OPTIMUM PLANNING OF CONTAINER YARDS

by

Adem EREN

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OPTIMUM PLANNING OF CONTAINER YARDS

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Ph.D. THESIS EXAMINATION RESULT FORM

We certify that we have read the thesis, entitled **"Optimum Planning Of Container Yards"** completed by Adem EREN under supervision of Prof. Dr. Orhan USLU and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.

Orhan USLU, Prof. Dr.

Supervisor

Sedat KABDAŞLI, Prof. Dr.

Jury Member

Ümit GÖKKUŞ, Prof. Dr.

Jury Member

Funda YERCAN, Assoc. Prof. Dr.

Jury Member

Erdem SAYIN, Asst. Prof. Dr.

Jury Member

Approved by the
Graduate School of Natural and Applied Sciences

Prof.Dr.Cahit Helvacı
Director

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Adem EREN

ABSTRACT

Container yard optimization can be carried out by evaluating together the mathematical modeling of container operations at yard and the cost analysis caused by yard capacity limited or excessive container traffic. Mathematical modeling can include some operational research techniques and classic mathematical theories. However, the costs appearing in a yard can be introduced as costs of idle slots, service and vehicle (ship, truck and wagon) waiting for service. The aim of the yard optimization is to yield the optimum size of container yard corresponding to the minimum total cost obtained from yard operations.

In order to optimize yard capacity, the studies conducted in this thesis deals with developing the Monte Carlo simulation which may be special for yard operations and presents the original applications of several operational research techniques in yard planning. The used techniques are the inventory modeling, queue modeling based on the bulk queue model, Monte Carlo simulation based on objective function solving by generating container traffic conditions to be coincided and queuing simulation realized by using the software, Container Yard Optimization CYO, which is completely new

The mathematical optimization and simulation models generated for only yard planning are applied to the container yard of İzmir Port. In case study, the statistics and assumptions which are taken into account are processed in accordance with the mentioned models. Even though models differentiate from each other, the results on yard container capacity obtained from each model show approximately similarity.

Key Words: Container Yard Planning, Storage Yard, Optimization, Queue Model, Inventory Model, Simulation, Port Cost Analysis

ÖZET

Konteynır sahası optimizasyonu, sahadaki konteynır hareketlerinin matematik modellemesinin değerlendirilmesiyle ve sınırlı kapasitedeki veya fazla konteynır trafiği olan sahaların maliyet analizi ile sağlanabilir. Matematik modelleme klasik matematik teorilerini ve bazı yöneylem araştırma tekniklerini dahil eder. Stok sahasındaki maliyetler boş konteynır yerlerinin, servis hizmetinin ve servis için bekleyen gemi, kamyon ve vagonların maliyetleri şeklinde yazılabilir. Saha optimizasyonunun amacı, saha operasyonlarından elde edilen minimum toplam maliyete karşılık gelen optimum konteynır sahasının boyutunu vermektir.

Bu tezde icra edilen çalışmalar, saha kapasitesini optimize etmek için, saha operasyonları için özel ve yeni kabul edilebilecek, Monte Carlo simülasyonu ve bazı orijinal yöneylem araştırma tekniklerini kullanır. Kullanılan teknikler; envanter modellemesi, toplu gelişli kuyruk modeli, konteynır trafiği oluşturarak amaç fonksiyonu çözümüne dayanan Monte Carlo simülasyonu ve kuyruk simülasyonu gerçekleştiren yeni geliştirilmiş Container Yard Optimization, CYO yazılımıdır.

Sadece saha planlaması için oluşturulmuş matematik optimizasyon ve simülasyon modelleri İzmir Limanı için uygulanmıştır. Örnek çalışmada, dikkate alınan kabuller ve istatistik bahsi geçen modellerde değerlendirilmiştir. Modeller birbirlerinden farklı olmasına rağmen, her bir modelden elde edilen konteynır saha kapasiteleri birbirlerine çok yakındır.

Anahtar Sözcükler: Konteyner Sahası Planlaması, Stok Sahası, Optimizasyon, Kuyruk Modeli, Envanter Modeli, Simülasyon, Liman Maliyet Analizi

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Development in the world trade has been increasing the importance of transportation systems. Especially, the marine transportation system provides many advantages in terms of transport economy and great amount of cargo flow for the national economy. One of the most essential prerequisites for economic progress and development of a country is to have reliable means of marine transportation and seaport of adequate capacity. Marine transportation system has been rapidly developing with the technological development in ship industry, containerization, the development of integrated transport system and mentality of door-to-door container operation, growth of land distribution system, and growth of shipping fleet and hinterland transport facilities. For this reason, the importance of planning of port facilities has been apparently increasing by the port authorities in the countries especially where the overseas trade acting on the national economy and the technological and social developments play an important role.

