economic optimum size of a harbor [19].

Şendil and Altan (1976) used a computer simulation programme which calculates the ship transit times, waiting times of ships, the utilization ratio of the berths and the average number of the berthing places. The total cost of the port with different queuing priority policies can also be determined by the simulation programme [20].

Kozan (1977) developed and utilized a simulation programme using queuing theory approach which simulates the port activities and calculates the necessary parameters for the evaluation of congestion. Kozan also determined the necessary investments for the port of İstanbul for the year 2000 [21].

Cantekin (1984) studied the queuing theory approach for the evaluation of congestion in ports, and

determination of optimum capacity and required number of berths under given traffic loads [8]. The optimum port requirements for Mersin port in 1993 was further analyzed by means of the computer simulation model (HARSOL).

Özkan (1989) used a computer simulation model (HARSOL) to optimize the design and operation of a port by looking for an optimal balance between the cost of ships waiting and the cost of size of a port. The simulation model is performed to analyze the importance of certain port parameters on the economic optimum size of any harbor [7].

Ergin and Yalçıner (1992) demonstrated a port simulation software (HARSOL) by analyzing the influential parameters on the economic optimum port size at the planning stage [6].

In this thesis study, the port simulation software is rewritten with some basic differences compared to HARSOL, and named as SERCG. The software SERCG;

- simulates both the container and the general cargo terminals,

- uses variable crane capacities at the terminal,

- simulates the arrival, waiting and service time of the ships on the same time scale.

CHAPTER V

SIMULATION MODEL

5.1 General Description

Simulation is a branch of modern management science and is a technique for modelling a complex process which would otherwise defy mathematical description, because of the stochastic behavior and non-linear characteristics of the process [22].

In simulation, the system is broken down into a number of subsystems that are fairly easy to describe mathematically. These parts are then combined to give a model of the whole system, and their responses to various inputs can be measured. The parameters of the model can be varied, which enables the user to simulate proposed changes to existing or future processes and hence evaluate the economics of various alternatives without costly capital investment.

Because of the large number of repetitive calculations and the volume of data involved in a simulation model, many models are run on a computer.

A port system can also be adopted to a simulation model by some parameters involved in the phenomena. It is easy to make rapid reproductions of the newly operational conditions, and in the case of very large number of repetitive calculations.

5.2 Harbor Simulation

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

By the help of the simulation model the optimum port size which gives the minimum total cost is found.

The minimum total cost depends on the size of the various cost elements. With respect to the port costs, they are made up of two parts:

a) A fixed component which is independent of the tonnage throughput (the capital cost),

b) A variable component which depends on tonnage throughput (operational costs).

In addition, there is the cost of ship's time (ship turn-around time) in port which is also made of two

parts:

i) The time the ship spends at the berth,

ii) The time the ship spends waiting for a berth to become vacant.

It is obvious that, the best service that can be given appears when there is no waiting time for ships calling to the port at any time. However, owing the fact that the ship arrivals and ship service time are random, to provide such a level of service in the port is somehow impossible unless the port offers extensive and very costly facilities to its users.

5.3 Simulation Programme

In this study, a numerical simulation programme is developed. It simulates general cargo and container terminals with a variable number of berths along a given length of quay and with characteristics of loading and unloading equipment.

The programme only deals with loading/unloading operations assuming the other operations in the port do not affect the port capacity. In the simulation, also the quay length is assumed to be continuous and the ships, which are once at the queue, never leave the queue before

the loading/unloading completed.

The simulation programme computes four different combinations of costs due to for different unit prices :

1) Yearly cost of quay per meter,

2) Yearly cost of cranes per unit,

3) Operation of cranes and ships' gear per unit hour,

4) Cost of the ship per DWT per hour which includes both waiting time and service time.

Actual computations performed by the main programme are ;

a) Determination of the time step,

b) Determination of ship arrivals, size of ship and length of quay required by the ship.

The functions of the 14 subroutines are briefly as follows ;

RANDOM is a random number generator subprogramme. This subprogramme works for the Microsoft FORTRAN 5.1 Compiler.

WORK determines whether loading and unloading has to be performed in the next time step or not.

CRANE performs the distribution of the available cranes to the ships present according to their DWT tonnages and finds the total handling capacity applied to each ship in the harbor.

DISCHA(rge) performs the actual loading and unloading of the ships and determines when each ship will be ready to leave the harbor in case of continuous working.

SQUEUE keeps a record of the ships in queue and rearranges the queue when a ship from the queue is brought to the quay.

SQUAY places the ships at the quay by the lowest possible berth number and determines the amount of cargo to be transferred to/from the ship, the number of hatches and the remaining length of idle quay.

DISTRI(butions) determines as discrete distributions of twenty classes the distributions of

1) Ship sizes,

2) Arrival intervals,

3) Service time,

4) Waiting time,

5) Extended service time.

LEAVE determines the results of the handling of each ship ready to leave the harbor and calculates the mean values obtained in the simulation and, the mean values are printed out for assigned number of ships treated.

TEXTPR(int) causes the text out-print at the beginning of each simulation and a number of results at the end of the simulation.

COSTP(rogram) performs the economic combinations.

ZERO is a defining subroutine which assigns the right initial values to all variables not defined through the input data and computes some basic values used later in the simulation.

OPTIMU(m) determines a new quay length and/or a new number of cranes to be the input data to the next simulation based on the results of the previous simulation.

CRATYP determines type of crane which has to serve to ships according to their sizes at the quay.

CRANNO calculates the number of each type of crane from the total number of cranes in the terminal.

Some basic parameters and events of the simulation programme will be introduced in the following sections.

The list of symbols and the simulation programme with a flow chart are given in Appendix A and in Appendix B respectively.

5.4 Principles of Simulation

The procedure of the simulation may shortly be summarized as follows :

1) The simulation starts of time T=0 where the first arrival is assumed to take place.

2) The time of the next arrival which is also the time step in the simulation is found - the arrivals are assumed to follow the Poisson Law of Random Occurences which is transformed to a negative exponential distribution of arrival intervals [19]:

$$DELTAT = - A * ALOG (RANDOM) \qquad (5.1)$$

3) It is checked whether there are ships waiting in queue. If not, the newly arrived ship is - if possible - placed at the quay, if not, in queue behind the last one. If there are already ships in queue, it is placed behind the last one.

4) The cranes available in the harbor are distributed uniformly to the ships present. A maximum number of cranes may be assigned to each ship depending upon the size and the type of the ship.

5) Loading/unloading takes place through the next step.

6) If a ship after that is full or empty, it leaves the harbor and all the data of simulated ship is stored in the results.

7) If any ship leaves the quay, the programme searches for a ship from the queue to be placed at quay within the time step of the simulation. First is first served queue discipline is applied. But this rule may be abolished if, at the quay there is place for a small ship waiting in line after bigger ships, for which the available free quay length is insufficient.

8) The programme returns to step 2 and finds out when the next event, i.e. new arrival or departure, will take place. This determines the next time step in the

computation.

9) The programme calculates and prints the cost combinations if all the ships are ran or the queue is full.

Other aspects of the computer programme can be summarized as follows:

a) The ship size distribution is assumed to be a truncated negative exponential distribution [19].

$$DWT_{actual} = DWT_{min} - ADDWT * ALOG\ (RANDOM) \qquad (5.2)$$

Where ADDWT is a constant and it is found by iteration of minimum, mean and maximum DWT of ship sizes.

b) The number of hatches (ACTM1) is assumed to be given by;

$$ACTM1 = 3.7 + 0.05 * (SQRT(DWT) - 60) \qquad (5.3)$$

with a lower limit 3 and the upper limit 8 where the tonnage of the ship is greater than 25000 DWT [19].

c) The number of cranes that can work on each ship is limited to number of hatches. Only one crane or ship's own gear is assigned for each hatch of the ship. The distribution of cranes is performed as follows:

i) The ship at the berth having the lowest number gets the first crane assigned.

ii) The ships at the berths having bigger numbers gets the following cranes assigned in turn.

iii) When all ships have got one crane assigned, the program returns to (i) and (ii) and assigns second, third, etc.

iv) The distribution of cranes stops when all cranes are put into work or when all ships have got ACTM1 cranes assigned.

d) If the number of cranes assigned to a ship is lower than ACTM1, additional loading/unloading is supposed to take place by the ship's own gear until the time when each hatch of the ship has got one loading/unloading equipment whether a shore crane or a ship's own gear which has a handling capacity of P_{gear} ($P_{gear} = P_{mean} * \gamma$) where γ is constant throughout the simulation. If no loading/unloading is taking place with the ship's own gear, use $\gamma = 0$ in the input data. Even if γ is not equal to 0, the ships having their own gear is also random. The capacity of ship's gear is assumed to be 60 or 70 % of the mean capacity of shore crane.

e) The actual crane capacity is found through the equation [19];

$$P_{actual} = P_{mean} + 2.40 * P_{mean} * (RANDOM-0.5)^3 \qquad (5.4)$$

The mean capacity of the cranes must be given as an input which is usually taken as 70 or 80 % of the crane capacities.

P_{actual} has a value near P_{mean} but it changes randomly, because, in a harbor, the loading and unloading equipment cannot work with full capacity at all times.

f) The amount of cargo transferred by each ship is assumed to be equal to β * DWT of the ship, where β is constant throughout the simulation and in general, it is usually taken as 70 or 85 % of DWT which is the weight of the load (in metric tons) that a vessel carries.

g) Working hours for the days of the weeks can be given as input to the programme:

- Monday to Friday HOUR1 of work is performed,
- Saturday HOUR2 of work is performed,
- Sunday HOUR3 of work is performed.

h) The length/DWT relationship for ships is found to be;

$$loa = -3.68 * 10^{-3} * DWT + 1.26 * SQRT(DWT) - 0.65 * (DWT^{0.33}) + 6.95 * (DWT^{0.25}) \quad (5.5)$$

and the quay length required by the ship is taken as 1.15 * loa, where loa is the overall length of the ship from stern to bow [19].

5.5 Usage of Quay Crane in the Simulation Programme

The simulation programme only deals with the loading/unloading among the ship and the quay. The handling equipment are shore cranes for the general cargo terminals and container gantry cranes for the container terminals where mobile cranes are used for both.

In harbors, there are many handling equipment with different capacities. The characteristics of the handling equipment utilized in some of the Turkish Ports are given in Appendix C.

Since the number and capacities of handling equipment varies within a harbor, the programme is developed to employ three different crane capacities. In order to minimize the mean waiting time and the mean service time hence the annual total cost; during

simulation, the programme assigns larger capacity quay cranes to greater size ships by controlling the size of the ship at berth waiting for service and the capacity of the available quay cranes.

If the number of the quay cranes suitable for the ship waiting at berth is not available, the cranes starting from one size smaller capacity are assigned for the ship.

A hypothetical case study showing the replacement and servicing of ships calling at a port is given in Appendix D.

5.6 Usage of Ship's Gear in the Simulation Programme

If the number of cranes are not sufficient for the number of ships present at quay, the use of ship's gear, if exists, will be the second alternative. In case of insufficiency of cranes, the programme generates a random number to determine whether the ship's gear exists or not with a 10 % of occurrence probability, and this may be changed in the programme easily to adopt the statistical data on ship's gear.

If ship's gear is in use, for each hatch of the ship, the loading/unloading equipment which are ships' own gear and quay cranes will be organized as one to one

correspondence.

The programme also determines the capacity of ships' own gears according to the size of the ship as in the case of quay cranes.

5.7 The Main Input Data of the Simulation Programme

The main input data used for the simulation programme is summarized below.

1) The yearly throughput (Q) ton/year.

2) The maximum DWT_{max}, mean DWT_{mean} and minimum DWT_{min}(in metric tons) ship sizes which are frequently calling the harbor.

3) The number of berths (N) and the number of different crane capacities employed at quay which are at most 3 in the programme.

4) The working hours: the number of working hours in a day during the week.

5) The actual cargo carrying capacity coefficient of ships (β).

6) The ships' gear utilization parameter (γ).

7) The maximum number of allowable ships at queue.

8) 5 or more digit integer random number.

9) The mean capacity of cranes, working at quay which are at most 3 in the programme, can be assigned as; P(1), P(2), and P(3) ton/hr.

10) The annual cost of quay per unit length is Cost(1) $/year/m and hourly cost of ships per DWT is Cost(8) $/hr/DWT.

11) The annual cost of cranes can be assigned as; Cost(2), Cost(3), and Cost(4) $/year/crane for the respective crane capacities.

12) The operational cost of cranes per hour can be assigned as; Cost(5), Cost(6), and Cost(7) $/hr for the respective crane capacities.

13) The operational cost of ships' gear per hour can be assigned as; Cost(9), Cost(10), and Cost(11) $/hr for the respective gear capacities.

14) The number of quay cranes (M) is assigned within a range with given increment.

As an initial input, number of cranes can be estimated as number of hatches of the mean ship size

times the average number of berths.

15) The quay length (q_l) is assigned within a range with given increment.

16) The ratios of numbers of respective crane capacities to the total number of cranes (M).

17) Ship size limits versus crane capacities which can work on ships.

5.8 The Main Output of the Simulation Programme

At the end of the simulation, the following port parameters are obtained as the main output of the programme.

1) The simulated mean ship size DWT_{mean}, mean service time t_s and mean waiting time t_w of ships.

2) Berth occupancy ratio (ø).

3) The maximum number of ships in the queue (q_{max}) during the simulation.

4) The annual total cost (annual cost of port + annual cost of ships).

CHAPTER VI

APPLICATION OF COMPUTER SIMULATION MODEL FOR THE GENERAL CARGO TERMINAL IN İZMİR PORT

In optimizing port capacities through computer simulation model, several parameters are involved in the phenomena which influences the optimization results. By using different values for the input parameters of the simulation the user can simulate proposed changes to existing or future processes, hence can evaluate the economies of various alternatives.

As a case study, the simulation programme presented in CHAPTER V is applied to the general cargo terminal in İzmir Port by using the computer programme "SERCG".

6.1 İzmir Port

İzmir port is situated in the coast by the Aegean Sea. It is the main port for the Aegean region's industrial and agriculture and it plays a vital function

in the country's exports. Service is provided to vessels 24 hours everyday, 362 days per year with a relation of three shifts.

At present İzmir Port is the 3rd biggest port of Türkiye. It has got the capacity of 3200000 tons/year and 2040 ships/year. Storage area consists of 133557 sq.m. open, and 23600 sq.m. covered. The container mole covers an area of 225000 sq.m. Holding capacity of container yard is 6500 TEU [1].

In future, it is planned to increase the capacity of the port from 3200000 tons/year to 10000000 tons/year and ship receipt from 2080 ship/year to 4080 ship/year by increasing the length of the berths from 3000m to 6000m. And container holding capacity will increase from 6500 TEU to 11000 TEU, when all the paving works at the container storage yard are completed.

In Figure 6.1 the plan of İzmir Port is shown and the information such as berth numbers, types, depths and the lengths of the all berths are shown in Table 6.1 [1].

The existing handling equipment used in İzmir Port, is also given in Table 6.2.

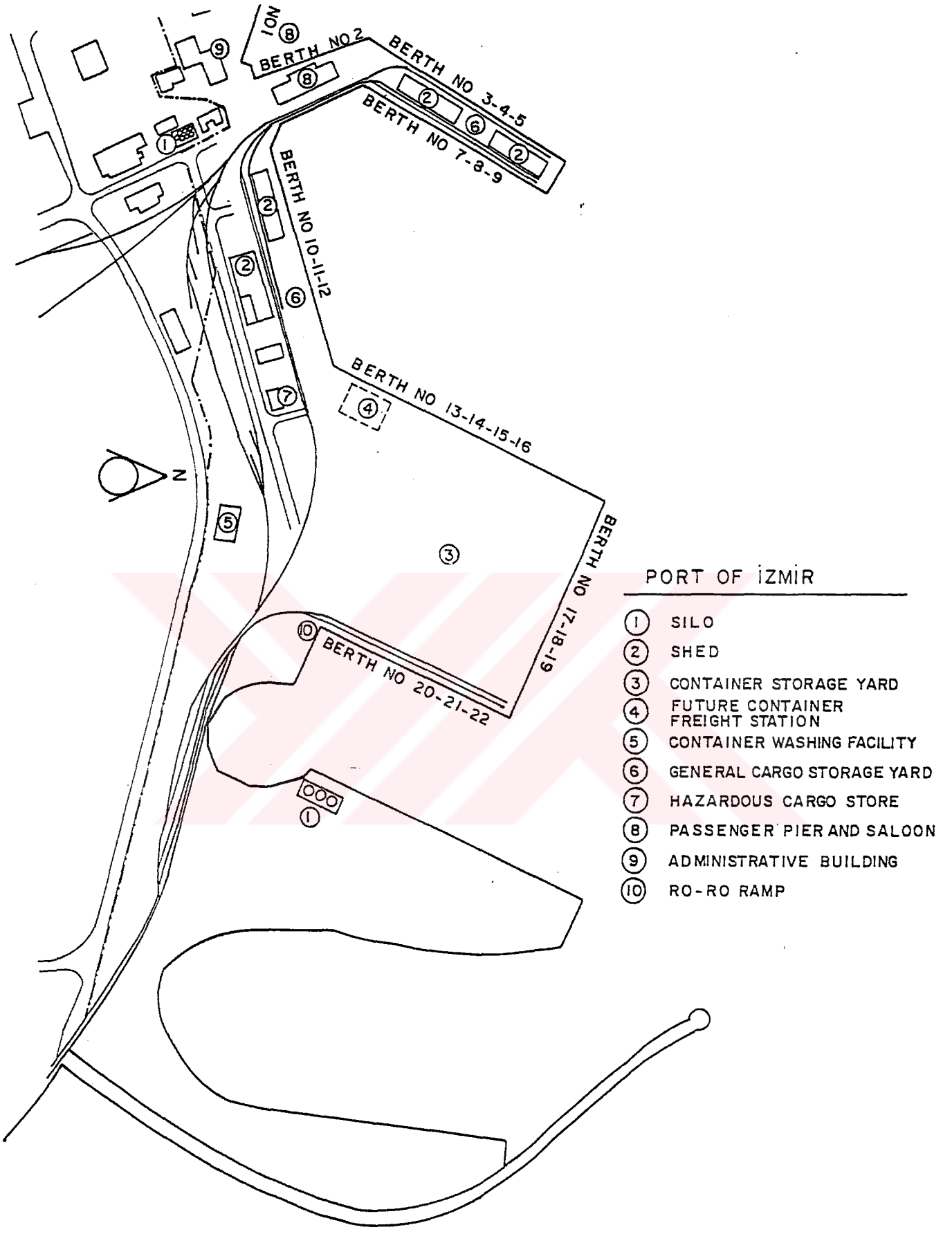

Figure 6.1 General Port Plan of İzmir Port

Table 6.1 Berthing Information about İzmir Port

Berth Number	Types	Length(m)	Depth(m)
3, 4, 5	General Cargo	420	-10.5
7, 8, 9	General Cargo	372	-10.5
10,11,12	General Cargo	348	- 7.0
13,14,15,16	Container	600	-12.0
17,18,19	Container	450	-13.0
20,21,22	Container	364	-13.0

Table 6.2 Existing Data for Handling Equipment of İzmir Port.

Container gantry cranes of 40 ton capacity	2
Shore cranes of 3 to 35 ton capacity	9
Special container mobile cranes of 40 tons cap.	2
Transtainers of 35 ton capacity	6
Mobile cranes of 3 to 25 tons capacity	14
Container forklifts of 10 to 42 tons capacity	13
General cargo forklifts of 2 to 8 tons cap.	33
Tugmaster-trailer sets	17
Loader	1

The optimization study of general cargo terminal for İzmir Port is carried out in two stages;

- The analysis of terminal size for the existing port capacity of Q = 4600000 ton/year,

- Determination of optimum port size for the expected future capacities.

6.2 Optimum Capacity Computations for the Existing Case

In this part of the study, optimum size of the general cargo terminal for the given port capacity of Q = 4600000 ton/year is determined. The input data (which is taken from Turkish Ports Operated by Turkish State Railways 1990) used in the simulation is given below;

a) Yearly throughput Q = 4600000 ton/year

b) -Maximum ship size (DWT_{max}) = 20000 DWT,

-Mean ship size (DWT_{mean}) = 10000 DWT,

-Minimum ship size (DWT_{min}) = 4000 DWT which are frequently calling the port.

c)-Number of berths (N) = 9

-Three different capacities of shore cranes are employed as; 36 t/hr, 60 t/hr and 70 t/hr.

d) Working hours;

-Monday-Friday: 15 Hours,

-Saturday : 15 Hours,

-Sunday : 15 Hours.

e) Actual cargo carrying coefficient of the ship (β) = 0.7

f) Ships' gear utilization parameter (γ) = 0.0 (it is taken 0 due to lack of statistical data).

g) Maximum allowable queue length is 10 ships.

h) Random number: Choose 5 or more digit integer number.

i) Mean capacity of shore cranes (P_{mean}) : 70, 60 and 36 t/hr.

This data is produced from Turkish Ports Operated by Turkish State Railways (1990) by taking the crane capacities of 20 ton/cycle, 7 ton/cycle, and 4 ton/cycle where the mean capacities can be accepted as 14 ton/cycle, 5 ton/cycle, and 3 ton/cycle assuming 5 cycle/hr, 12 cycle/hr, and 12 cycle/hr respectively.

j)-Annual cost of quay per meter COST(1): 1200 $/year/m,

-Hourly cost of ships COST(8): 0.012 $/hr/DWT where cost parameters are obtained from Review of Maritime Transport (1991) [23].

k) Cost of shore cranes [23]:

-For 70 t/hr, COST(2): 256000 $/year/crane

-For 60 t/hr, COST(3): 240000 $/year/crane

-For 36 t/hr, COST(4): 165000 $/year/crane

l) Operational cost of shore cranes [23]:

For 70 t/hr, COST(5): 8.4 $/hr

For 60 t/hr, COST(6): 8.2 $/hr

For 36 t/hr, COST(7): 6.6 $/hr

m) Operational cost of ship's gear is zero since γ is equal to 0.0.

n) Number of shore cranes (M) are assigned within a range (10-30) with given increments.

o) Quay length (q_1) is assigned within a range (400m-600m) with given increments (50m).

p) Ratios of numbers of respective crane capacities to total number of cranes are 0.10, 0.30 and 0.60 for 70, 60 and 36 t/hr respectively.

r) Lower and upper limits of ship sizes (DWT) are given as;

-70 t/hr shore cranes will serve: 15000-20000 DWT,

-60 t/hr shore cranes will serve: 8000-15000 DWT,

-36 t/hr shore cranes will serve: 4000-8000 DWT.

The main outputs obtained from the simulation programme is presented in a graphical form (Fig.6.2) by plotting total annual cost versus quay length. As it is seen from Fig.6.2 the optimum size of the terminal which corresponds to minimum annual port cost 8668271 $/year is obtained with a quay length of 700 m where M = 19 total shore cranes are utilized.

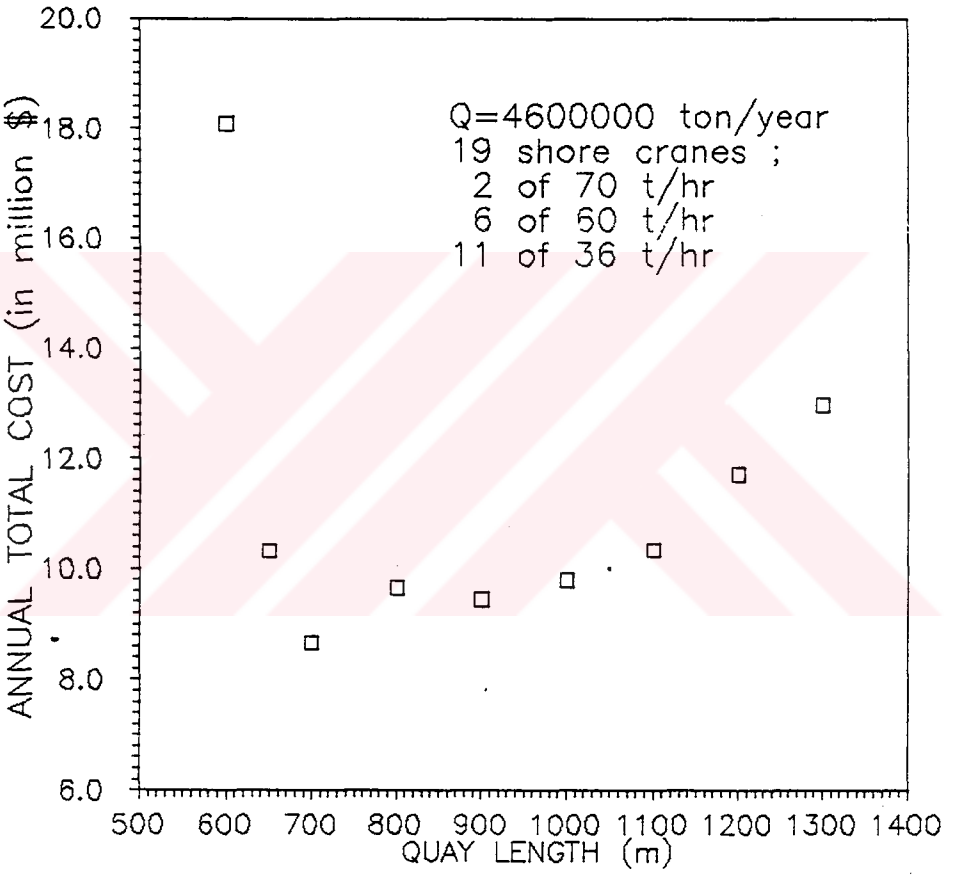

Figure 6.2 Result of the Simulation for the Optimum Terminal Size of Q = 4600000 ton/year

In order to investigate the optimum number of cranes to be utilized along the optimum quay length, a set of simulations are performed with the same throughput

(Q) but different crane number and the corresponding optimum quay length.

From the results of simulation, the minimum annual total cost for the number of cranes 18 and 20 for the quay lengths of 850 m and 750 m obtained as 9.97 and 8.73 million $ respectively, which are found to be far from the optimum combination of quay length and shore cranes.

Hence, the optimum size of the terminal which corresponds to the minimum annual total cost of 8668271 $/year is obtained with a quay length of 700 m and total number of shore cranes (M) of 19.

This size of the terminal yields ;

-Mean service time : 34.55 hr

-Mean waiting time : 7.19 hr

-Actual mean interval between ship arrivals : 13.32 hr/ship

-Berth utilization ratio: 0.29

-Maximum number of ships at the queue : 3 ships

At present the existing quay length and the number of shore cranes for general cargo terminal are 1150m and 23 of variable sizes respectively. The capacities of shore cranes are grouped into three different categories as ; 70 t/hr, 60 t/hr and 36 t/hr. Also the existing capacity of the terminal is stated as Q = 4600000 ton/year [1].

In the computations the optimum port size is obtained with a quay length of 700m and total number of cranes of 19 (which has the same three categories) as 2 of 70 t/hr, 6 of 60 t/hr and 11 of 36 t/hr.

Therefore the results can be taken as an indication of a fact that, general cargo terminal in İzmir Port is not satisfying the optimum capacity requirements. However it is to be noted that, the programme is confined only to the activities taking place between ship and quay. Hence the results should be reviewed, considering the other activities taking place at port for the final decision.

6.2.1 Analysis of Influence of Random Number Generator

In this part, the influence of the random number generator on the optimization results of the simulation

programme is carried out.

The simulation results, performed with different random numbers for the same input data where Q = 4600000 ton/year, DWT_{mean} = 10000 DWT and A = 13.22 hr/ship, are presented in Table 6.3.

It is seen from Table 6.3 that, the results differ slightly from each other.

From Table 6.3, the random number 6275817 gives the closest values of simulated mean interval between ship arrivals (A) and the mean DWT (DWT_{mean}) to the input data which confirm the reliability of the simulation.

Table 6.3 Influence of Random Number Generator for Optimum Terminal Size of Q = 4600000 ton/year

PARAMETERS	RANDOM NUMBERS		
	1257985	6275817	9618795
simulated A (hr/ship)	14.32	13.32	12.86
simulated (DWT_{mean})	9550	10014	9742
total annual cost (million $)	8.46	8.67	8.51
optimum crane number	19	19	20
optimum quay length (m)	750	700	700

The change of the fluctuation among the shore cranes, quay length and total annual cost are 5, 7, and 2 % respectively. Hence it can be stated that, the results of the simulation model is not sensitive to random number generator.

Some of the simulated results of arrival time, waiting time and service time, and print outs of the programme for general cargo terminal capacity of Q = 4600000 ton/year in İzmir Port are presented in Appendix E and in Appendix F respectively.

6.3 The Future Terminal Capacities of the Port

In order to handle the increasing volume of trade, the terminal capacity of the ports must be increased.

There are several ways to develop an existing port i.e. increasing the quay length and/or increasing the number and capacity of loading/unloading equipment.

The principal aim of the port planners should be to yield a solution for the most economic transfer of cargo, since very high costs involved in any kind of additional investments to the port.

The results of computations carried out in Section 6.2 for the reported yearly throughput of Q = 4600000 ton/year indicated that the existing quay length with increasing equipment capacity might give the optimum terminal size for the expected increase in yearly throughput.

Hence, firstly set of simulations are carried out to find the optimum number of loading/unloading equipment for the existing quay length (1150m) which would yield the optimum terminal capacity.

Secondly, set of simulations run to find out optimum quay length and optimum number of loading/unloading equipment for the expected future demand of Q = 8500000 and 9000000 ton/year.

The input data for different yearly throughput values are kept same as given in Section 6.2.

Results of simulation are plotted as annual total cost versus quay length for different yearly throughput in Figure 6.3 and in Figure 6.4.

As it is seen from Figure 6.3 for the existing quay length (1150m) the optimum number of cranes is obtained as 32. The optimum yearly throughput is 7500000 ton/year which results in minimum annual total cost of

13.35 million $.

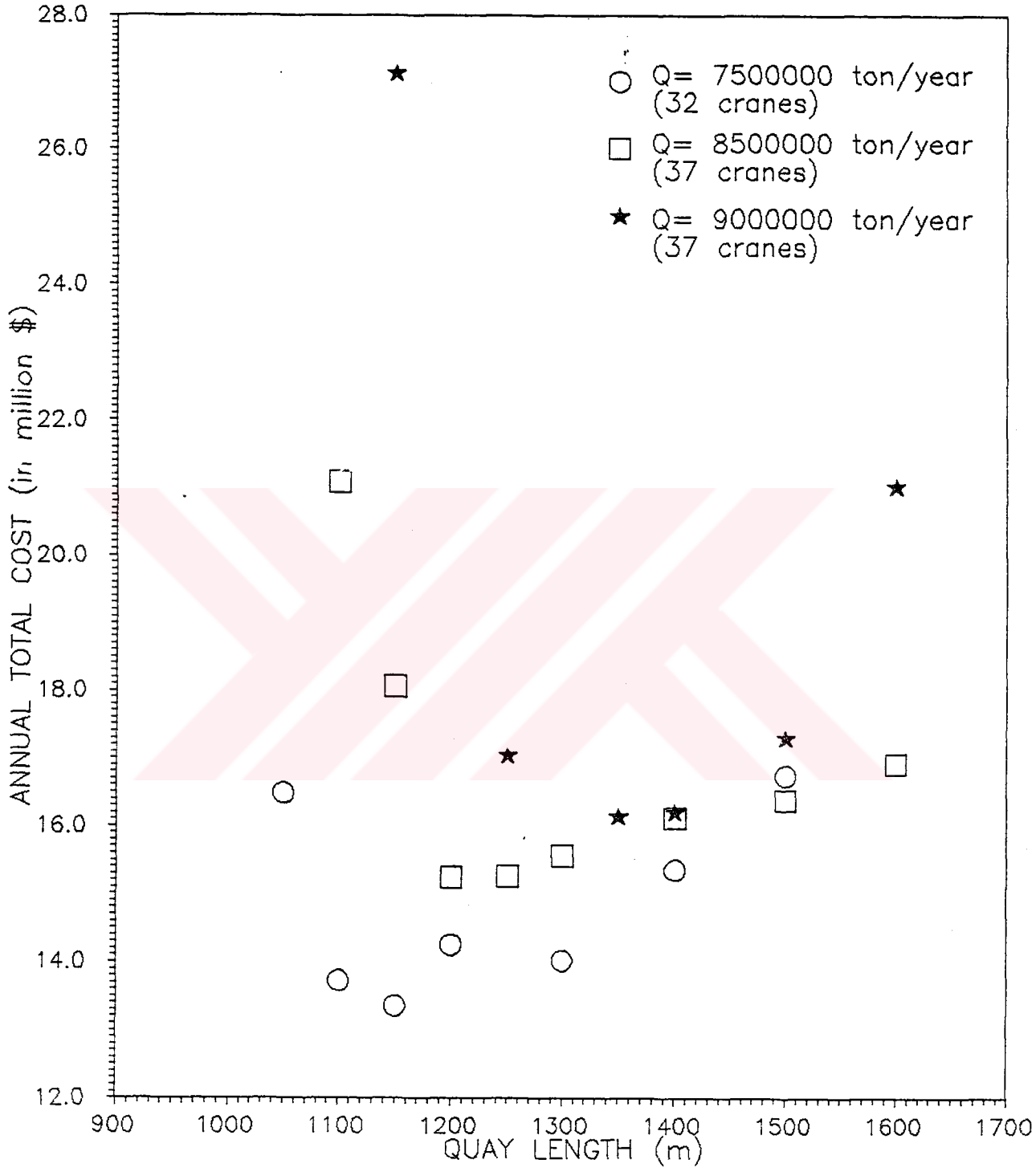

Figure 6.3 Result of the Simulation for the Future Terminal Capacities

With increasing yearly throughput values to Q = 8500000 and 9000000 ton/year the optimum quay length increases to 1200m and 1350m with optimum number of cranes 37 and 37 which corresponds to minimum annual total cost of 15.24 and 16.13 million $ respectively.

Unit cost of cargo transfer ($/ton) which is computed as annual total cost / terminal capacity are also presented in Table 6.4.

Table 6.4 Results of Simulations for the Future Terminal Capacities

PARAMETERS	TERMINAL CAPACITY (million ton/year)		
	7.5	8.5	9.0
annual total cost (million $)	13.35	15.24	16.13
optimum crane number	32	37	37
optimum quay length(m)	1150	1200	1350
unit cost of cargo transfer ($/ton)	1.78	1.79	1.79

As it is seen from Table 6.4 with increasing optimum terminal capacity (yearly throughput) minimum annual total cost increases, but unit cost of cargo transfer remains almost constant.

Since optimum capacity corresponds to optimum combination of quay length and number of cranes which results the most economic transfer of cargo. From the results it is seen that, for the existing quay length of general cargo terminal in İzmir Port (1150m) the optimum yearly terminal capacity is 7500000 ton/year where optimum number of cranes is 32.

Since, construction of new berths for the general cargo traffic is not considered in the development plans of İzmir Port in near future, the optimum capacity with existing quay length of 1150m can be increased by improving the cargo handling by adequate equipment.

In 1990, the general cargo consist 40 % of the total of two groups (general cargo and container) concerned. Regarding the increasing share of unitized cargo especially the containers in the world trade, the capacity of 7500000 ton/year for general cargo terminal obtained for existing quay length with additional investments on increasing number of cranes will result in nearly 75 % of the reported total future demand of Q = 10000000 ton/year which may not be future planning target of İzmir Port.

6.4 Influence of Crane Distribution

The simulation programme is run with different crane distributions. The results are given in Table 6.5 where ;

The crane distribution combinations are :

A:100 % of 70 ton/hr, total 22 cranes,

B:50,30,20 % of 70,60,36 ton/hr, total 26 cranes

C:20,35,45 % of 70,60,36 ton/hr, total 29 cranes

D:10,30,60 % of 70,60,36 ton/hr, total 32 cranes

E:100 % of 46.6 ton/hr, total 33 cranes

F:100 % of 36 ton/hr, total 43 cranes

In Table 6.5, the optimum combinations of shore cranes and quay length are given for the terminal capacity, computed for 7500000 ton/year throughput and ship sizes are kept same as given in Section 6.2 with different crane distributions. The results are tabulated in Table 6.5.

Table 6.5 Influence of Crane Distribution on Annual Total Cost

PARAMETERS	CRANE DISTRIBUTIONS					
	A	B	C	D	E	F
annual total cost (million $)	10.73	11.79	12.78	13.35	15.45	20.19
quay length (m)	700	900	1000	1150	1050	1400
crane number	22	26	29	32	33	43
weighted average of crane cap.(t/hr)	70	60.2	51.2	46.6	46.6	36

It is seen from Table 6.5 that, annual total cost decreases with the increasing weighted average of shore crane capacities.

Comparison of the annual total costs of cases D and E which have the same weighted average of crane capacities (but different crane number and capacity combinations) show that using a wider range of crane capacities at a port results less annual total cost.

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS FOR FUTURE STUDIES

In this study, a computer simulation model is prepared to obtain an economic optimum size of a port by creating arrival rate of ships, queuing system and service rate in the form of mathematical statements.

The optimum size of a port, which gives the minimum annual total cost, is the best combination of quay length and loading/unloading equipment for any given arrival rate and terminal capacity.

Regarding the fact that a port has different capacity of quay cranes, the programme is developed for three different crane capacity ranges.

The simulation model is generated both for general cargo terminals and container terminals where the traffic and cargo handling operations are limited at the quay apron between the ship and the quay.

The simulation model assumes the quay length to be continuous with a fixed number of berths. If there is a vacant place along the quay at any time during the simulation, the first ship in the queue can berth, if the first ship is not of a suitable size, it searches for a suitable one for the available length in quay.

The cranes available in the harbor are distributed uniformly to the ships present. A maximum number of cranes may be assigned to each ship depending upon the number of hatches of the ship. It assigns a crane (or a ship's gear) per hatch of the ship. In fact, it is not a practical approach to provide more than one handling equipment per hatch of the ship.

In order to minimize the mean waiting time, mean servicing time and annual total cost, the programme assigns larger capacity quay cranes to greater size ships by controlling the size of the ship at berth waiting for service and the capacity of the available quay cranes.

If the number of cranes are not sufficient for the number of ships present at quay, the use of ship's gear, if exists, will be the second alternative. In case of insufficiency of cranes, the programme generates a random number to determine whether the ship's gear exists or not with a 10 % existence probability.

The subprogramme RANDOM which generates the numbers between 0.0 and 1.0 randomly is sensitive and it is dependent on the compiler's characteristics. If a user uses SERCG in any computer with different FORTRAN compilers other than Microsoft 5.1 he/she should check subprogramme RANDOM.

The variation of the costs affect the annual total cost, as the cost of cranes increases the annual port cost so the annual total cost also increases. However, the optimum port size remains the same since the cost variations have no effect on the traffic of the port.