Even though the port planning principles change according to the local, economical and political conditions of a country, the main objectives of port planning are generally stable. These are described as: serving international trade, assisting in generating trade and regional industrial development, capturing an increased share of international traffic either by trans-shipment or by inland routing, and providing transit facilities for distant hinterlands not traditionally served or for neighboring land-locked countries. Planning studies are carried out in physical planning of infra and super structures and economical planning. Both the physical and economical planning necessitates the optimization process.

1.2 Study Content

This study aims to state the optimum size of container yard except for the area of container freight station. The known operational research methods are executed for obtaining the optimum value of yard container capacity. However the development of new approach and software to be able to solve it is objected in the scope of this thesis. The mathematical optimization methods such as the inventory and queuing methods are progressively used in addition to simulation. The main objectives of this thesis are dealt with as follows:

- To optimize the size of container yard by using the known mathematical optimization methods and developing new approaches.
- To select the different type of queuing model based on bulk queue system and realize its application especially for bulking container system in yard optimization.

- To develop Monte Carlo simulation to search all extreme conditions of the container traffic flows to be able to solve optimally the yard capacity.
- To develop new queuing simulation software, Container Yard Optimization, CYO, to be able to use in solving the complicated traffic operation in yard.
- To develop an approach and offer a solution for missing and incomplete data of container terminals to simulate traffic.
- To compare the mathematical optimization methods with their advantages and disadvantages to show their applications to yard problem.
- To analysis and compare the dominant parameters affecting the optimum container size and cost functions.

In the study, first of all, literature background on container terminals and yard optimization in Chapter Two. The principles of container port planning, operation and management for a port are summarized in Chapter Three. This part covers general principles of planning of port facilities, operations applied to containers flowing from gate to berth and basic elements of a port management.

Chapter Four includes general yard planning, yard operations in export and import storage areas, the procedure applied to empty and full containers and activities in container fright station, CFS.

In Chapter Five, the mentioned basic elements of yard planning are processed by using the optimization methods such *as inventory method, queuing modeling, Monte Carlo simulation and queuing simulation.*

Chapter Six presents the information about the realization and application of optimization methods. In order to determine the container yard capacity, all methods are essayed by using the design parameters obtained from İzmir Port. Data on ships, trucks and containers is gathered and tested by Chi-square method. The mentioned four optimization methods are utilized however with the evaluation of cost analysis projected by each method.

In conclusion, it is dealt with the objectives of this study, the advantages and disadvantages of employed optimization methods, the contribution to the scientific and technical environment, findings obtained from the mentioned methods, and design input parameters and results of methods applied for İzmir Port.

CHAPTER TWO
LITERATURE BACKGROUND

2.1 Literature Background

Port evaluation, port development, port capacity analysis, investment cost, port management, handling equipment, productivity analysis, technological developments and their application, traffic forecast, re-handling and marshalling, optimum berth sizing and many as these were researched by researchers and project teams in the past and have been developing continuously.

Creton (1973) studied on an approach to the optimal design of a container terminal for his master thesis using a G.P.S.S. simulation. The analysis of a container terminal points out the significant controllable variables used in the design. The model developed is static, discrete and stochastic. It is limited to the operational aspects of the transfer of containers from ship to hinterland transportation equipments and vice-versa. The literature does not present any specific. This model allows the comparison of different types of designs while varying the number of facilities. This optimization technique could be refined and extended to more comprehensive designs.

Hoong, Lui and Hua (1982) studied on computer simulation model to find the optimum level of equipment investment in a container terminal. In Quay Cranes and yard equipment would be one where the overall cost to the terminal and to the ship operators is at a minimum for a particular level of container traffic. This article describes a simulation model developed to forecast the optimum equipment investment for the Tanjong Pagar container terminal, Port of Singapore, over the next five years of study.