The necessary data used as an input to the programme is not easy to obtain for any harbor or port in Türkiye. However, by the help of some registrations from TCDD and the General Directorate of Construction of Railways, Harbors, Airports of the Ministry of Transportation some useful data can be obtained.

The introduced methodology is then applied to the general cargo terminal in İzmir Port. The optimization developed in this thesis gave some valuable results. These results are;

- The optimum size of the general cargo terminal in İzmir Port is obtained by the quay length of 700m with 2

of 70 t/hr, 6 of 60 t/hr, and 11 of 36 t/hr capacity shore cranes for the yearly throughput of Q = 4600000 ton/year.

- For the existing quay length of 1150m where the optimum number of cranes is 32, the optimum yearly throughput is obtained as Q = 7500000 ton/year.

- It is seen that, increasing the crane numbers, increase the service rate which decreases the ship cost. However, there is an optimum number of cranes which minimizes the annual total cost, and increasing the crane number further only increases the annual 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 annual total cost increases because of the unused additional cranes.

- Utilizing cranes with higher capacity (hence less number of cranes) results in lowering the total port cost and a shorter quay length. Also it is better to have the same weighted average capacity of quay cranes with bigger capacity cranes.

- While developing an existing port, first of all, the number and the capacity of the cranes are recommended to be increased before increasing the quay length which is more costly.

For the future development of the simulation model sensitivity analysis of cost parameters, ship sizes, berth number, ship's gear utilization and working hours can be checked.

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.

It is also recommended to develop this simulation model with a special simulation languages such as SIMDL. The special simulation languages (i.e. SIMDL, SIMSCRIPT, PROSIM etc.) can be applied to this kind of port problems by rearranging this model.

The simulation programmes enable the users to simulate proposed changes to existing or future processes, and hence evaluate the economies of various alternatives in a short time without costly capital investment.

When the port development is considered, it can be seen that the main reason for development is an existing or expected need for improved port capacity and

services. While examining all these facts, the actual conditions of the hinterland or region involved, must be taken into account, as well as technological changes in shipping and handling equipment.

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APPENDICES

APPENDIX A

LIST OF SYMBOLS USED IN THE SIMULATION PROGRAMME SERCG

FOR THE MAIN PROGRAM

A	Mean interval between ship arrivals
AD1	Constants in the trunchated exponential
AD2	Distribution of ship sizes
ADQUAY	Quay length required by MINDWT
ADT	Time step in the simulation
AM	CM/CN
AMELOA	Quay length required by MEANDWT
AN	Quay length
ANIDLE	Length of idle quay
B2	Actual mean traffic load
CMEAN=MCMEAN	Number of hatches of MEANDWT
DEL	Actual mean interval between ship arrivals
DELTAT	Arrival interval
ERHAN,RHAN	Limits of DWTS that cranes serve
IA	5 or more digit integer random number
II	Number of different kind of cranes
IN=AIN	Number of ship arrivals
IOTARR	Total number of ships to be treaten in the simulation

IR1,IR2,IR3	Determines whether work is going on or not
IRUN=NO	Simulation number
MAXDWT=AMAXDW	Maximum ship size
MAXNOC	Maximum number of berths occupied
MAXQUE	Biggest number of ships possible in queue
MAXWAI	Maximum number of ships in queue
MC=C1	Number of cranes that can work on MINDWT
MEANDW=AMEAND	Mean ship size
MINDWT=AMINDW	Minimum ship size
MQURUN	MAXQUE*100000+IRUN
M=CM	Number of total cranes
N1	N+2
NOC	Actual number of berths occupied
NWAIT	Dummy number of ships in dummy queue
NWITT	Actual number of ships in queue
N=CN	Number of berths
QQ	Yearly amount of cargo ton/year
RANDOM	Random number between 0 and 1
STEP	Number of time step used in the simulation
T	Running time in the simulation
TBERTH	The least time among the berths
THEDWT	Actual mean DWT
TOCOST1	Total yearly cost combination

FOR SUBROUTINES

A	Actual mean interval between ship arrivals

ACTM1=ISHIP(3,J)	Number of hatches of each ship
ACTM3	Number of ships own gear
ACTM=ISHIP(4,J)	Number of cranes assigned on each ship
AM=M	Number of cranes
AVWAIT	Mean number of ships in queue
B1	Mean crane utilization
BI	Theoretical mean traffic load (TEXTPR)
BI=II	Ship size classes in DISTRI
B=B2	Mean traffic load
CI	Handling time classes in DISTRI
COSTCF	Yearly total fixed cost of cranes
COSTCV	Yearly total working cost of cranes
COSTGV	Yearly total working cost of gears
COSTQ	Yearly cost of quay
COSTS1	Yearly cost of waiting of ships
COSTS2	Yearly cost of handling of ships
CRANHR=CRHR	Yearly crane hours
DI	Waiting time classes in DISTRI
DWTHR1	Yearly waiting DWT hours
DWTHR2	Yearly handling DWT hours
EI	Extended handling time classes in DISTRI
FI	Arrival interval classes in DISTRI
FIXCOS	COSTQ+COSTCF
GI	Arrival interval classes in DISTRI
HOUR	Hour of the day
IDAYW	Day of the week

IDAYY=DAYY	Day of the year
IWEEK	Week of the year
MACM	Total number of cranes at work
QUAYL=AN	Quay length
RATIO1	Ratio of cranes with capacity P(1)
RATIO2	Ratio of cranes with capacity P(2)
RATIO3	Ratio of cranes with capacity P(3)
TOCOST	Total yearly cost of terminal and ships
VARCOS	COSTCV+COSTGV+COSTS1+COSTS2
WH=AMEAN(6)	Mean handling time of ships
WW=AMEAN(5)	Mean waiting time of ships

ARRAYS

AMEAN(I)	Means of ships which had service at quay
I=1	Number of ships treated
I=2	Mean DWT
I=3	Mean minimum handling time
I=4	Mean time of arrival
I=5	Mean handling time (DWT*HOUR)
I=6	Mean waiting time (DWT*HOUR)
I=7	Mean extended handling time
I=8	Probability of delay in queue

ARRIVE(I)	Ship arrivals
I=1	Time of new arrival
I=2	DWT of newly arrived ship

	I=3	Quay length required by ship
B3(I)		Crane utilizations
	I=1,3	Mean crane utilization for P(I) crane capacity
COST(I)		Variable and fix costs
	I=1	Yearly cost per meter of quay
	I=2,4	Yearly fixed cost per P(I) crane capacity
	I=5,7	Hourly operation cost per P(I) crane capacity
	I=8	Cost of ship delay in $/DWT/hour
	I=9,11	Hourly operation cost per ships' gear belonging to P(I) crane capacity
CRHR(I)		Working hour of cranes
	I=1,3	Total working hours for P(I) crane capacity
DISTRI(I,J)		Distribution of ship characteristics
		I=1,20
	J=1	Distribution of ship sizes
	J=2	Distribution of arrival intervals
	J=3	Distribution of handling time
	J=4	Distribution of extended handling time
GEARHR(I)		Working hour of ships' gear
	I=1,3	Total working hours for ships' gear

belonging to P(I) crane capacity

ISHIP(I,J)	Ship chacteristics
	J=Berth number
I=1	ISHIP(I,J)=3 Then ship being loaded/unloaded
I=1	ISHIP(I,J)=2 Then berth occupied
I=1	ISHIP(I,J)=1 Then ship just left
I=1	ISHIP(I,J)=0 Then berth idle
I=2	DWT of ship
I=3	Number of ship hatches
I=4	Actual number of cranes on ship
MACMP(I)	Working crane numbers type by type
I=1,3	Number of cranes working with P(I) crane capacity
MM(I)	Available number of cranes type by type
I=1,3	Number of cranes with P(I) crane capacity
OPTM(I,J)	Input data for the next simulation
	I=Simulation number
J=1	Length of quay (=AN)
J=2	Number of cranes (=M)
J=3	Traffic load (=B=B2)
J=4	Total yearly cost of terminal and ships
P(I)	Crane capacities type by type
I=1,3	Capacity of P(I) cranes P(1) > P(2) > P(3)

PMEAN(I) Average of generated crane capacities P(I)

I=1,3 Mean P(I) (P(I)=P(I)+random number)

PMEAN1(I) Average working crane capacities P(I)

I=1,3 Average P(I)

QUAY(I,J) Cracteristics of ships at quay

J=Berth number in quay

II=3	II=2	II=1	
I=1	I=1	I=1	Remaining cargo in ship
I=2	I=2	I=2	Actual P(1) crane capacity
I=3	I=3		Actual P(2) crane capacity
I=4			Actual P(3) crane capacity
I=5	I=4	I=3	Time of arrival at terminal
I=6	I=5	I=4	Time of arrival at quay
I=7	I=6	I=5	Actual handling time
I=8	I=7	I=6	Length of quay occupied by ship
I=9	I=8	I=7	Number of ships' gear used
I=10	I=9	I=8	Total unloading capacity

QUEUE(J,I) Dummy queue outside the terminal

J=Ship number at queue

I=1 Time of new arrival in queue

I=2 DWT of newly arrived ship at queue

I=3 Quay length required by the ship at queue

RESULT(I) Ships which had service at quay

I=1 Ship number

	I=2	DWT of ship
	I=3	Minimum handling time
	I=4	Time of arrival at terminal
	I=5	Handling time
	I=6	Waiting time
	I=7	Extended handling time
	I=8	RESULT(I)=1 if ship was delayed in queue, else RESULT(I)=0
SH(I)		Number of ships treated between limits
	I=1	Between MINDWT and ERHAN
	I=2	Between ERHAN and RHAN
	I=3	Between RHAN and MAXDWT
TEST(I)		Test of time
	I=1,N	Time until ship at berth I is empty/full. If berth is idle TEST(I)=10*10
	I=N+1	Time until next arrival
	I=N+2	Time until working condition changes
TQY(I)		Time at each berth I