Wong, Grant and Curley (1983) coded a software on marine and rail container terminal simulation model called TANDEM. SRI International's terminal analysis, design, and evaluation model (TANDEM) is a computer-based tool that assists designers in the planning, design or rehabilitation, and operational evaluation of marine or rail container terminal facilities. The unique characteristics of each terminal facility dictate that engineering judgment and past experience by augmented by systematic analysis methods such as TANDEM. The use of TANDEM permits the designer to evaluate and explore alternative designs and methods of operation for intermodal terminals so that the optimum design can be selected. An example is presented of the use of TANDEM to determine the effect of a change from a two-ship-a-week to a three-ship-a-week schedule on operations at a hypothetical terminal.

Macisaac, Brown and Grunwell (1984) presented a report on container terminal simulation model. The container terminal simulation is a computer simulation of the major operations in an inland container terminal: inbound train arrivals and unloading, outbound train's departures and loading, storage of containers arriving by train or by truck, customer pick-up of containers. The model consists of a batch simulation and a graphical postprocessor. The simulation evaluates plant designs. The results are then transmitted to a microcomputer where the simulated operations in the terminal are replayed on a graphics monitor. The model was used to study equipment trade-offs at CN's Toronto container facility under projected increased traffic levels.

Frankel (1986) studied on Modeling Container Terminal Operations that is an application of stochastic probabilistic simulation.

Hedrick and Akalin (1989) developed a software, PCTERM (Pc-Based Terminal Equipment And Resource Model) And TOSP (Terminal Operations Simulation Program) for container terminal operations using simulation

Batchelor (1993) studied impact of productivity improvements on container terminal planning in his master thesis. A port is a complex system. Inter-relations between ships and terminals cannot be expressed in a simple mathematical form. Computer simulation provides a tool that can be used to measure the response of a port system to different inputs. His report examines the impact that different productivity levels have on the planned expansion of container and multipurpose facilities at Fisherman Islands, Port of Brisbane. It assesses a number of different measures of productivity and the factors that influence productivity levels. Comparisons are made between the Port of Brisbane, Australian ports and international ports The report details the use of a comprehensive computer simulation model of the Port of Brisbane to measure the impact of a range of different container handling rates on planned facilities.

Ramani (1996) studied on interactive simulation model for the logistics planning of container operations in seaports. Today, more than 90 percent of international cargo moves through seaports, and 80 percent of sea-borne cargo moves in containers. It has thus become imperative for major seaports to manage their container operations both effectively and efficiently. He has designed and developed an interactive computer simulation model to support the logistics planning of container operations. Logistics planning of container operations deals with the assignment and coordination of port equipment such as quay cranes, prime movers, and yard cranes in the transportation of containers between the ship's bay and the container storage yards. This model provides estimates for port performance indicators such as berth occupancy, ship outputs, and ship turnaround time for various operating strategies in the logistics planning of container operations. The main objective of port management is to reduce the ship turnaround time by optimally utilizing the port resources. Reduced turnaround time encourages trade and improves the competitiveness of the port to provide efficient and effective services at low cost

Ballis and Abacoumkin (1996) coded a container terminal simulation model with animation capabilities. The objective of their paper is to introduce a computer simulation model with on-screen animation graphics which can simulate the operations of a container terminal equipped with straddle carriers. The movements of the equipment are simulated as realistically as possible, to include time losses due to the mismatch in the sequence of equipment movements and to traffic congestion. Trucks are normally served in a special area, but in some cases, straddle carrier drivers can call the truck to be served directly in the container storage areas. The experience of operators is incorporated in the model, in the form of a knowledge base that is used to simulate the above process and determine the service discipline. The model was designed to evaluate different configurations of the simulated system. The proposed model was used to examine the differences between "the observed" operations strategy and the strategy dictated by the operational rules of the port of Piraeus. The results indicate that "the observed" strategy leads to shorter truck service time but increases the traffic conflicts in the terminal's internal transportation networks.

Powell and Carvalho (1998) studied on real-time optimization of containers and flatcars for intermodal operations. The authors propose a dynamic model for optimizing the flows of flatcars that considers explicitly the broad range of complex constraints that govern the assignment of trailers and containers to a flatcar. The problem is formulated as a logistics queuing network which can handle a wide range of equipment types and complex operating rules. The complexity of the problem prevents a practical implementation of a global network optimization model. Instead, the authors formulate a global model with the specific goal of providing network information to local decision makers, regardless of whether they are using optimization models at the yard level. Thus, the approach should be relatively easy to implement given current rail operations. Initial experiments suggest that a flatcar fleet that is managed locally, without the benefit of the network information, can achieve the same demand coverage as a fleet that is 10 percent smaller, but is managed locally with this network information.