APPENDIX B

SIMULATION PROGRAMME SERCG

```
C     SERCG SERCG.INP OUTPUT SERCG.A1 OUT dene
C
C     This Program Runs for General Cargo and Container Terminal
      DIMENSION ARRIVE(3),QUEUE(500,3),QUAY(10,20),ISHIP(4,20),RESULT(8)
     *,AMEAN(8),DISTR(20,5),p(3),MM(3),sh(3),b3(3),PMEAN1(3),TQY(20)
      DIMENSION TEST(22),OPTM(200,4),COST(11),PMEAN(3),GEARHR(3),CRHR(3)
      COMMON IR2,K,COST  ,OPTM,NO,CMEAN,AMELOA,ADQUAY,L10,K1,T,ADT,ARRIV
     *E,MAXQUE,QUEUE,IR1,NWAIT,BNWAIT,N1,N,PMEAN,GEARHR,TOCOS1,B2,QUAY,I
     *SHIP,TEST,AMEAN,MAXWAI,AMINDW,MINDWT,AMAXDW,MAXDWT,AMEAND,MEANDW,M
     *CMEAN,CN,CM,M,AM,MAXNOC,NOC,MC,L,STEP,IN,DEL,C1,KSZ,L3,L4,KEE,MACM
     *,MMACM
      common/W/pmean1
      common/ttt/erhan,rhan
      common/aaa/b3
      common /pr/ kcr
      common /kara / serhan
      common /ncr/ mm
      common /DWT1/ THEDWT,irr
      common/treat/sh
      common /type/ntype
      common/ratio/ratio1,ratio2,ratio3
      common/say/ii
      common/rand/ia
      COMMON/ACY/IAA
      COMMON/berth/TQY
      COMMON/SK/NOSAYI,DWTQE
      COMMON/AVW/AVWAIT
      open(5,file=' ')
      open(6,file=' ')
      open(7,file='dummy')
      open(8,file='dum')
      open(9,file='CON')
      open(50,file='quay')
      open(60,file='result')
      open(70,file='queue')

      WRITE(6,*)' PLEASE WRITE KIND OF TERMINAL (NTYPE)'
      WRITE(6,*)' GENERAL CARGO TERMINAL WITH SHORE CRANES OR '
      WRITE(6,*)' CONTAINER TERMINAL WITH GANTRY CRANES !!'
      READ(5,10) NTYPE
      WRITE(6,10) NTYPE
```

```
   10 FORMAT(14X,A1)
      if(ntype.eq.'C'.or.ntype.eq.'c') goto 5194
      write(9,8286)
 8286 format(/,'  This run is for a General Cargo Terminal',
     *        ' with Shore Cranes ',/)
      goto 5112
 5194 write(6,6998)
      write(9,6998)
 6998 format(/,'  This run is for a Container Terminal',
     *        ' with Gantry Cranes ',/)
 5112 CONTINUE
      WRITE(6,*)' PLEASE ENTER YEARLY AMOUNT OF CARGO (QQ) ton/year !!'
      READ(5,*) QQ
      WRITE(6,30) QQ
      WRITE(6,*)' PLEASE ENTER MAXDWT,MEANDW & MINDWT OF SHIP'
      WRITE(6,*)' RESPECTIVELY !!'
      READ(5,*) MAXDWT,MEANDW,MINDWT
      WRITE(6,*) MAXDWT,MEANDW,MINDWT
      WRITE(6,*)' PLEASE ENTER BERTH NUMBER (N) & '
      WRITE(6,*)' NUMBER OF DIFFERENT KIND OF CRANES (ii) '
      WRITE(6,*)' RESPECTIVELY !!'
      READ(5,*) N,II
      WRITE(6,*) N,II
      WRITE(6,*)' PLEASE ENTER WORKING HOURS; MONDAY TO FRIDAY (HOUR1)'
      WRITE(6,*)'                             SATURDAY (HOUR2)'
      WRITE(6,*)'                             SUNDAY (HOUR3)'
      WRITE(6,*)' RESPECTIVELY !!'
      READ(5,*) HOUR1,HOUR2,HOUR3
      WRITE(6,20) HOUR1,HOUR2,HOUR3
      WRITE(6,*)' PLEASE ENTER ACTUAL CARGO CARRYING CAPACITY'
      WRITE(6,*)'  COEFFICIENT (BETA) !!'
      READ(5,*) BETA
      WRITE(6,20) BETA
      WRITE(6,*)' PLEASE ENTER SHIP GEAR UTILIZATION PARAMETER(GAMMA)!!'
      READ(5,*) GAMMA
      WRITE(6,20) GAMMA
      WRITE(6,*)' PLEASE ENTER MAXIMUM NUMBER OF SHIPS'
      WRITE(6,*)' IN THE QUEUE * 10E5 (MQURUN) !! '
      READ(5,*) MQURUN
      WRITE(6,*) MQURUN
      WRITE(6,*)' PLEASE ENTER 5 OR MORE DIGIT INTEGER'
      WRITE(6,*)' RANDOM NUMBER (IA) !! '
      READ(5,*) IA
      WRITE(6,*) IA
      WRITE(6,*)' PLEASE ENTER CAPACITY OF CRANES P(1),P(2) & P(3)'
      WRITE(6,*)' IN TONS RESPECTIVELY !!'
      READ(5,*) P(1),P(2),P(3)
      WRITE(6,30) P(1),P(2),P(3)
      WRITE(6,*)' PLEASE ENTER COST OF QUAY COST(1) &'
      WRITE(6,*)' HOURLY COST OF SHIP COST(8) RESPECTIVELY !!'
      READ(5,*) COST(1),COST(8)
      WRITE(6,*) COST(1),COST(8)
      WRITE(6,*)' PLEASE ENTER COST OF CRANES'
      WRITE(6,*)' COST(2),COST(3) & COST(4) RESPECTIVELY !!'
      READ(5,*) COST(2),COST(3),COST(4)
      WRITE(6,30) COST(2),COST(3),COST(4)
      WRITE(6,*)' PLEASE ENTER OPERATION COST OF CRANES'
      WRITE(6,*)' COST(5),COST(6) & COST(7) RESPECTIVELY !!'
      READ(5,*) COST(5),COST(6),COST(7)
      WRITE(6,20) COST(5),COST(6),COST(7)
```

```
      WRITE(6,*)' PLEASE ENTER OPERATION COST OF SHIP GEAR'
      WRITE(6,*)' COST(9),COST(10) & COST(11) RESPECTIVELY !!'
      READ(5,*) COST(9),COST(10),COST(11)
      WRITE(6,20) COST(9),COST(10),COST(11)
      WRITE(6,*)' PLEASE ENTER INITIAL,FINAL & INCREMENT OF CRANE'
      WRITE(6,*)' NUMBER RESPECTIVELY !!'
      READ(5,*) MINI,MEND,MINC
      WRITE(6,*) MINI,MEND,MINC
      WRITE(6,*)' PLEASE ENTER INITIAL,FINAL & INCREMENT OF QUAY'
      WRITE(6,*)' LENGTH RESPECTIVELY !!'
      READ(5,*) LINI,LEND,LINC
      WRITE(6,*) LINI,LEND,LINC
      WRITE(6,*)' PLEASE ENTER RATIOS OF CRANE(1),CRANE(2) & CRANE(3)'
      WRITE(6,*)' IN TOTAL CRANE NUMBER RESPECTIVELY !!'
      READ(5,*) RATIO1,RATIO2,RATIO3
      WRITE(6,20) RATIO1,RATIO2,RATIO3
      IF(II.EQ.2) THEN
      WRITE(6,*)' PLEASE ENTER THE LOWER LIMIT OF DWT'
      WRITE(6,*)' THAT CRANE(1) SERVES !!'
      READ(5,*) ERHAN
      WRITE(6,30) ERHAN
      ELSE
      ENDIF
      IF(II.EQ.3) THEN
      WRITE(6,*)' PLEASE ENTER THE LOWER & UPPER LIMIT OF DWT'
      WRITE(6,*)' THAT CRANE(2) SERVES !!'
      READ(5,*) ERHAN,RHAN
      WRITE(6,30) ERHAN,RHAN
      ELSE
      ENDIF
      IOTARR=QQ/0.7/MEANDW
      TOTARR=IOTARR
      A=24*362./TOTARR
      WRITE(6,*)' TOTAL NUMBER OF SHIPS TO BE TREATED =',IOTARR
      WRITE(6,*)' MEAN INTERVAL BETWEEN SHIP ARRIVALS =',A,' H.'
   20 FORMAT(3(3X,F6.3,3X))
   30 FORMAT(3(3X,F9.1,3X))
      IAA=IA
      NO=0
      L7=1
    1 CONTINUE
      do 119 i=1,1000
      AM62=AMEAN(6)/(AMEAN(2)+1)
      AM52=AMEAN(5)/(AMEAN(2)+1)
      read(7,222,end=115) IS,MAXdwS,MEANdS,MINdwS,AM62,AM52,E,PS1,MS1,pS
     *2,MS2,pS3,MS3,MS,ANS,TCSTS,TqcosS,thedwS,costdwS,result(1)
  119 write(8,222) IS,MAXdwS,MEANdS,MINdwS,AM62,AM52,E,PS1,MS1,pS2,MS2,p
     *S3,MS3,MS,ANS,TCSTS,TqcosS,thedwS,costdwS,result(1)
  222 format(I8,3I6,28X,F7.2,6X,F7.2,/,f5.2,3(f5.0,I3),I3,F6.0,2f7.2,f8.
     *1,f6.2,F7.1)
  115 continue
      close(7)
      close(8)
      open(10,file='DUM')
      open(11,file='DUMMY')
      open(12,file=' ')
      open(13,file=' ')
      open(14,file=' ')

      do 1191 i=1,1000
```

```
      read(10,222,end=1151) IS,MAXdwS,MEANdS,MINdwS,AM62,AM52,E,PS1,MS1,
     *pS2,MS2,pS3,MS3,MS,ANS,TCSTS,TqcosS,thedwS,costdwS,result(1)
 1191 write(11,222) IS,MAXdwS,MEANdS,MINdwS,AM62,AM52,E,PS1,MS1,pS2
     *,MS2,pS3,MS3,MS,ANS,TCSTS,TqcosS,thedwS,costdwS,result(1)
 1151 continue

      trput=8760*meandw*beta/(A*1000000.)
      IF(MINDWT.gt.MAXDWT) goto 601
      irr1=(Mend-Mini)/Minc+1
      irr2=(Lend-Lini)/Linc+1
      irr=irr1*irr2

      serhan=0.
      do 7 im=Mini,Mend,Minc
      do 7 iL=Lini,Lend,Linc
      IA=IAA
      sumDWT=0.
      isumDWT=0
      M=iM
      AN=iL*1.
      WRITE(6,410)
      MAXQUE=(MQURUN+1)/100000
      IRUN=MQURUN-MAXQUE*100000
      MAXQUE=maxque-1
C     TO BE PRINTED BEFORE  COMPUTATION
   41 ANIDLE=AN
      do 444 in=1,ii
  444 CRHR(in)=0.
      DO 445 IN=1,20
  445 TQY(IN)=0
      TBERTH=0
      AVWAIT=0.
      MAXWAI=0
      NWITT=0
      NWAIT=0
      NNWAIT=0
      ARTQUA=0.
      SHIN=0.

      CALL ZERO

      WEEK=0.
      AD2=MEANDW-MINDWT
      DO 59 I=1,20
      AD1=AMEAND-AMAXDW+(AMAXDW-AMINDW)/(1.-EXP(-(AMAXDW-AMINDW)/AD2))
   59 AD2=AD1*5./3.-AD2*2./3.
      KS3=1

      CALL TEXTPR(IRUN,AN,P,A,BETA,GAMMA,KS3,HOUR1,HOUR2,HOUR3)

      CALL DISTRI(4,RESULT,MAXDWT,MINDWT,AMAXDW,AMINDW,C1,P,AM,A,DELTAT,
     *DISTR)

      IF(NO) 70,70,71

   70 CALL OPTIMU(1,AN,L9)

   71 GOTO(101,1),KS3
C     START  MAIN  PROGRAM
   88 GO TO (91,89),IR2
```

```
   89 ADT=TEST(N+1)
      IF(ADT-TEST(N+2)) 92,92,90
   90 ADT=TEST(N+2)
      TEST(N+1)=TEST(N+1)-ADT
      T=T+ADT
      GOTO 330
   91 ADT=TEST(1)
      DO 94 I=2,N1
      IF(TEST(I)-ADT) 93,94,94
   93 ADT=TEST(I)
   94 CONTINUE
C     IF(TEST(I)-TEST(N+2)) 92,193,193
C 193 ADT=TEST(N+2)
   92 T=T+ADT
      STEP=STEP+1.
      DO 96 J=1,N
      IF(ISHIP(1,J)-2) 96,95,96
   95 ISHIP(1,J)=3
   96 CONTINUE
      IF(ABS(T-ARRIVE(1))-.02) 97,97,98
   97 ARRIVE(1)=T
   98 IF(T-ARRIVE(1)) 99,101,101
   99 TEST(N+1)=TEST(N+1)-ADT
      IF(ADT) 100,100,200
  100 IF(TEST(N+1)) 101,101,200

  101 CALL RANDOM(IA,RANDEM)

C     FIND  NEXT  ARRIVAL
  103 DELTAT=-A*ALOG(RANDEM)

      CALL DISTRI(2,RESULT,MAXDWT,MINDWT,AMAXDW,AMINDW,C1,P,AM,A,DELTAT,
     *DISTR)

 1000 IN=IN+1
      DEL=DEL+DELTAT
 1001 TEST(N+1)=DELTAT

  105 CALL RANDOM(IA,RANDEM)

      ARRIVE(2)=AMINDW-AD2*ALOG(RANDEM)
      IF(ARRIVE(2)-AMAXDW) 106,106,105
  106 ARRIVE(3)=1.15*(-3.68*ARRIVE(2)/1000.+1.26*SQRT(ARRIVE(2))-.65*
     *(ARRIVE(2)**.33)+6.95*(ARRIVE(2)**.25))
      iSUMDWT=iSUMDWT+1
      SUMDWT=SUMDWT+ARRIVE(2)
      THEDWT=SUMDWT/isumDWT
      WRITE(13,*) ARRIVE(1),ARRIVE(2),ARRIVE(3),THEDWT
  104 ARRIVE(1)=ARRIVE(1)+DELTAT

C     SHIPS  IN  QUEUE ( 1 )
 1002 IF(QUEUE(1,1)) 110,120,110
C     PLACE   SHIP  IN  QUEUE

  110 CALL SQUEUE(1,NWAIT,MAXQUE,QUEUE,ARRIVE,DELTAT,L,I,TBERTH,NWITT,N
     *WAIT)

      GOTO (200,330,381),L
C     IDLE  BERTH  (  1  )
  120 IF(ANIDLE-ARRIVE(3)) 121,130,130
```

```
  121 L=2
  122 GOTO 110
C     PLACE SHIP AT QUAY (1)
  130 KSZ=1

      CALL SQUAY(KSZ,N,ISHIP,NOC,ARRIVE,QUAY,BETA,DELTAT,T,ANIDLE,L3,J1,
     1QUEUE,NWAIT,J,I)

  144 CALL RANDOM(IA,RANDEM)

  149 do 555 kr=2,ii+1
      kl=kr-1
  555 QUAY(kr,J)=P(kl)+2.40*P(kl)*((RANDEM-.5)**3)
  150 GO TO 310
C     SHIPS  IN  QUEUE  AND  IDLE  QUAY
  199 ADT=0.
      STEP=STEP+1.
  200 J1=1
  201 L3=2
  202 IF(QUEUE(1,1)) 203,301,203
  203 IF(ANIDLE-QUEUE(1,3)) 205,204,204
  204 I=1
      GOTO 220
C     NOT  FIRST  IN  FIRST  SERVED
  205 DO 208 I=2,NWAIT
  206 IF(QUEUE(I,1)) 207,209,207
  207 IF(ANIDLE-QUEUE(I,3)) 208,220,220
  208 CONTINUE
  209 GOTO (310,301),L3
C     PLACE  SHIP  AT  QUAY
  220 KSZ=2

      CALL SQUAY(KSZ,N,ISHIP,NOC,ARRIVE,QUAY,BETA,DELTAT,T,ANIDLE,L3,J1,
     1QUEUE,NWAIT,J,I)

  233 CALL RANDOM(IA,RANDEM)

  251 do 666 kr=2,ii+1
      kl=kr-1
  666 QUAY(kr,J)=P(kl)+2.40*P(kl)*((RANDEM-0.5)**3)
C     REARRANGE QUEUE

      CALL SQUEUE(2,NWAIT,MAXQUE,QUEUE,ARRIVE,DELTAT,L,I,TBERTH,NWITT,N
     *NWAIT)

  270 J1=J+1
  271 IF(J1-1-N) 202,272,272
  272 GOTO (310,301) ,L3
C     DEPARTURES AT TIME T- ADT
  301 DO 303 J=1,N
  302 IF(ISHIP(1,J)-1) 303,310,303
  303 CONTINUE
  304 GOTO 310
C     REARRANGING  OF  CRANES

  310 CALL CRANE(ISHIP,QUAY,M ,GAMMA,N)

      DO 870 J=1,50
      IF(QUEUE(J,1).EQ.0.)THEN
      DO 869 K=1,3
```

```
      QUEUE(J,K)=QUEUE(J+1,K)
  869 QUEUE(J+1,K)=0.
      ELSE
      ENDIF
  870 CONTINUE
C     DISCHARGE  ALL  SHIP

  330 CALL WORK(HOUR1,HOUR2,HOUR3,T,TEST(N+2),IR1,IR2)

      GOTO (331,88),IR1

  331 CALL DISCHA(ISHIP,QUAY,TEST,ADT,N,CRHR,GEARHR,NWITT,BNWAIT,p)

      TBERTH=100000.
      DO 665 MN=1,N
      IF((ISHIP(2,MN).gt.0.1).AND.(QUAY(II+4,MN).GT.0.1))THEN
      BER=QUAY(II+3,MN)+QUAY(II+4,MN)
      IF(BER.LT.TBERTH)TBERTH=BER
      ELSE
      ENDIF
  665 CONTINUE

CC     WRITE(50,1050)((QUAY(KJ,JK),KJ=1,10),JK=1,N)
CC     WRITE(50,*)'T=',T,'  TBERTH=',TBERTH
CC1050 FORMAT(10F8.2)
CC     WRITE(50,1090)((QUEUE(IT,ik),ik=1,3,2),IT=1,NWAIT)
CC1090 FORMAT(10F9.2)
  337 L=1
      L4=1
      IF(MAXNOC-NOC) 371,338,338
  371 MAXNOC=NOC
  338 IF(MAXWAI-NWITT) 339,1340,1340
  339 MAXWAI=NWITT
 1340 IF(MMACM-MACM) 1339,340,340
 1339 MMACM=MACM
C     ANY  EMPTY  SHIP  IF  YES MAKE  BERTH  IDLE  AND  STORE RESULTS
  340 DO 368 J=1,N
  341 IF(ISHIP(1,J)-2) 368,368,3411
 3411 IF(ABS(QUAY(1,J))-AMAXDW/100000.) 3412,3412,342
 3412 QUAY(1,J)=0.
  342 IF(QUAY(1,J)) 344,344,368
  344 ISHIP(1,J)=1
      TQY(j)=QUAY(II+3,J)+QUAY(II+4,J)

      CALL LEAVE(RESULT,ANIDLE,BETA,J,TOTARR)

CC      WRITE(60,1060)(RESULT(KH),KH=1,8)
CC 1060 FORMAT(F5.0,F9.2,6F8.2)

      CALL DISTRI(1,RESULT,MAXDWT,MINDWT,AMAXDW,AMINDW,C1,P,AM,A,DELTAT,
     *DISTR)

  368 CONTINUE
C     HOW MANY SHIPS HAVE BEEN HANDLED

  372 IF(AMEAN(1)-TOTARR) 380,381,381
  380 GO TO (88,199),L4
  381 WRITE(6,412)
      WRITE(9,412)
```

```
      QDWT=0.
      NQUAY=0
      ARTQUA=0.
      DO 3702 J=1,N
      IF(QUAY(1,J).GT.0.)THEN
      IF(QUAY(II+2,J).GE.ARTQUA)ARTQUA=QUAY(II+2,J)
      QDWT=QDWT+ISHIP(2,J)
      NQUAY=NQUAY+1
      ELSE
      ENDIF
 3702 CONTINUE

C     NUMBER OF SHIPS TREATED

      SHIN=AMEAN(1)+NQUAY+NOSAYI
      THEDWT=(AMEAN(2)*AMEAN(1)+QDWT+dwtqe)/SHIN
      T=WEEK*168.+T
      AIN=SHIN
      IN=SHIN
      DEL=TBERTH/SHIN
      T=TBERTH
      IF(AMEAN(1).GE.IOTARR)T=RESULT(4)+RESULT(5)+RESULT(6)
      IF(DEL.EQ.0.)DEL=RESULT(4)/RESULT(1)
      NWAIT=NNWAIT

      DO 5651 I=1,II
      GEARHR(I)=GEARHR(I)*8760./T
C     PMEAN(I)=PMEAN(I)/AMEAN(1)
      IF(SH(I).EQ.0.) SH(I)=1
      IF(CRHR(I).EQ.0.) CRHR(I)=1
      PMEAN(I)=PMEAN(I)/sh(I)
      PMEAN1(i)=AMEAN(2)*sh(i)/CRHR(i)*BETA
      B3(i)=CRHR(i)/T/mm(i)
      CRHR(I)=CRHR(I)*8760./T
 5651 CONTINUE

      CALL TEXTPR(IRUN,AN,P,A,BETA,GAMMA,2,HOUR1,HOUR2,HOUR3)

      CALL DISTRI(3,RESULT,MAXDWT,MINDWT,AMAXDW,AMINDW,C1,P,AM,A,DELTAT,
     *DISTR)

      WRITE(6,417)AD1,AD2,IA,PMEAN(1),PMEAN(2),PMEAN(3)
C     write(9,417)AD1,AD2,IA,PMEAN(1),PMEAN(2),PMEAN(3)
C     WRITE(12,415)IRUN,MAXDWT,MEANDW,AMEAN(2),DEL,GAMMA,P(1),P(2),P(3),P
C     *MEAN(1),PMEAN(2),PMEAN(3),AN,M,B2,AMEAN(5),AMEAN(6),CRHR(1),CRHR(
C     *2),CRHR(3),GEARHR(1),GEARHR(2),GEARHR(3),MAXNOC,MMACM

      CALL COSTP(L7,P,GAMMA,AN,AMEAN(5),AMEAN(6),CRHR,trput,beta)

      L7=2

      CALL OPTIMU(2,AN,L9)

      GOTO (7,599),L9
  410 FORMAT(/)
  412 FORMAT(/)
  415 FORMAT('IRUN=',I2,'MAXDWTX=',I5,'MEANDWT=',I5,'AMEAN2=',F8.2,'DEL=
     *',F5.1,'GAMMA=',F5.1,/,'P(1)=',F5.1,'P(2)=',F5.1,'P(3)=',F5.1,/,'P
     *MEAN(1)=',F5.1,'PMEAN(2)=',F5.1,'PMEAN(3)=',F5.1,/,'AN=',F5.0,'M='
     *,I2,'B2=',F6.2,'AMEAN5=',F7.1,/,'AMEAN6=',F7.0,/,'CRHR(1)=',F7.0,'
```

```
     *CRHR(2)=',F7.0,'CRHR(3)=',F7.0,/,'GEARHR(1)=',F8.1,'GEARHR(2)=',F8
     *.0,'GEARHR(3)=',F8.1,/,'MAXNOC=',I2,'MMACM=',I2)
  416 FORMAT(I10)
  417 FORMAT(//'  AD1=',F6.0,5H AD2=,F6.0,4H IA=,I10,/,11H  PMEAN(1)=,F8
     *.2,10H PMEAN(2)=,F8.2,10H PMEAN(3)=,F8.2)
  418 FORMAT(3F10.2,F6.3,F6.3)
  599  continue
C     WRITE(12,418) HOUR1,HOUR2,HOUR3,BETA,GAMMA
C     WRITE(12,416) IA
C     WRITE(12,2)MAXDWT,MEANDW,MINDWT,N,P(1),p(2),p(3),A,TOTARR,MQURUN

      CALL OPTIMU(3,AN,L9)

C     GOTO 602
    7 continue
  601 continue
C     WRITE(12,416) IA
  602 STOP
      END

      SUBROUTINE WORK(HOUR1,HOUR2,HOUR3,T,TESTN2,IR1,IR2)

  702 IR1=IR2
  703 IDAYY=(T+.01)/24.
      IWEEK=IDAYY/7
      IDAYW=IDAYY-IWEEK*7
      DAYY=IDAYY
      HOUR=T-DAYY*24.
      IF(IDAYW-5) 710,720,730
  710 IF(HOUR-HOUR1) 711,712,712
  711 TESTN2=HOUR1-HOUR
      IR2=1
      GOTO 733
  712 TESTN2=24.-HOUR
      IR2=2
      GOTO 733
  720 IF(HOUR-HOUR2) 721,722,722
  721 TESTN2=HOUR2-HOUR
      IR2=1
      GOTO 733
  722 IF(HOUR3) 724,724,723
  723 TESTN2=24.-HOUR
      IR2=2
      GOTO 733
  724 TESTN2=48.-HOUR
      IR2=2
      GOTO 733
  730 IF(HOUR-HOUR3) 731,732,732
  731 TESTN2=HOUR3-HOUR
      IR2=1
      GOTO 733
  732 TESTN2=24.-HOUR
      IR2=2
  733 RETURN
      END

      SUBROUTINE CRANE(ISHIP,QUAY,M,GAMMA,N)
      DIMENSION ISHIP(4,20),QUAY(10,20),MM(3),macmp(3),Ka1(20),Ka2(20),K
     *a3(20),A12(20),KASA(20)
      common/say/ii
```

```
      common /ncr/ mm
      common/pr/kcr
      common/cwork/macmp,MACM
      common/rand/ia
      COMMON/Q/A12

310   DO 311 J=1,N
      QUAY(ii+6,J)=0.
      Ka1(j)=0
      Ka2(j)=0
      Ka3(j)=0
311   ISHIP(4,J)=0.
312   MACM=0
      do 12 k=1,ii
 12   macmp(k)=0
313   DO 321 I=1,8
314   DO 320 J=1,N
315   IF(ISHIP(1,J)-1) 320,332,316
332   ISHIP(1,J)=0.
      GOTO 320
316   IF(ISHIP(4,J)-ISHIP(3,J)) 317,320,320
317   ISHIP(4,J)=ISHIP(4,J)+1
318   MACM=MACM+1

      if(kcr.eq.1) then
      macmp(1)=macmp(1)+1
      Ka1(j)=Ka1(j)+1
      else
      endif