Kim and Kim (1994) studied on group storage methods at container port terminals. Assignment of storage locations to export containers is an important issue to improve the efficiency of loading operation in port container terminals. To expedite the loading operation, containers bound for a ship should be located close together. To put together containers for a ship, yard spaces should be allocated in advance for each arriving ship. In this paper, authors discuss how to allocate yard spaces which are released by loading containers to a ship. It is shown that the problem may be formulated as a mixed integer problem. A practical example is solved to illustrate the algorithm in this paper.

Kiesling and Walton (1995) studied on loading/unloading operations and vehicle queuing processes at container ports. Their report describes wharf crane operations at container ports. In particular, it explores econometric models of wharf crane productivity, as well as simulation and analytical models that focus on the queuing phenomenon at the wharf crane. The econometric model revealed factors that significantly affect wharf crane productivity, while all other models, based on extensive time-motion studies, revealed that assumptions of exponential service times are not always appropriate. Time distributions were also investigated for the arrival and backcycle processes at the wharf crane. All findings were incorporated into simulation and mathematical queuing models for the loading and unloading of container ships.

Kruk, Steltsov and Vik (1996) studied on methods of increasing of the port container handling equipment productivity. Their paper analyses possible ways of increasing the productivity of container ship handling quay equipment. Technical possibilities of various container handling quay installations with divided working cycles and various levels of their control automization are discussed. To define time parameters of cargo handling processes, a mathematical model for the simulation of modern quay reloader operation was calculated. The simulation model was calculated on the basis of a generalized calculation scheme, and therefore the model embraces the whole multitude of reloader constructions. It also takes into account various stochastic factors (such as ship arrival times, amount of cargo at each ship, probabilities of cargo handling equipment break downs etc) which have significant impact on container handling quay equipment operation.

Kim and Kim (1997) studied on routing algorithm for a single transfer crane to load export containers onto a containership. They determine the number of containers which transfer crane picks up at each yard-bay as well as the sequence of yard-bays which transfer crane visits during the tour. The objective is to minimize the total container handling time of the transfer crane including the set-up time at each yard-bay and the travel time between consecutive yard-bays. This routing problem is formulated as an integer programming. An efficient optimizing algorithm is also developed for the crane routing problem.

Cheung and Chen (1998) studied on a two-stage stochastic network model and solution methods for the dynamic empty container allocation problem. In their paper, the authors consider the dynamic empty container allocation problem where they need to reposition empty containers and to determine the number of leased containers needed to meet customers' demand over time. The authors formulate this problem as a two-stage stochastic network: in stage one, the parameters such as supplies, demands, and ship capacities for empty containers are deterministic; whereas in stage two, these parameters are random variables. Decisions need to be made in stage one such that the total of the stage one cost and the expected stage two cost is minimized. By taking advantage of the network structure, the authors show how a stochastic quasi-gradient method and a stochastic hybrid approximation procedure can be applied to solve the problem. In addition, the authors propose some new variations of these methods that seem to work faster in practice. The authors conduct numerical tests to evaluate the value of the two-stage stochastic model over a rolling horizon environment and to investigate the behavior of the solution methods with different implementations.

Kim and Bae (1998) studied on re-marshaling export containers in port container terminals. In order to speed up the loading operation of export containers onto a ship stated in their paper, the re-marshaling operation is a usual practice in port container terminals. It is assumed that the current yard map for containers is available and a desirable bay layout is provided. A methodology is proposed to convert the current bay layout into the desirable layout by moving the fewest possible number of containers and in the shortest possible travel distance. The problem is decomposed into three sub-problems such as the bay matching, the move planning, and the task sequencing. The bay matching is to match a specific current bay with a bay configuration in the target layout. In the move planning stage, the number of containers to be moved from a specific bay to another is determined. Sequencing the moving tasks in the final stage minimizes the completion time of the re-marshaling operation. A mathematical model is suggested for each sub-problem. A numerical example is provided to illustrate the solution procedure.

2.2 Literature Background on Container Handling

Ridder and Bernard (1983) studied on container handling capacity simulation. Their paper describes simulation by a computer of the container handling capacity of a container terminal. The aim is to forecast the time when new investments in equipment will become profitable.