      if(macmp(1).gt.mm(1)) then
      macmp(2)=maCMp(2)+1
      macmp(1)=macmp(1)-1
      Ka1(j)=Ka1(j)-1
      Ka2(j)=Ka2(j)+1
      IF(MACMP(2).GT.MM(2)) THEN
      MACMP(2)=MACMP(2)-1
      Ka2(j)=Ka2(j)-1
      IF(MACMP(3).LT.MM(3)) then
      MACMP(3)=MACMP(3)+1
      Ka3(j)=Ka3(j)+1
      else
      endif
      ELSE
      ENDIF
      else
      endif

      if(kcr.eq.2) then
      macmp(2)=macmp(2)+1
      Ka2(j)=Ka2(j)+1
      else
      endif
      if(macmp(2).gt.mm(2)) then
      macmp(3)=maCMp(3)+1
      macmp(2)=macmp(2)-1
      Ka2(j)=Ka2(j)-1
      Ka3(j)=Ka3(j)+1
      IF(MACMP(3).GT.MM(3)) THEN
      MACMP(3)=MACMP(3)-1
      Ka3(j)=Ka3(j)-1
```

```
      IF(MACMP(1).LT.MM(1)) then
      MACMP(1)=MACMP(1)+1
      Ka1(j)=Ka1(j)+1
      else
      endif
      ELSE
      ENDIF
      else
      endif

      if(kcr.eq.3) then
      macmp(3)=macmp(3)+1
      Ka3(j)=Ka3(j)+1
      else
      endif
      if(macmp(3).gt.mm(3)) then
      macmp(3)=macmp(3)-1
      macmp(2)=macmp(2)+1
      Ka3(j)=Ka3(j)-1
      Ka2(j)=Ka2(j)+1
      if(macmp(2).GT.mm(2)) then
      macmp(2)=macmp(2)-1
      Ka2(j)=Ka2(j)-1
      IF(macmp(1).LT.mm(1)) then
      macmp(1)=macmp(1)+1
      Ka1(j)=Ka1(j)+1
      else
      endif
      else
      endif
      ELSE
      endif

      KASA(J)=KA1(J)+KA2(J)+KA3(J)
      macm=macmp(1)+macmp(2)+macmp(3)
      a123=KA1(j)*QUAY(2,j)+KA2(j)*QUAY(3,j)+KA3(j)*QUAY(4,j)
      QUAY(ii+7,J)=a123
      A12(J)=A123/KASA(J)
      IF(M-MACM) 330,330,320
  320 CONTINUE
  321 CONTINUE
  330 DO 428 KL=1,N
      IF(ISHIP(1,KL)) 428,428,425
  425 ACTM=ISHIP(4,KL)
      ACTM1=ISHIP(3,KL)
      ACTM3=ACTM1-ACTM
      IF(GAMMA) 430,430,424
  430 IF(QUAY(ii+7,KL)) 1,1,5
    1 continue
      WRITE(6,2) ACTM,ACTM1,Quay(ii+7,KL),KL
C     WRITE(9,2) ACTM,ACTM1,Quay(ii+7,KL),KL
    2 FORMAT('ACTM ACTM1 QUAY(ii+7,KL) KL',3F10.2,i3)
    5 GOTO 399
  424 IF(MACM.GE.M.AND.iship(3,KL).GT.KASA(KL)) GOTO 25
      GOTO 399
   25 CALL RANDOM(IA,RA)
      IF(RA.GT.0.6.AND.RA.LE.0.7) GOTO 30
      GOTO 399
   30 WRITE(14,*)'    ADDITIONAL  UNLOADDING  BY SHIPS OWN  GEAR'
      WRITE(6,*)'    ADDITIONAL  UNLOADDING  BY SHIPS OWN  GEAR'
```

```
      QUAY(ii+7,KL)=(A123+GAMMA*ACTM3*QUAY(KCR+1,KL))*(ACTM1/(ACTM+ACTM3
     *))**.25
      QUAY(ii+6,KL)=ACTM3
  399 IF(Quay(ii+7,KL).NE.0.) goto 428
      Quay(ii+7,KL)=0.001
      write(6,995)
C     write(9,995)
  995 format('  Quay(ii+7,J)   is changed from 0.  to 0.001  ')
  428 CONTINUE
      RETURN
      END

      SUBROUTINE DISCHA(ISHIP,QUAY,TEST,ADT,N,CRHR,GEARHR,NWITT,BNWaIT,P
     *)
      DIMENSION ISHIP(4,20),QUAY(10,20),TEST(22),CRHR(3),GEARHR(3),P(3)
      dimension macmp(3)
      common/pr/ kcr
      common /kara/serhan
      common/say/ii
      common/cwork/macmp,macm

      WRITE(14,140)
  140 FORMAT(/)
  331 DO 336 J=1,N
      IF(ISHIP(1,J)-2) 336,335,333
  333 ACTM=ISHIP(4,J)

      do 11 m=1,ii
      ORAN=ADT/(MACMP(1)*P(1)+MACMP(2)*P(2)+MACMP(3)*P(3)+QUAY(II+6,J)*P
     *(KCR))
      CRHR(M)=CRHR(M)+ACTM*ORAN*MACMP(M)*P(M)
   11 GEARHR(kcr)=GEARHR(kcr)+QUAY(ii+6,J)*ORAN*P(KCR)
  334 QUAY(1,J)=QUAY(1,J)-ADT*QUAY(ii+7,J)
      IF(QUAY(1,J).LT.0.)THEN
      CADT=QUAY(1,J)/QUAY(II+7,J)
      ADT=ADT+CADT
      QUAY(1,J)=0.
      ELSE
      ENDIF
      QUAY(ii+4,J)=QUAY(ii+4,J)+ADT
  335 TEST(J)=QUAY(1,J)/QUAY(ii+7,J)
  336 CONTINUE
      ANWAIT=NWITT
      BNWAIT=BNWAIT+NWITT*ADT
      RETURN
      END

      SUBROUTINE SQUEUE(KS1,NWAIT,MAXQUE,QUEUE,ARRIVE,DELTAT,L,I,TBERTH,
     *NWITT,NNWAIT)
      DIMENSION QUEUE(500,3),ARRIVE(3)
      COMMON/SK/NOSAYI,DWTQE

      DWTQE=0.
      NOSAYI=0
      NWITT=0
      GO TO (110,259),KS1
  110 NWAIT=NWAIT+1
  111 IF(NWAIT-500) 115,115,112
  112 WRITE(6,113)
      WRITE(9,113)
```

```
  113 FORMAT('  INCREASE THE DIMENSION OF QUEUE(500,3)')
      L=3
      GOTO 264
  115 continue
      QUEUE(NWAIT,1)=ARRIVE(1)-deltat
  116 QUEUE(NWAIT,2)=ARRIVE(2)
  117 QUEUE(NWAIT,3)=ARRIVE(3)
      DO 120 JN=1,NWAIT
      IF((QUEUE(JN,1).LE.TBERTH).AND.(QUEUE(JN,1).GT.0.))THEN
      DWTQE=DWTQE+QUEUE(JN,2)
      NWITT=NWITT+1
      NOSAYI=NWITT
      ELSE
      ENDIF
  120 CONTINUE
      NNWAIT=NWITT
      IF(NWITT-MAXQUE)125,125,130
  130 L=3
      WRITE(6,135)
      WRITE(9,135)
  135 FORMAT('     QUEUE FULL  -  SHIP LOST      ')
  125 GOTO 264
  259 I1=I
  260 DO 265 I=I1,NWAIT
  261 DO 263 J2=1,3
  262 QUEUE(I,J2)=QUEUE(I+1,J2)
  263 QUEUE(I+1,J2)=0.
  265 CONTINUE
CC  264 WRITE(70,1080)((QUEUE(IT,JI),JI=1,3),IT=1,NWAIT)
CC 1080 FORMAT(3F9.2)
  264 CONTINUE
      RETURN
      END

      SUBROUTINE SQUAY(KSZ,N,ISHIP,NOC,ARRIVE,QUAY,BETA,DELTAT,T,ANIDLE,
     *L3,J1,QUEUE,NWAIT,J,I)
      DIMENSION ISHIP(4,20),ARRIVE(3),QUAY(10,20),QUEUE(500,3),tqy(20)
      common/say/ii
      common/pr/kcr
      common /kara /serhan
      common /type/ntype
      COMMON/berth/TQY

      GO TO (130,220),KSZ
  130 DO 132 J=1,N
  131 IF(ISHIP(1,J)-1) 136,136,132
  132 CONTINUE
      return
  136 ISHIP(1,J)=2
      NOC=NOC+1
  137 ISHIP(2,J)=ARRIVE(2)
      serhan=iship(2,J)

      call CRATYP(serhan,kcr)

  138 QUAY(1,J)=ARRIVE(2)*BETA
  139 QUAY(ii+2,J)=ARRIVE(1)-deltat
  140 QUAY(ii+3,J)=T
  141 QUAY(ii+5,J)=ARRIVE(3)
  142 ANIDLE=ANIDLE-ARRIVE(3)
```

```
      ISHIP(3,J)=3.7+.05*(SQRT(ARRIVE(2))-60.)
      IF(ARRIVE(2).GE.25000.)ISHIP(3,J)=8
      IF(ntype.eq.'C'.or.Ntype.eq.'c') ISHIP(3,J)=2
      return
  220 L3=1
  221 DO 223 J=J1,N
  222 IF(ISHIP(1,J)-1) 224,224,223
  223 CONTINUE
      RETURN
  224 IF(NWAIT.EQ.0)RETURN
  225 ISHIP(2,J)=QUEUE(I,2)
      serhan=iship(2,j)

      call CRATYP(serhan,kcr)

      IF(ISHIP(2,J)) 1,1,226
    1 continue
      WRITE(6,2) ISHIP(2,J),I,J
    2 FORMAT('               QUEUE(I,2)=',I6,' I=',I2,' J=',I2)
      RETURN
  226 ISHIP(1,J)=2
      ANIDLE=ANIDLE-QUEUE(I,3)
      nwait=NWAIT-1
      QUAY(1,J)=QUEUE(I,2)*BETA
  227 QUAY(ii+2,J)=QUEUE(I,1)
  228 QUAY(ii+3,J)=TQY(j)
      IF(QUAY(ii+2,j).GT.TQY(j))QUAY(ii+3,J)=QUAY(II+2,J)
  229 QUAY(ii+5,J)=QUEUE(I,3)
      NOC=NOC+1
      ISHIP(3,J)=3.7+.05*(SQRT(QUEUE(I,2))-60.)
      IF(QUEUE(I,2).GE.25000.)ISHIP(3,J)=8
      IF(ntype.eq.'C'.or.Ntype.eq.'c') ISHIP(3,J)=2
      RETURN
      END

      SUBROUTINE DISTRI(L,RESULT,MAXDWT,MINDWT,AMAXDW,AMINDW,C1,P,AM,A,D
     *ELTAT,DISTR)
      DIMENSION RESULT(8),DISTR(20,5),p(3)
      common/say/jii

      pj=p(1)
      DO 5 K=1,JII
      if(p(K).GT.PJ) pj=p(K)
    5 CONTINUE
      GOTO (501,541,550,580),L
C     SHIP  SIZE  DISTRIBUTION
  501 DO 506 I=1,20
      BI=MINDWT+(MAXDWT-MINDWT)*I/20
      IF(RESULT(2)-BI) 504,504,506
  504 DISTR(I,1)=DISTR(I,1)+1
      GOTO 511
  506 CONTINUE
C      HANDLING  TIME  DISTRIBUTION
  511 DO 516 I=1,20
      AI=I
      CI=AMINDW/(C1*1.3*Pj)+(AMAXDW/(AM*.7*P(1))-AMINDW/(C1*1.3*Pj))*AI/
     *20.
      IF(RESULT(5)-CI) 514,514,516
  514 DISTR(I,3)=DISTR(I,3)+1.
      GOTO 520
```

```
  516 CONTINUE
C     WAITING TIME DISTRIBUTION
  520 IF(RESULT(8))530,530,521
  521 DO 526 I=1,19
      AI=I
      DI=AMAXDW/(7.*P(1))*AI/20.*2.
      IF(RESULT(6)-DI) 524,524,526
  524 DISTR(I,4)=DISTR(I,4)+1.
      GOTO 530
  526 CONTINUE
      DISTR(20,4)=DISTR(20,4)+1.
C      EXTENDED  HANDLING  TIME  DISTRIBUTION
  530 IF(RESULT(7)-.005) 539,539,531
  531 DO 536 I=1,20
      AI=I
      EI=AMAXDW*AI*(1./(AM*.7*P(1))-1./(7.*1.3*P(1)))/20.
      IF(RESULT(7)-EI) 534,534,536
  534 DISTR(I,5)=DISTR(I,5)+1
  535 RETURN
  536 CONTINUE
  539 RETURN
C     DISTRIBUTION  OF  ARRIVALS
  541 DO 546 I=1,19
      AI=I
      FI=4.*A*AI/20.
      IF(DELTAT-FI) 544,544,546
  544 DISTR(I,2)=DISTR(I,2)+1
      RETURN
  546 CONTINUE
      DISTR(20,2)=DISTR(20,2)+1.
      RETURN
  550 GI=AMINDW/(C1*1.3*Pj)
C     WRITE(6,403) MINDWT,GI
      DO 383 I=1,20
      AI=I
      II=MINDWT+(MAXDWT-MINDWT)*I/20
      CI=AMINDW/(C1*1.3*Pj)+(AMAXDW/(AM*.7*P(1))-AMINDW/(C1*1.3*Pj))*AI/
     *20.
      DI=AMAXDW/(7.*P(1))*AI/20.*2.
      EI=AMAXDW*AI*(1./(AM*.7*P(1))-1./(7.*1.3*P(1)))/20.
      FI=4.*A*AI/20.
C     WRITE(6,405) (DISTR(I,J),J=1,5)
C 383 WRITE(6,404) II,FI,CI,DI,EI
  383 continue
      RETURN
  403 FORMAT(//,  ' DISTRIBUTION OF',//,'    SHIP           ARRIVAL
     *   HANDLING         WAITING        EXTENDED',/,   '    SIZE
     *    INTERVALS      TIME             TIME           HANDLING TIME
     *',/,'   (DWT)     NO   (HOURS)    NO  (HOURS)     NO    (HOURS)
     *NO   (HOURS)      NO',/,I8,13X,1H0,F18.1,2(15X,1H0))
  404 FORMAT(I8,4F16.1)
  405 FORMAT(5F16.0)
  580 DO 60 I=1,20
      DO 60 J=1,5
   60 DISTR(I,J)=0.
      RETURN
      END

      SUBROUTINE LEAVE(RESULT,ANIDLE,BETA,J,TOTARR)
      DIMENSION ARRIVE(3),QUEUE(500,3),QUAY(10,20),ISHIP(4,20),RESULT(8)
```

```
     1,AMEAN(8),A12(20)
      DIMENSION TEST(22),OPTM(200,4),COST(11),pmean(3),gearhr(3),sh(3)
      COMMON IR2,K,COST  ,OPTM,NO,CMEAN,AMELOA,ADQUAY,L10,K1,T,ADT,ARRIV
     1E,MAXQUE,QUEUE,IR1,NWAIT,BNWAIT,N1,N,PMEAN,GEARHR,TOCOS1,B2,QUAY,I
     2SHIP,TEST,AMEAN,MAXWAI,AMINDW,MINDWT,AMAXDW,MAXDWT,AMEAND,MEANDW,M
     3CMEAN,CN,CM,M,AM,MAXNOC,NOC,MC,L,STEP,IN,DEL,C1,KSZ,L3,L4,KK
      common /pr/ kcr
      common/say/ii
      common/treat/sh
      COMMON/Q/A12

      NOC=NOC-1
      TEST(J)=10000000000.
      L4=2
      ANIDLE=QUAY(ii+5,J)+ANIDLE
      ACTM1=ISHIP(3,J)
  347 KK=KK+1
  348 RESULT(1)=AMEAN(1)+1.0
  349 RESULT(2)=ISHIP(2,J)
  350 RESULT(3)=RESULT(2)*BETA/ACTM1/QUAY(KCR+1,J)
  351 RESULT(4)=QUAY(ii+2,J)
  352 RESULT(5)=QUAY(ii+4,J)
  353 RESULT(6)=QUAY(ii+3,J)-QUAY(ii+2,J)
  101 format(2f10.2)
  354 RESULT(7)=QUAY(ii+4,J)-RESULT(3)
  355 RESULT(8)=0.0
  365 IF(RESULT(6).LE.0.001) GOTO 358
  357 RESULT(8)=1.0
  358 DO 359 I=2,4
  359 AMEAN(I)=(AMEAN(I)*AMEAN(1)+RESULT(I))/(AMEAN(1)+1.0)
      DO 3592 I=7,8
 3592 AMEAN(I)=(AMEAN(I)*AMEAN(1)+RESULT(I))/(AMEAN(1)+1.0)
      DO 3593 I=5,6
 3593 AMEAN(I)=(AMEAN(I)*AMEAN(1)+RESULT(I)*RESULT(2))/(AMEAN(1)+1.0)
  360 AMEAN(1)= AMEAN(1)+1.0
      PMEAN(kcr)=PMEAN(kcr)+QUAY(kcr+1,J)
      do 444 i=1,ii
  444 if(kcr.eq.i)sh(i)=sh(i)+1
      QUAY(II+4,J)=0.
      IF(AMEAN(1)-TOTARR) 362,363,363
  362 IF(KK-100) 368,363,363
C 363 WRITE(6,401)  (AMEAN(I),I=1,3),(AMEAN(I),I=5,8)
  363 continue
C     WRITE(9,401)  (AMEAN(I),I=1,3),(AMEAN(I),I=5,8)
  364 KK=0
  401 FORMAT(F7.0,1X,F11.0,4X,F6.2,4X,F10.2,2X,F10.2,2X,F10.2,2X,F10.3)
  368 RETURN
      END

      SUBROUTINE TEXTPR(IRUN,AN,P,A,BETA,GAMMA,KS3,HOUR1,HOUR2,HOUR3)
      DIMENSION ARRIVE(3),QUEUE(500,3),QUAY(10,20),ISHIP(4,20),AMEAN(8)
      DIMENSION TEST(22),OPTM(200,4),COST(11),pmean(3),gearhr(3)
      dimension p(3),mm(3),sh(3),b3(3),PMEAN1(3),MACMP(3)
      COMMON IR2,K,COST,OPTM,NO,CMEAN,AMELOA,ADQUAY,L10,K1,T,ADT,ARRIV
     *E,MAXQUE,QUEUE,IR1,NWAIT,BNWAIT,N1,N,PMEAN,GEARHR,TOCOS1,B2,QUAY,I
     *SHIP,TEST,AMEAN,MAXWAI,AMINDW,MINDWT,AMAXDW,MAXDWT,AMEAND,MEANDW,M
     *CMEAN,CN,CM,M,AM,MAXNOC,NOC,MC,L,STEP,IN,DEL,C1,KSZ,L3,L4
      common/W/pmean1
      common/aaa/b3
      common/say/ii
```

```
      common /kara/ serhan
      common /pr/ kcr
      common /ncr/ mm
      common/treat/sh
      common/cwork/macmp,macm
      COMMON/AVW/AVWAIT

      save iread
      iread=iread+1

      CALL CRANNO(mm,m,ii)

      GOTO (10,3812),KS3
   10 WRITE(6,11)
      if(iread.gt.1) goto 3
      WRITE(9,11)
   11 FORMAT('  DETERMINATION  OF  OPTIMUM  SIZE  HARBOR  TERMINAL')
    3 WRITE(6,4) IRUN
      if(iread.gt.1) goto 9912
      WRITE(9,4)IRUN
    4 FORMAT(/,'  VARIABLE BERTHS AND POISSON FREIGHTER SIZE VARIATION',
     */,'  SIMULATION NO=',I6,/)
 9912 WRITE(6,13) MINDWT,MAXDWT
      WRITE(6,8) MEANDW
      if(iread.gt.1) goto 9911
      WRITE(9,13) MINDWT,MAXDWT
      WRITE(9,8) MEANDW
    8 FORMAT('  MEAN  SHIP  SIZE       =',I6,'  DWT')
 9911 IF(MINDWT-100) 12,14,14
   12 WRITE(6,414)
      if(iread.gt.1) goto 9914
      WRITE(9,414)
 9914 KS3=2
      RETURN
   13 FORMAT('  SHIP SIZE              =',I6,5H   TO,I6,4H DWT)
   14 WRITE(6,15) AN
      WRITE(9,15) AN
   15 FORMAT('  QUAY LENGTH AVAILABLE  =',F6.0,2H M)
   16 WRITE(6,17) M,mm(1),macmp(1),mm(2),macmp(2),mm(3),macmp(3)
      WRITE(9,17) M,mm(1),macmp(1),mm(2),macmp(2),mm(3),macmp(3)
   17 FORMAT('  TOTAL NUMBER OF CRANES =',I6,/,'  NUMBER OF CRANES WITH
     *CAP. P(1)         =',I4,/,'  NUMBER OF CRANES WORKING WITH CAP. P(
     *1) =',I3,/,'  NUMBER OF CRANES WITH CAP. P(2)         =',I4,/,'  N
     *UMBER OF CRANES WORKING WITH CAP. P(2) =',I3,/,'  NUMBER OF CRANES
     * WITH CAP. P(3)         =',I4,/,'  NUMBER OF CRANES WORKING WITH C
     *AP. P(3) =',I3)
   18 DO 40 JJ=1,II
   40 WRITE(6,19) JJ,P(JJ),JJ,P(JJ)*GAMMA
C     WRITE(6,419) HOUR1,HOUR2,HOUR3,BETA
C     if(iread.gt.1) goto 9915
      DO 50 JJ=1,II
   50 WRITE(9,19) JJ,P(JJ),JJ,P(JJ)*GAMMA
      WRITE(9,419) HOUR1,HOUR2,HOUR3,BETA
   19 FORMAT(/'  CAPACITY OF QUAY CRANES P(',I1,') =',F7.2,' T/H +-  0.5
     * T/H',/,'  CAPACITY OF SHIP GEAR',I2,'      =',F7.2,' T/H +-  0.5
     *T/H')
 9915 WRITE(6,412)
      if(serhan.LE.0.) return
   24 WRITE(6,25)
   25 FORMAT(/,'       **********   RESULT OF SIMULATION  **********',/)
```

```
C  26 WRITE(6,27)
   26 continue
   27 FORMAT(1X,/,' NO OF       MEAN       MIN          ACTUAL       MEAN
     *          EXTENDED   PROBABILITY')
C  28 WRITE(6,29)
   28 continue
   29 FORMAT(' SHIPS       DWT        HANDLING     HANDLİNG    WAITING
     *       HANDLING   OF')
C  30 WRITE(6,31)
   30 continue
   31 FORMAT(  ' TREATED                TIME         TIME        TIME(DW
     *THR)   TIME       DELAY',/)
      RETURN
 3812 IF(SERHAN.LE.0) RETURN
      AMC=MCMEAN*MAXNOC
      CN=MAXNOC
      B1=AMEAND*BETA/(A*P(kcr)*AMC)
      B2=AMEAN(1)*AMEAN(5)/AMEAN(2)/(CN*T)
C     Cm=m
      AVWAIT=BNWAIT/T
      ADT=T/STEP
      WRITE(6,406) B1,B2,B3(1),b3(2),b3(3)
      WRITE(6,407) A,DEL,IN
  382 WRITE(6,402) MAXWAI,NWAIT,AVWAIT,T,ADT,MAXNOC,PMEAN1(1),pmean1(2),
     *pmean1(3)
      write(9,402) MAXWAI,NWAIT,AVWAIT,T,ADT,MAXNOC,PMEAN1(1),pmean1(2),
     *pmean1(3)
      return
  402 FORMAT('  MAX NUMBER OF SHIPS IN QUEUE     =',I5,/,'  ACTUAL NUMBE
     *R OF SHIPS IN QUEUE  =',I5,/,'  AVERAGE NUMBER OF SHIPS IN QUEUE =
     *',F6.2,/,'  TIME AT END OF SIMULATION        =',F7.1,/,'  MEAN TIM
     *E STEP USED              =',F07.2,/,'  MAX NUMBER OF SHIPS AT QUAY
     *      =',I4,/,'  ACTUAL MEAN P(1) CRANE CAPACITY  =',F7.2,'  T/H',
     */,'  ACTUAL MEAN P(2) CRANE CAPACITY  =',F7.2,'  T/H',/,'  ACTUAL
     *MEAN P(3) CRANE CAPACITY  =',F7.2,'  T/H',)
  406 FORMAT('  THEORETICAL MEAN TRAFFIC LOAD =',F9.2,/,'  ACTUAL MEAN T
     *RAFFIC LOAD      =',F9.2,//,'  MEAN P(1) CRANE UTILIZATION   =',F9
     *.2,/,'  MEAN P(2) CRANE UTILIZATION   =',F9.2,/,'  MEAN P(3) CRANE
     * UTILIZATION   =',F9.2)
  407 FORMAT('  THEORETICAL MEAN INTERVAL BETWEEN SHIP ARRIVALS =',F7.2,
     *' H.',/,'  ACTUAL MEAN INTERVAL BETWEEN SHIP ARRIVALS      ='F7.2,
     *' H.',//,'  NUMBER OF SHIPS ARRIVED          =',I5)
  412 FORMAT(/)
  414 FORMAT('  WRONG DATA   *****   READ NEXT DATA CARD')
  419 FORMAT(/,'  WORKING HOURS',/,6X,'MON - FRI',F6.2,' HOURS',/,6X,'SA
     *TURDAY',F7.2,' HOURS',/,6X,'SUNDAY',F9.2,' HOURS',/,'  CARGO TRANS
     *FER PER SHIP =',F6.3,'  DWT  TONS',/)
      end

      SUBROUTINE COSTP(L7,P,GAMMA,AN,WH,WW,CRHR,trput,beta)
      DIMENSION ARRIVE(3),QUEUE(500,3),QUAY(10,20),ISHIP(4,20),AMEAN(8)
      DIMENSION TEST(22),OPTM(200,4),COST(11)
      dimension pmean(3),gearhr(3),p(3),crhr(3),mm(3),B3(3)
      COMMON IR2,K,COST  ,OPTM,NO,CMEAN,AMELOA,ADQUAY,L10,K1,T,ADT,ARRIV
     1E,MAXQUE,QUEUE,IR1,NWAIT,BNWAIT,N1,N,PMEAN,GEARHR,TOCOS1,B  ,QUAY,I
     2SHIP,TEST,AMEAN,MAXWAI,AMINDW,MINDWT,AMAXDW,MAXDWT,AMEAND,MEANDW,M
     3CMEAN,CN,CM,M,AM,MAXNOC,NOC,MC,L,STEP,IN,A  ,C1,KSZ,L3,L4
      common /DWT1/ THEDWT,irr
      common/ncr/mm
      common/aaa/b3
```

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DOKÜMANTASYON MERKEZİ

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      common/say/ii
      COMMON/ACY/IAA

      GOTO(1,2) L7
    1 continue
    2 AMAXDW=MAXDWT
      AMEAND=MEANDW
C  20 WRITE(6,207)
   20 continue
C     WRITE(6,203)
      write(9,203)
    3 WRITE(6,4) NO+1,irr
      write(9,4) NO+1,irr
    4 FORMAT(/,'  SIMULATION NO=',I4,'/',i3,/)
C  14 WRITE(6,15) AN
   14 continue
C     write(9,15) AN
   15 FORMAT('  QUAY LENGTH AVAILABLE =',F6.0,'  M')
C  16 WRITE(6,17) M
   16 continue
   17 FORMAT('  NUMBER OF CRANES =',I6)
C     write(9,17) M
   18 DO 40 JJ=1,II
      WRITE(6,19) JJ,P(JJ),JJ,P(JJ)*GAMMA
      WRITE(9,19) JJ,P(JJ),JJ,P(JJ)*GAMMA
   40 CONTINUE
   19 FORMAT('  CAPACITY OF QUAY CRANES P(',I1,')=',F7.2,' T/H +-  0.5 T
     */H',/,'  CAPACITY OF SHIPS GEAR',I2,'    =',F7.2,' T/H +-  0.5 T/H
     *')
C     WRITE(6,205) MAXDWT,MEANDW
      QUAYL=AN
  104 AM=M
      DWTHR1=WW*8760./A
      DWTHR2=WH*8760./A
C     WRITE(6,206)A,BMEAND,PMEAN(1),PMEAN(2),PMEAN(3),B,B3(1),b3(2),b3(3)
C     write(9,206)A,BMEAND,PMEAN(1),PMEAN(2),PMEAN(3),B,B3(1),b3(2),b3(3)
      COSTQ=COST(1)*QUAYL
      COSCF1=COST(2)*mm(1)
      COSCF2=COST(3)*mm(2)
      COSCF3=COST(4)*mm(3)
      COSTCF=COScf1+coscf2+coscf3
      COSCV1=CRHR(1)*COST(5)
      COSCV2=CRHR(2)*COST(6)
      COSCV3=CRHR(3)*COST(7)
      COSTCV=coscv1+coscv2+coscv3
      COSTS1=COST(8)*DWTHR1
      COSTS2=COST(8)*DWTHR2
      COSGV1=COST(9)*GEARHR(1)
      COSGV2=COST(10)*GEARHR(2)
      COSGV3=COST(11)*GEARHR(3)
      COSTGV=COSgv1+cosgv2+COSgv3
      FIXCOS=COSTQ+COSTCF
      VARCOS=COSTCV+COSTS1+COSTS2+COSTGV
      TOCOST=FIXCOS+VARCOS
      WRITE(6,204) COST(1),QUAYL,COSTQ,COST(2),mm(1),coscf1,cost(3),mm(2
     *),coscf2,cost(4),mm(3),coSCF3,costcf,COST(5),crhr(1),coscv1,cost(6
     *),crhr(2),coscv2,cost(7),CRHR(3),coscv3,costcv,COST(9),GEARHR(1),c
     *osgv1,cost(10),gearhr(2),cosgv2,cost(11),gearhr(3),cosgv3,COSTGV
      WRITE(6,208)COST(8),DWTHR1,COSTS1,COST(8),DWTHR2,COSTS2,TOCOST
C     WRITE(9,204) COST(1),QUAYL,COSTQ,COST(2),mm(1),coscf1,cost(3),mm(2
```

```
C     *),coscf2,cost(4),mm(3),coSCF3,costcf,COST(5),crhr(1),coscv1,cost(6
C     *),crhr(2),coscv2,cost(7),CRHR(3),coscv3,costcv,COST(9),GEARHR(1),c
C     *osgv1,cost(10),gearhr(2),cosgv2,cost(11),gearhr(3),cosgv3,COSTGV
C      write(9,208) COST(8),DWTHR1,COSTS1,COST(8),DWTHR2,COSTS2,TOCOST
       TOCOS1=TOCOST
       Tq=8760.*beta*MEANdw/(A*1000000)
       FXCOS=FIXCOS/1000000.
       VRCOS=VARCOS/1000000.
       TCST=FXCOS+VRCOS
       Tqcost=VRCOS/tq*trput+FXCOS
       Tqc=8760.*beta*theDWT/(A*1000000)
       costDWT=VRCOS/tqc*trput+FXCOS
       write(9,991) TCST,TQCOST,COSTDWT
  991 format(/,'  Average            Annual Total Cost =  US $',f12.7,'
     *million',/,     '  Corrected(ARRIVAL) Annual Total Cost =  US $',f1
     *2.7,' million',/,     '  Corrected(DWT)     Annual Total Cost =  US
     * $',f12.7,' million',//)
       AM62=AMEAN(6)/AMEAN(2)
       AM52=AMEAN(5)/AMEAN(2)
       write(12,91)IAA,MAXdwt,MEANdw,MINdwt,AM62,AM52,A,P(1),MM(1),p(2),M
     *M(2),p(3),MM(3),M,AN,TCST,Tqcost,thedwt,costdwt,AMEAN(1)
       write(11,91)IAA,MAXdwt,MEANdw,MINdwt,AM62,AM52,A,P(1),MM(1),p(2),M
     *M(2),p(3),MM(3),M,AN,TCST,Tqcost,thedwt,costdwt,AMEAN(1)
   91 format(I8,3I6,28X,F7.2,6X,F7.2,/,f5.2,3(f5.0,I3),I3,F6.0,2f7.2,f8.
     *1,f6.2,F7.1)

C      stop
  201 FORMAT(11F10.4,30X)
  203 FORMAT('  TOTAL  YEARLY COSTS FOR HARBOR TERMINAL AND FOR SHIPS')
  204 FORMAT(/,29X,'1/UNIT',13X,'NO OF UNITS',12X,'1/YEAR',/,'  COST OF
     *QUAY',F23.0,F20.0,' M',F19.0,/,'  COST OF CRANES',/,'     P(1) CRA
     *NES',F21.0,I19,F22.0,/,'     P(2) CRANES',F21.0,I19,F22.0,/,'
     *P(3) CRANES',F21.0,I19,F22.0,/,56X,F22.0,/,'  OPERATION OF CRANES'
     *,/,'     P(1) CRANES',F20.4,F20.0,' HR',F19.0,/,'     P(2) CRANES'
     *,F20.4,F20.0,' HR',F19.0,/,'     P(3) CRANES',F20.4,F20.0,' HR',F1
     *9.0,/,58X,F20.0,/,'  OPERATION OF SHIPS GEAR',/,'     P(1) SHIP GE
     ,AR'F17.4,F20.0,' HR',F19.0,/,'     P(2) SHIP GEAR',F17.4,F20.0,' H
     *R',F19.0,/,'     P(3) SHIP GEAR',F17.4,F20.0,' HR',F19.0,/,59x,F19
     *.0)
  205 FORMAT('  MAXIMUM SHIP SIZE =',I10,'  DWT',/,'  MEAN SHIP SIZE =',
     *I13,'  DWT')
  206 FORMAT(/,'  RESULT OF SIMULATION',/,5X,'  MEAN INTERVAL BETWEEN SH
     *IP ARRIVALS =',F7.2,'  H.',/,5X,'  MEAN SHIP SIZE              =',F
     *8.0,' DWT',/,5X,'  MEAN CRANE CAPACITY OF P(1)=',F7.2,' T/H',/,5X,
     *'  MEAN CRANE CAPACITY OF P(2)=',F7.2,' T/H',/,5X,'  MEAN CRANE CA
     *PACITY OF P(3)=',F7.2,' T/H',/,5X,'  MEAN TRAFFIC LOAD          ='
     *,F5.2,/,5X,'  MEAN P(1) CRANE UTILIZATION=',F5.2,/,5X,'  MEAN P(2)
     * CRANE UTILIZATION=',F5.2,/,5X,'  MEAN P(3) CRANE UTILIZATION=',F5
     *.2,//)
  207 FORMAT(///)
  208 FORMAT('  WAITING OF SHIPS',/,5X,'  WAITING TIME',F17.4,F20.0,' DW
     *THR',F16.0,/,5X,'  HANDLING TIME',F16.4,F20.0,' DWTHR',F16.0,//,
     *'  TOTAL COST PER YEAR',F57.0,///)
       RETURN
       END

       SUBROUTINE OPTIMU(L11,AN,L9)
       DIMENSION ARRIVE(3),QUEUE(500,3),QUAY(10,20),ISHIP(4,20),AMEAN(8)
       DIMENSION TEST(22),OPTM(200,4),COST(11),pmean(3),gearhr(3)
       COMMON IR2,K,COST  ,OPTM,NO,CMEAN,AMELOA,ADQUAY,L10,K1,T,ADT,ARRIV
```

```
     1E,MAXQUE,QUEUE,IR1,NWAIT,BNWAIT,N1,N,PMEAN,GEARHR,TOCOST,B ,QUAY,I
     2SHIP,TEST,AMEAN,MAXWAI,AMINDW,MINDWT,AMAXDW,MAXDWT,AMEAND,MEANDW,M
     3CMEAN,CN,CM,M,AM,MAXNOC,NOC,MC,L,STEP,IN,DEL,C1,KSZ,L3,L4

C    FIND OPTIMUM SIZE TERMINAL THROUGH CHANGE OF AN AND M
     GOTO (10,30,111),L11
  10 READ(5,122) NO
     CMEAN=MCMEAN
     AMELOA=1.15*(-3.68*AMEAND/1000.+1.26*SQRT(AMEAND)-.65*(AMEAND**.33
    *)+6.95*(AMEAND**.25))
     ADQUAY=1.15*(-3.68*AMINDW/1000.+1.26*SQRT(AMINDW)-.65*(AMINDW**.33
    *)+6.95*(AMEAND**.25))
     K1=0
     L10=1
     IF(NO) 130,130,20
  20 READ(5,121) ((OPTM(I,J),J=1,4),I=1,NO)
     GOTO 130
  30 NO=NO+1
     OPTM(NO,1)=AN
     OPTM(NO,2)=M
     OPTM(NO,3)=B
     OPTM(NO,4)=TOCOST
     IF(NO-2) 35,35,55
  35 IF(B-.55) 37,36,36
  36 AN=AN+(AMELOA+ADQUAY)/2.
     M=M+MCMEAN
     GOTO 100
  37 IF(B-.25) 39,38,38
  38 AN=AN+(AMELOA+ADQUAY)/2.
     GOTO 100
  39 IF(B-.10) 41,40,40
  40 M=M-MCMEAN
     GOTO 100
  41 AN=AN-(AMELOA+ADQUAY)/2.
     M=M-MCMEAN
     GOTO 100
  55 IF(OPTM(NO,4)-OPTM(NO-1,4)) 56,58,57
  56 IF(OPTM(NO-1,4)-OPTM(NO-2,4)) 63,63,62
  57 IF(OPTM(NO-1,4)-OPTM(NO-2,4)) 61,61,60
  58 IF(OPTM(NO-1,4)-OPTM(NO-2,4)) 63,61,60
  60 N1=NO-2
     N2=NO-1
     N3=NO
     GOTO 64
  61 N1=NO-1
     N2=NO-2
     N3=NO
     GOTO 64
  62 N1=NO-2
     N2=NO
     N3=NO-1
     GOTO 64
  63 N1=NO
     N2=NO-1
     N3=NO-2
  64 GOTO (65,70),L10
  65 IF(OPTM(N1,2)/CMEAN-OPTM(N1,1)/AMELOA) 67,67,70
  67 IF(OPTM(N1,3)-OPTM(N2,3)) 80,69,81
  69 IF(OPTM(N2,3)-OPTM(N3,3)) 80,80,81
  70 K1=K1+1
```

```
      IF(K1-3) 74,72,72
   72 K1=0
      L10=1
   74 IF(OPTM(N1,3)-OPTM(N2,3)) 82,75,83
   75 IF(OPTM(N2,3)-OPTM(N3,3)) 82,82,83
   80 AN=OPTM(N1,1)+(AMELOA+ADQUAY)/2.
      GOTO 100
   81 AN=OPTM(N1,1)-(AMELOA+ADQUAY)/2.
      L10=2
      GOTO 100
   82 M=OPTM(N1,2)+2.
      GOTO 100
   83 M=OPTM(N1,2)-2.
  100 IF(M) 104,105,105
  104 M=0
  105 DO 108 I=1,NO
      AM=M
      IF(AM-OPTM(I,2)) 108,107,108
  107 IF(AN-OPTM(I,1)) 108,103,108
  108 CONTINUE
  102 IF(NO-10) 101,103,103
  101 L9=1
      GOTO 130
  103 L9=2
  110 WRITE(6,120) ((OPTM(I,J),J=1,3),OPTM(I,4)/1000000.,I=1,NO)
      GOTO 130
  111 IF(NO-10) 112,130,130
  112 WRITE(9,122) NO
      WRITE(9,121) ((OPTM(I,J),J=1,3),OPTM(I,4)/1000000.,I=1,NO)
      GOTO 110
  120 FORMAT(1H3/5X,12H QUAY LENGTH,5X,13H NO OF CRANES,5X,13H TRAFFIC L
     1OAD,5X,11H TOTAL COST//10(F14.0,F15.0,F20.2,F20.7/))
  121 FORMAT(2F14.0,1X,F9.4,1X,F15.7)
  122 FORMAT(I3)
  130 RETURN
      END

      SUBROUTINE ZERO
      DIMENSION ARRIVE(3),QUEUE(500,3),QUAY(10,20),ISHIP(4,20),AMEAN(8)
      DIMENSION TEST(22),OPTM(200,4),COST(11),pmean(3),gearhr(3),sh(3)
      COMMON IR2,K,COST ,OPTM,NO,CMEAN,AMELOA,ADQUAY,L10,K1,T,ADT,ARRIV
     1E,MAXQUE,QUEUE,IR1,NWAIT,BNWAIT,N1,N,PMEAN,GEARHR,TOCOS1,B2,QUAY,I
     2SHIP,TEST,AMEAN,MAXWAI,AMINDW,MINDWT,AMAXDW,MAXDWT,AMEAND,MEANDW,M
     3CMEAN,CN,CM,M,AM,MAXNOC,NOC,MC,L,STEP,IN,DEL,C1,KSZ,L3,L4,KEE,MACM
     4,MMACM
      common/treat/sh
      common/say/ii
      COMMON/SK/NOSAYI,DWTQE