Roth and Reis (1986) studied on design and operational features of yard gantry cranes and straddle carriers, stressing in particular the progress made in the past 5 years. This equipment is reported to permit higher stack densities and require less operating space than other types of container-handling equipment. The straddle carrier, apart from fulfilling the double requirement of stacking and loading in a flexible fashion, is also considered an excellent vehicle for container transport. However, they state that there is available no general or ultimate rule for system selection. Feasibility studies considering cost calculation and operational evaluation turn out differently under different conditions. Often the results are found to be quite close. The basic considerations of such investigations are outlined in their paper. The final choice of system and equipment, however, will remain with the user and this choice may sometimes be difficult. In any case there is excellent equipment to choose from in designing a container port or intermodal facility.

Ralston (1988) studied on handing of today's cargo at a competitive cost and in good time and on new ways of handling the container needed, not only in the method of handling the container/trailer itself, but in utilizing the available yard area to the maximum efficiency. The automation of the motions of a gantry crane (which can be overridden manually by an operator) provides a system that is able to consistently position the crane quickly and accurately since the drives always operate at maximum rates of speed and stop in minimum distance during automatic moves. The drives are not limited by visual parallax problems, nor do they become fatigued. The result on his paper is that the automated container/trailer handling gantry crane can position itself over the containers with greater speed and accuracy than an operator could consistently provide.

Chung, Randhawa and McDowell (1988) studied on a simulation analysis for a transtainer-based container handling facility. The paper states that the efficiency of a marine cargo terminal depends primarily upon a smooth and orderly flow of material during the container loading process. It has been observed that the transtainer operation is the bottleneck in the loading process due to the frequent container rehandles and its speed. Past attempts at improving port operations have concentrated on the computerization of the load planning function and the efficient warehousing of the outbound containers. These attempts have, to some extent, been successful but have not been able to significantly eliminate the unproductive movements of the material handling equipment during the loading operation. Their paper proposes a methodology of utilizing a buffer space as a method to increase the utilization of the material handling equipment and reduce the total container loading time. A methodology model using a graphics simulation system is developed to compare the proposed methodology with the current practice at the Port of Portland. The results from 96 simulation runs shows that the use of a buffer space significantly improves the flow of material during the loading operation, resulting in an average of 4% reduction in the total loading time. The methodology proposed in their study can be evaluated and implemented for any transtainer-based container port operation, and is anticipated to make considerable contribution to the planning of future container port design.

Rudnik (1991) coded a software on organizing the container terminal. Container terminals handling large freight volumes with defined access times can no longer be operated economically without computer-aided terminal organization. At the heart of this type of automation, notes the author, is a yard computer that tracks all the containers and coordinates their movements.

Kim and Kim (1994) studied on group storage methods at container port terminals. Assignment of storage locations to export containers is an important issue to improve the efficiency of loading operation in port container terminals. To expedite the loading operation, containers bound for a ship should be located close together. To put together containers for a ship, yard spaces should be allocated in advance for each arriving ship. In this paper, authors discuss how to allocate yard spaces which are released by loading containers to a ship. It is shown that the problem may be formulated as a mixed integer problem. A practical example is solved to illustrate the algorithm in this paper.

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CHAPTER THREE

CONTAINER PORT PLANNING, OPERATIONS And MANAGEMENT

3.1 Container Terminal Planning Principles

Planning principles of a port vary depending on local, economical and political conditions of a country.

A port development must consists of medium-term and long-term planning of new facilities and technological developments or combination of the terms. And also a short-term planning is required in the case of an existing port development to improve the management, the present facilities and their use.

1. Firstly, each investment must have a planning phase. This phase should give a recommendation on which course of action the port should follow giving only a broad treatment of each technological aspect.
2. Secondly, being a substantial decision phase including the security of funds should be followed.
3. Thirdly, a design phase turning the chosen plan in to the detailed engineering designs.
4. And lastly, the construction or implementation phase.
5. Final estimates of cost are predominantly dependent on the engineering difficulty and magnitude of the project. These estimates must be made and the subsequent engineering designs are construction work carried out after the conduct of more detailed investigations by qualified civil and mechanical engineers in consultation with the port authority.