      QDWT=0.
      NQUAY=0
      ARTQUA=0.
      DWTQE=0.
      NOSAYI=0
      NWITT=0
      SHIN=0
   43 T=0.
      ADT=0.
   44 ARRIVE(1)=0.
      DO 46 J=1,3
```

```
   45 DO 46 I=1,500
   46 QUEUE(I,J)=0.
      IR2=1
   47 NWAIT=0
      BNWAIT=0.
      N1=N+2
      DO 60 I=1,ii
      sh(i)=0
      PMEAN(I)=0.
   60 GEARHR(I)=0.
      TOCOS1=0.
      B2=0.
   48 DO 53 J=1,N
   49 DO 51 I=1,4
   51 ISHIP(I,J)=0
      TEST(J)=10000000000.
      DO 53 I=1,ii+7
   53 QUAY(I,J)=0.
   54 DO 55 I=1,8
   55 AMEAN(I)=0.
   56 MAXWAI=0
      MMACM=0
      AMINDW=MINDWT
      AMAXDW=MAXDWT
      AMEAND=MEANDW
      MCMEAN=3.7+.05*(SQRT(AMEAND)-60.)
   57 K=0
      CN=N
      CM=M
      AM=CM/CN
      MAXNOC=1
      NOC=0
      MC=3.7+.05*(SQRT(AMINDW)-60.)
   58 L=1
      STEP=0.
      IN=0
      DEL=0.
      C1=MC
      RETURN
      END

      SUBROUTINE RANDOM(IX,YFL)

C     SAVE no
      IY=MOD(IX,65536)*655.36+3*IX*.01
    1 IF(IY.LT.21474836.48) GO TO 2
      IY=IY-21474836.48
      GO TO 1
    2 YFL=IY*.4656611287525E-9*100.
      IX=IY*100
C     NO=NO+1
C     WRITE(9,99) NO,YFL
C  99 FORMAT(I5,F10.7)
      RETURN
      END

      SUBROUTINE CRATYP(serhan,kcr)
      common/say/ii
      common/ttt/erhan,rhan
```

```
      if(ii.eq.3) then
      kcr=2
      if(serhan.lt.erhan) kcr=3
      if(serhan.gt.rhan) kcr=1
      else
      endif
      if(ii.eq.2) then
      kcr=1
      if(serhan.lt.erhan) kcr=2
      else
      endif
      if(ii.eq.1) kcr=1
      return
      end

      SUBROUTINE CRANNO(mm,m,ii)
      dimension mm(3)
      common/ratio/ratio1,ratio2,ratio3

      GOTO (10,20,30),II
10    MM(1)=M
      RETURN
20    mm(1)=m*ratio1
      mm(2)=m*ratio2
      GOTO 40
30    mm(1)=m*ratio1
      mm(2)=m*ratio2
      mm(3)=m*ratio3
40    DO 50 J=1,II
      NC=mm(1)+mm(2)+mm(3)
      IF(NC.LT.M) THEN
      mm(J)=mm(J)+1
      else
      endif
50    CONTINUE
      return
      end
```

The user of the simulation programme, must take into account that, if a bigger harbor, able to handle more than 20 ships at a time, is to be simulated the DIMENSION statements including QUAY(10,N), ISHIP(4,N), TEST(N+2), and TQY(N) should be changed according to the berth number (N).

Also, it is recommended to input the increment of the quay length to be half of the minimum size of the ships calling the port.

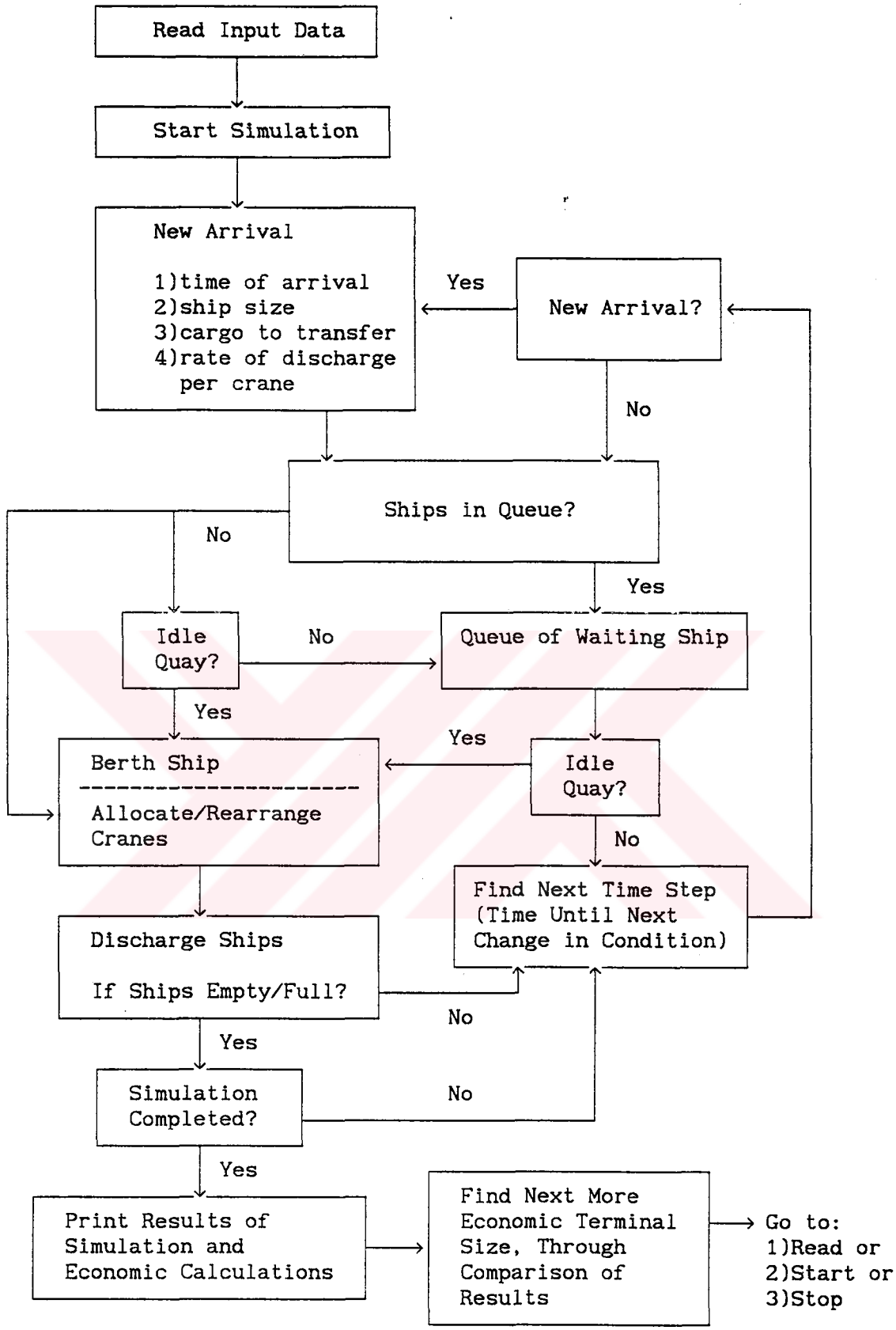


Figure B.1 Flow Chart of the Computer Simulation Programme SERCG

APPENDIX C

HANDLING EQUIPMENT OF SOME PORTS IN TÜRKİYE

In ports loading and unloading are maintained by various equipment. These equipment change in number and capacity both among themselves and in their sub-divisions. The handling equipment of some ports in Türkiye are given in the following [1].

a) Port of Samsun

Samsun port is located on the Black Sea. The port is protected by two breakwaters. 2700 m and 1130 m long. The width at the port entrance is 200 m. The port provides facilities for handling general cargo and dry bulk.

Handling Equipment

19 Shore and yard cranes of 3 to 35 tons capacity.
8 Mobile cranes of 3 to 25 tons capacity.
18 General cargo forklifts of 2 to 5 tons capacity.
2 Tugmaster-Trailer sets.

1 Loader.

b) Port of Haydarpaşa

Haydarpaşa port is situated on the Anatolian side of the Bosphorus. The port has two breakwaters about 1700 m and 600 m long. The Sea area inside breakwaters is 62 hectares. There is no special entrance channel to the port as the sea outside the breakwater is deep enough for the larger ships expected.

Handling Equipment

2 Container gantry cranes of 40 tons capacity.
28 Shore and yard cranes of 3 to 35 tons capacity.
2 Special container mobile cranes of 40 tons cap.
6 Transtainers of 35 tons capacity.
22 Mobile cranes Of 3 to 25 tons capacity.
5 Container forklifts of 10 to 42 tons capacity.
54 General cargo forklifts of 2 to 5 tons capacity.
20 Tugmaster-Trailer sets.
1 Loader.

c) Port of Bandırma

Bandırma port is situated on the south side of Marmara Sea. The port is protected by two breakwaters, 1000 m and 500 m long.The port provides facilities for

handling general cargo and dry bulk.

Handling Equipment

15 Shore cranes of 3 to 35 tons capacity.
5 Mobile cranes of 3 to 25 tons capacity.
11 General cargo forklifts of 2 to 5 tons capacity.
2 Loaders.

d) Port of Mersin

Mersin port is situated in the eastern part of the Mediterranean coast. The port is protected by two breakwaters, 2360 m and 1500 m long. The depth at the entrance is 14 m and 12 m. inside the breakwaters. It is the main port for the Eastern Mediterranean region's industry and agriculture. Mersin port is also a major transit port to Iraq and Iran. The facilities at the port handle general cargo, containers, dry and liquid bulk and ro-ro.

Handling Equipment

5 Container gantry cranes.
17 Shore cranes of 3 to 35 tons capacity.
2 Special container mobile cranes of 40 tons cap.
13 Transtainers of 35 tons capacity.
18 Mobile cranes of 3 to 25 tons capacity.

6 Container forklifts of 10 to 42 tons capacity.

46 General cargo forklifts of 2 to 5 tons capacity.

32 Tugmaster-Trailer sets.

1 Loader.

APPENDIX D

A HYPOTHETICAL CASE STUDY SHOWING THE REPLACEMENT AND SERVICING OF SHIPS CALLING AT A PORT

Existing number and capacity of cranes which serve for the following ship sizes are given as:

3 of P_1 t/hr serving to ships; 15000 < ship size < 20000

2 of P_2 t/hr serving to ships; 8000 < ship size < 15000

2 of P_3 t/hr serving to ships; 4000 < ship size < 8000

Only one crane or ship's gear is assigned for each hatch of the ship. Size of the ships which arrived to a port and corresponding crane sets assigned to the ship at quay is given in Table D.1. and in the following figures.

Table D.1 Hypothetical Distribution of Cranes at a Port

SHIP NO	SIZE DWT	THEORETICAL CRANE SET	ACTUAL CRANE SET
1	16900	$3P_1$	$3P_1$
2	8500	$2P_2$	$2P_2 \rightarrow P_2 + P_3$
3	14500	$3P_2$	$P_2 + P_3 \rightarrow 2P_2 + P_3$
4	12500	$3P_2$	$2P_2 + P_3 \rightarrow P_2 + 2P_1$
5	4700	P_3	P_3
6	5300	P_3	P_3
7	10100	$2P_2$	$P_2 + P_3 \rightarrow P_1 + P_2 \rightarrow 2P_2$
8	19000	$5P_1$	$2P_1 + P_2 + P_3 + \text{GEAR}$ $\rightarrow 3P_1 + P_3 + \text{GEAR}$ $\rightarrow 3P_1 + 2P_3 \rightarrow 2P_1 + P_2 + P_3$
9	6100	P_3	P_3
10	16600	$4P_1$	$3P_1 + \text{GEAR}$ $\rightarrow P_1 + P_2 + P_3 + \text{GEAR}$
11	6000	P_3	P_3
12	9000	$2P_2$	$2P_2$
13	17000	$3P_1$	$P_1 + P_2 + P_3$

(o o o) ship at queue

(o o o) ship at quay

quay cranes on ship

o o o hatches

* * * hatches with ship's gear

* * * ship's gear on use

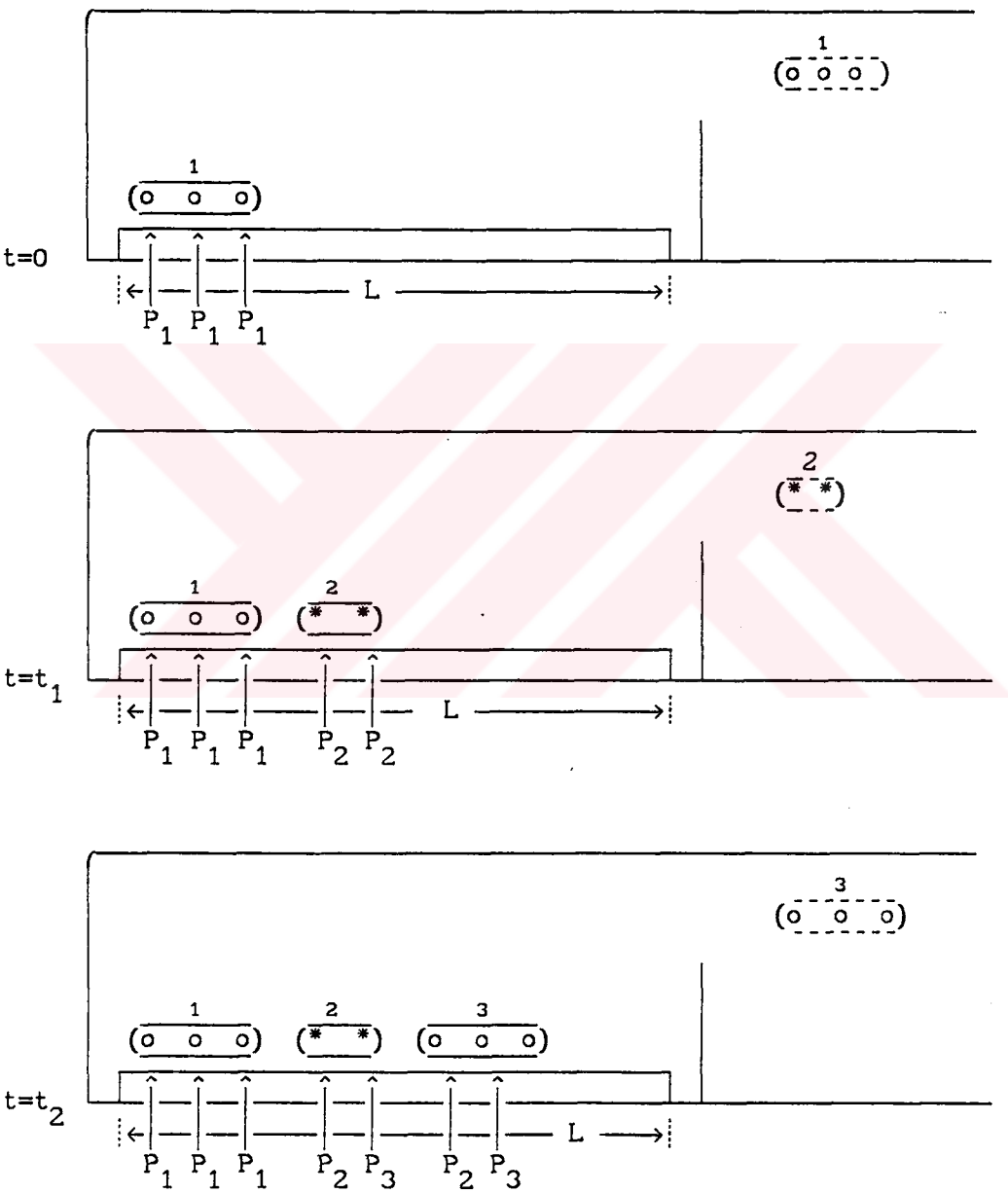


Figure D.1 A Hypothetical Case Study Showing the Replacement and Servicing of Ships

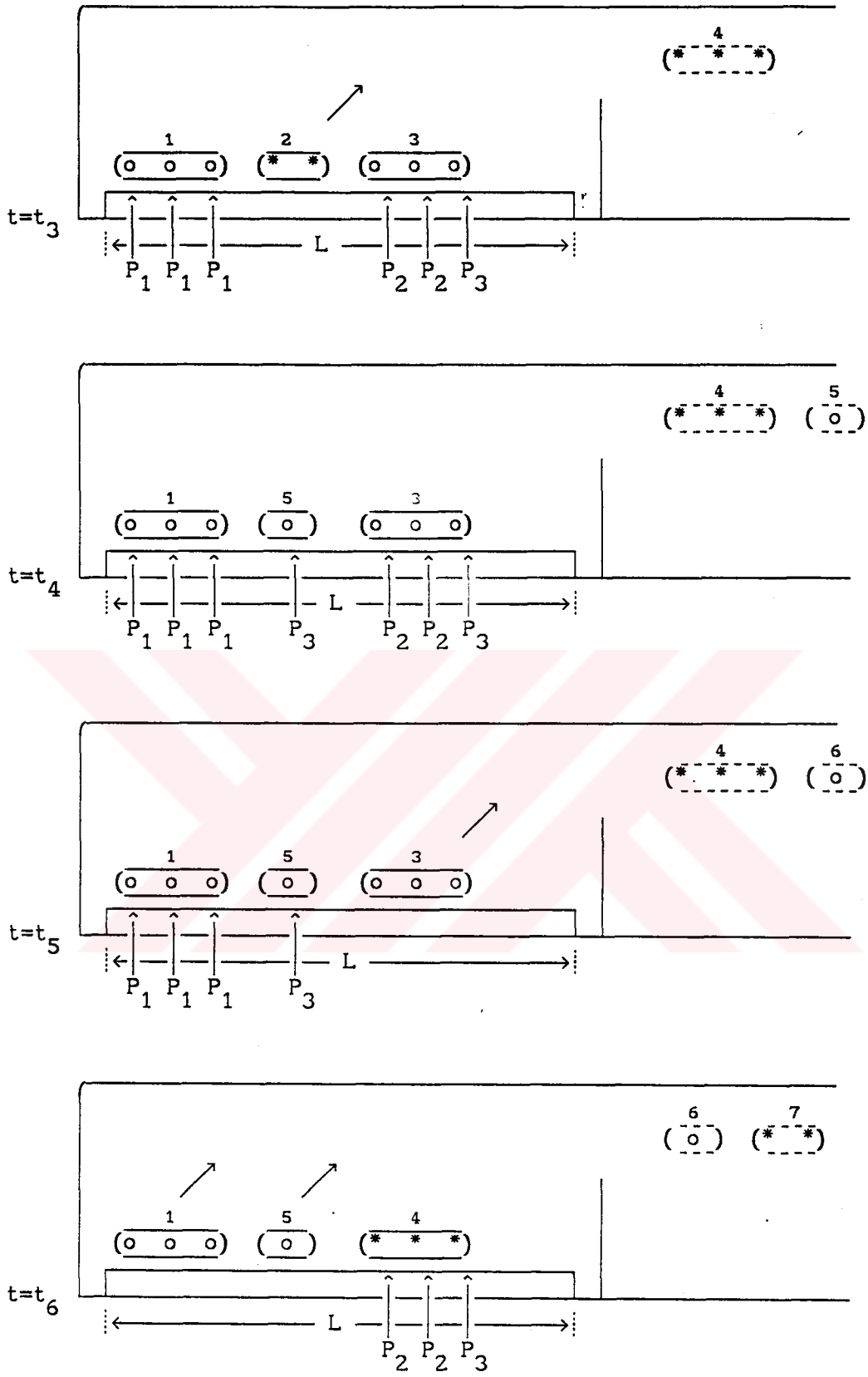


Figure D.1 A Hypothetical Case Study Showing the Replacement and Servicing of Ships

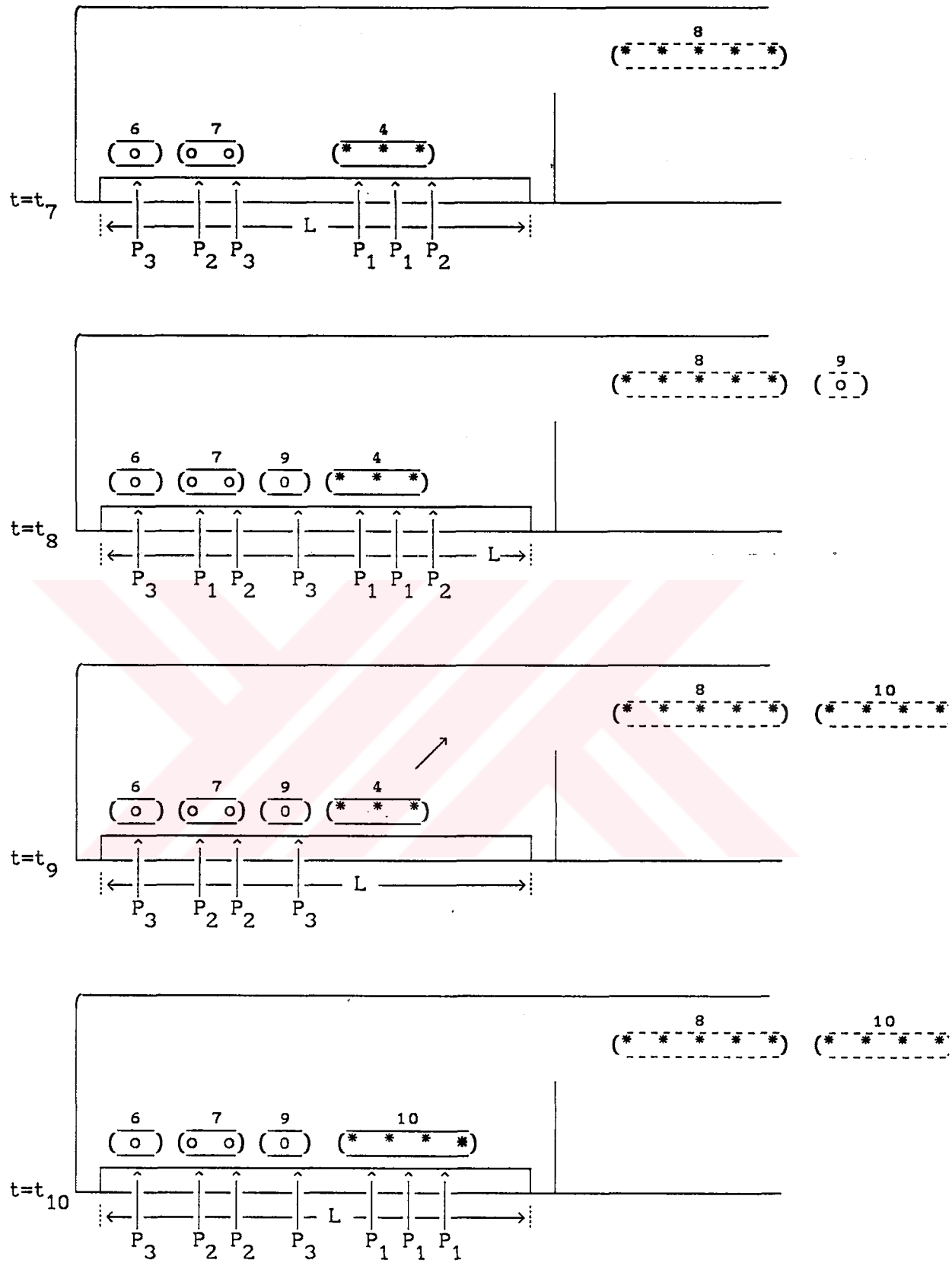


Figure D.1 A Hypothetical Case Study Showing the Replacement and Servicing of Ships

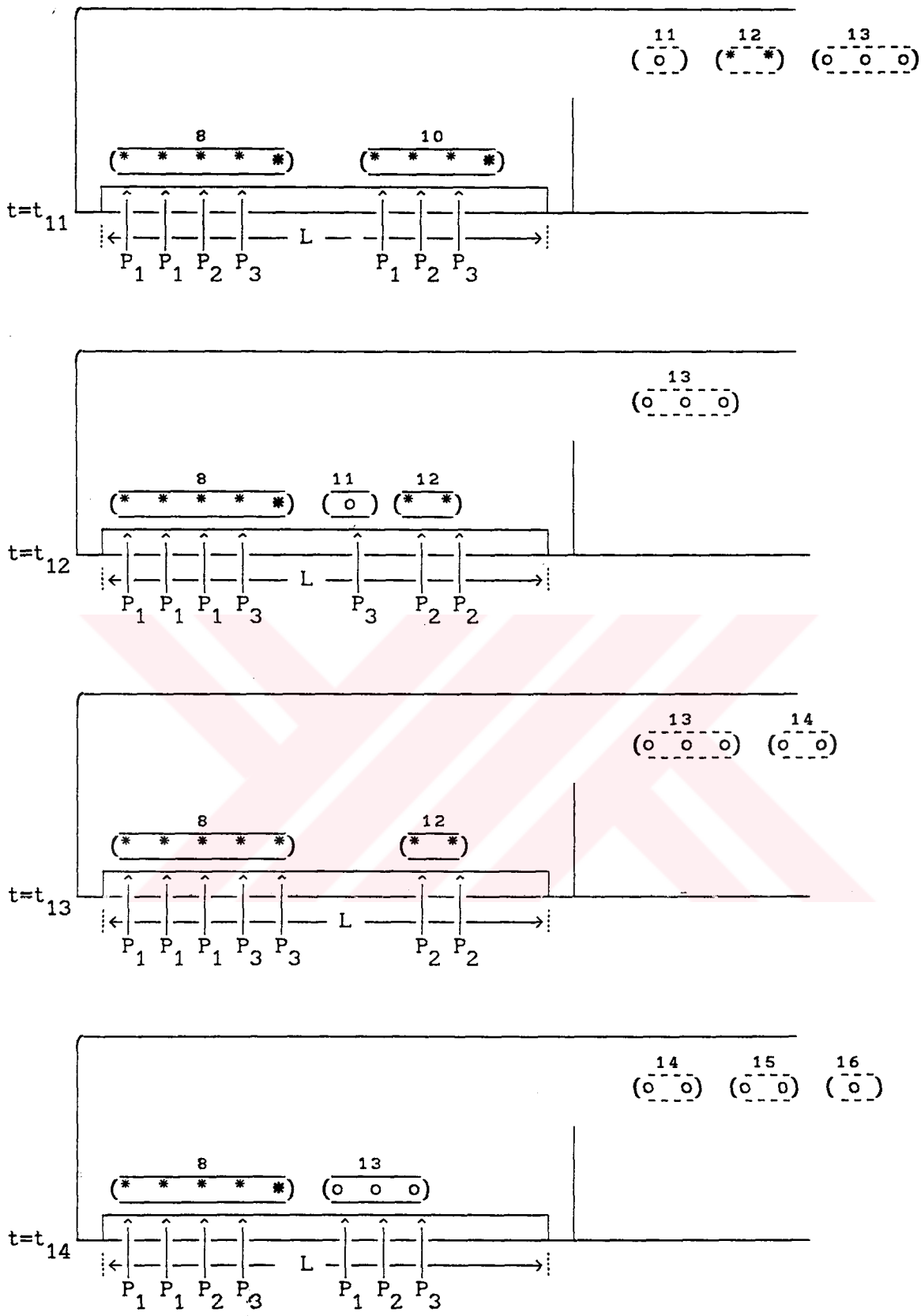
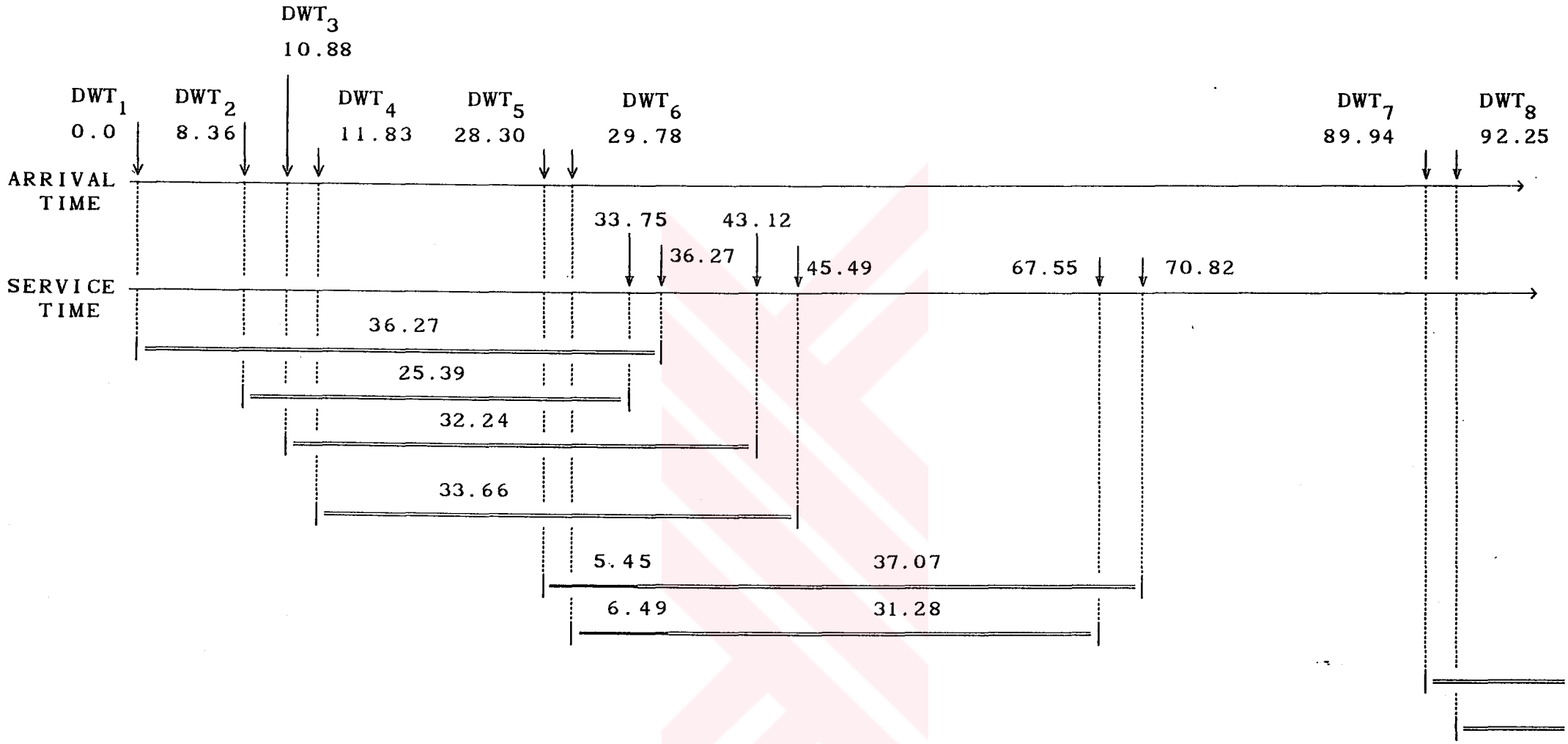


Figure D.1 A Hypothetical Case Study Showing the Replacement and Servicing of Ships

APPENDIX E

SOME OF THE SIMULATED RESULTS OF ARRIVAL, WAITING AND SERVICE TIME FOR THE GENERAL CARGO TERMINAL IN İZMİR PORT



——— : WAITING TIME ═══ : SERVICE TIME

DWT_1 : 9239 DWT_2 : 8999 DWT_3 : 13645 DWT_4 : 10836 DWT_5 : 11848 DWT_6 : 5365 DWT_7 : 8118 DWT_8 : 5093 DWT_9 : 6173

OME OF THE SIMULATED RESULTS OF ARRIVAL, WAITING AND SERVICE TIME FOR THE GENERAL CARGO TERMINAL IN İZMİR PORT

APPENDIX F

PRINT OUTS OF THE SIMULATION PROGRAMME

```
PLEASE WRITE KIND OF TERMINAL (NTYPE)
GENERAL CARGO TERMINAL WITH SHORE CRANES OR
CONTAINER TERMINAL WITH GANTRY CRANES !!
           g
PLEASE ENTER YEARLY AMOUNT OF CARGO (QQ) ton/year !!
 7500000.0
PLEASE ENTER MAXDWT,MEANDW & MINDWT OF SHIP
RESPECTIVELY !!
     20000       10000        4000
PLEASE ENTER BERTH NUMBER (N) &
NUMBER OF DIFFERENT KIND OF CRANES (ii)
RESPECTIVELY !!
         9           3
PLEASE ENTER WORKING HOURS; MONDAY TO FRIDAY (HOUR1)
                           SATURDAY (HOUR2)
                           SUNDAY (HOUR3)
RESPECTIVELY !!
 15.000      15.000      15.000
PLEASE ENTER ACTUAL CARGO CARRYING CAPACITY
 COEFFICIENT (BETA) !!
   .700
PLEASE ENTER SHIP GEAR UTILIZATION PARAMETER(GAMMA)!!
   .000
PLEASE ENTER MAXIMUM NUMBER OF SHIPS
IN THE QUEUE * 10E5 (MQURUN) !!
  20000000
PLEASE ENTER 5 OR MORE DIGIT INTEGER
RANDOM NUMBER (IA) !!
   6275817
PLEASE ENTER CAPACITY OF CRANES P(1),P(2) & P(3)
IN TONS RESPECTIVELY !!
      70.0          60.0          36.0
PLEASE ENTER COST OF QUAY COST(1) &
HOURLY COST OF SHIP COST(8) RESPECTIVELY !!
   1200.000000    1.200000E-02
PLEASE ENTER COST OF CRANES
COST(2),COST(3) & COST(4) RESPECTIVELY !!
  256000.0       240000.0       165000.0
PLEASE ENTER OPERATION COST OF CRANES
COST(5),COST(6) & COST(7) RESPECTIVELY !!
  8.400       8.200       6.600
PLEASE ENTER OPERATION COST OF SHIP GEAR
COST(9),COST(10) & COST(11) RESPECTIVELY !!
  8.400       8.200       6.600
PLEASE ENTER INITIAL,FINAL & INCREMENT OF CRANE
NUMBER RESPECTIVELY !!
        32          32           1
PLEASE ENTER INITIAL,FINAL & INCREMENT OF QUAY
LENGTH RESPECTIVELY !!
      1150        1150          50
PLEASE ENTER RATIOS OF CRANE(1),CRANE(2) & CRANE(3)
IN TOTAL CRANE NUMBER RESPECTIVELY !!
   .100        .300        .600
PLEASE ENTER THE LOWER & UPPER LIMIT OF DWT
THAT CRANE(2) SERVES !!
    8000.0        15000.0
```

```
 9618795 20000 10000  4000                                  331.23      32.35
12.70  70.  2  60.  6  36. 11 19  400.  33.68  32.52  9925.9 32.73  163.0
 9618795 20000 10000  4000                                  346.46      30.61
13.54  70.  2  60.  6  36. 11 19  450.  31.82  32.49  9942.1 32.65  304.0
 9618795 20000 10000  4000                                  252.34      32.19
13.55  70.  2  60.  6  36. 11 19  500.  26.38  26.92  9951.9 27.03  456.0
 9618795 20000 10000  4000                                  244.74      32.43
13.34  70.  2  60.  6  36. 11 19  550.  26.91  27.11 10027.9 27.04  657.0
 9618795 20000 10000  4000                                   95.71      32.25
14.01  70.  2  60.  6  36. 11 19  600.  14.74  15.36  9951.0 15.41  657.0
 9618795 20000 10000  4000                                   51.95      32.54
13.38  70.  2  60.  6  36. 11 19  650.  12.00  12.08 10083.6 12.02  657.0
 9618795 20000 10000  4000                                   13.97      34.92
12.84  70.  2  60.  6  36. 11 19  700.   9.36   9.22  9983.1  9.23  657.0
 9618795 20000 10000  4000                                    7.16      36.82
13.18  70.  2  60.  6  36. 11 19  750.   8.95   8.94 10072.1  8.91  657.0
 9618795 20000 10000  4000                                   12.33      38.46
13.30  70.  2  60.  6  36. 11 19  800.   9.54   9.56 10120.5  9.51  657.0
 9618795 20000 10000  4000                                    8.13      40.24
14.01  70.  2  60.  6  36. 11 19  850.   9.05   9.31  9822.6  9.39  657.0
 9618795 20000 10000  4000                                    3.04      42.96
13.29  70.  2  60.  6  36. 11 19  900.   9.07   9.09  9646.2  9.25  657.0
 9618795 20000 10000  4000                                   23.22      48.54
12.48  70.  2  60.  6  36. 11 19  950.  11.79  11.41 10094.0 11.34  657.0
 9618795 20000 10000  4000                                   15.81      49.51
12.75  70.  2  60.  6  36. 11 19 1000.  11.18  10.95 10122.9 10.88  657.0
 9618795 20000 10000  4000                                    4.78      50.35
13.81  70.  2  60.  6  36. 11 19 1050.   9.96  10.18 10068.0 10.15  657.0
 9618795 20000 10000  4000                                    7.99      49.32
13.36  70.  2  60.  6  36. 11 19 1100.  10.15  10.20  9650.0 10.39  657.0
 9618795 20000 10000  4000                                   13.59      56.65
12.92  70.  2  60.  6  36. 11 19 1150.  11.60  11.45  9942.4 11.48  657.0
 9618795 20000 10000  4000                                    4.71      55.27
13.49  70.  2  60.  6  36. 11 19 1200.  10.63  10.74 10040.4 10.71  657.0
 9618795 20000 10000  4000                                    1.42      53.71
14.28  70.  2  60.  6  36. 11 19 1250.   9.95  10.32  9849.0 10.40  657.0
 9618795 20000 10000  4000                                   10.30      62.72
12.50  70.  2  60.  6  36. 11 19 1300.  12.13  11.76  9855.5 11.85  657.0
 9618795 20000 10000  4000                                    7.32      63.04
12.92  70.  2  60.  6  36. 11 19 1350.  11.71  11.57  9781.6 11.71  657.0
 9618795 20000 10000  4000                                    7.64      67.19
13.01  70.  2  60.  6  36. 11 19 1400.  12.21  12.10  9928.4 12.15  657.0
 9618795 20000 10000  4000                                   10.81      66.75
13.19  70.  2  60.  6  36. 11 19 1450.  12.46  12.44 10034.5 12.42  657.0
 9618795 20000 10000  4000                                    3.04      66.97
13.34  70.  2  60.  6  36. 11 19 1500.  11.78  11.84  9948.8 11.87  657.0
 9618795 20000 10000  4000                                    3.37      66.65
13.52  70.  2  60.  6  36. 11 19 1550.  11.80  11.94 10016.8 11.93  657.0
 9618795 20000 10000  4000                                    6.84      79.01
13.17  70.  2  60.  6  36. 11 19 1600.  13.59  13.56 10454.3 13.22  657.0
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