The master plan, it is mostly called as long-term plan, consists of a view of the future situation as it will be after a series of individual developments have been carried out. However, it does not try to say whether and exactly when each of them will occur, since this will depend on traffic development. The master plan will be set within the framework of the national ports plan and in turn will provide a framework within which the medium-term plans for action can be drawn up and specific projects defined. This principle of going from a broad long-term plan to a detailed medium-term proposal should be a standard procedure.

However, for the use of existing facilities, the program of immediate practical improvements for the use of existing facilities can go ahead independently of the medium- and long-term plans. There will always be an urgent need for moderate technical and operational improvements, such as the extension of available storage space, the introduction of additional cargo-handling equipment or the purchase of pilot boats or lighters. Improvements of this kind are independent of future capital investments and should not be delayed until the main investment plan is finalized.

United Nations Conference on Trade and Development (UNCTAD, 1978, p.11) outlines a Check-list of the steps involved in preparing a port development plan:

1. General development policy: Identify the role of the port and its range of planning and financing responsibility (long-, medium- and short-term).

2. Traffic forecasting: Carry out for the time period of the development.

3. Technology policy: For each class of traffic that is forecast, and bearing in mind the expected form of presentation of the cargo, examine the alternative port handling techniques and their impact on future productivity.

4. Traffic assignment: Group together traffic classes with similar or compatible characteristics and assign them to separately planned berth groups or terminals.

5. Preliminary determination of dimensions: For each berth group or terminal, use the planning charts to find the approximate level of additional facilities required, and make a rough estimate of their dimensions.

6. Preliminary site selection: For each alternative combination of berth groups and terminals, propose alternative water and land areas of appropriate size and in locations that will not cause interference with the traffic in adjoining zones.

7. Engineering feasibility: For each of the locations, carry out the engineering studies needed to show all the main categories of work involved. Adjust site locations where necessary to eliminate excessively costly proposals.

8. Rough cost estimates: Estimate the cost of constructing and equipping each of the facilities under consideration.

9. Preliminary narrowing down of alternatives: from all information and where necessary repeating the interrelated steps 4-8, eliminates the less attractive alternative solutions.

10. Discuss conclusions with decision authority and obtain agreement on a short list of possibilities.

11. Operational planning: For all alternatives retained, prepare a plan showing how the facilities are to be operated, what equipment is needed and what will be the productivity target.

12. Final determination of dimensions: Repeat step 5 at a detailed level, using the appropriate planning charts.

13 Preliminary design: For each alternative solution, design the layout of all facilities required in sufficient detail to show up any problems in the matter of access by water or by land and in the location of operating and storage areas.

14. Detailed cost estimates: Refine the cost estimates for all works and services in order to produce a basis for the economic and financial analyses.

15. Cost-benefit analysis: Analyze the economic case for each of the alternatives.

16. Financial analysis: Analyze the financial viability of each alternative and review the available methods of achieving financial health.

17. Final selection: Bring together all analyses and compare the over-all advantages and disadvantages of each alternative so as to produce a recommended solution.

18. Discuss conclusions with decision authority and obtain agreement in principle on recommended solution.

19. Reporting: Formalize agreed solution in a report with supporting analyses.

20. Obtain authority to proceed with implementation and arrange for local and international, funds

3.2 Operations and Cargo Flow

Container ports are a distribution node of cargoes but act as a super-node. They are a gate of the country where the goods come or go. Incoming cargoes (container boxes) coming from the hinterland are export cargoes and a different procedure is applied differing from import container boxes. Additionally, they are categorized as empty and full. An empty container can be filled in container fried station (CFS) or can be send as empty but full containers are categorized as full container load (FCL) or low container load (LCL). A FCL container is send directly to the storage yard or ship to be load. A

LCL container is send to the storage yard directly or is send to CFS to be filled to be full.

Figure 3.1a and 3.1b show the flow of a container port and procedures to be applied. This cargo flow can differs from port to port considering the ownership of the port or specialty. Private ports can figure out the terminal due to the functions of the port that the owner requires.

3.3 The Management of Container Terminal

It is known that ports live longer than ships. For example, majority of ports and docks were designed and developed between one and two centuries ago when ships were small and much dockside distribution was done by horse and cart. It is not always easy to escape from some bad decisions. In shipping, For instance, if one were to buy the wrong size or type of ship, one could with any luck find a buyer for one's mistake and start again. However it is not so easy, if not impossible, to sell a terminal or dock that is in the wrong place or is the wrong size or of unsatisfactory design. A port is not a coherent entity like a ship, but a loose collection of trading activities within a fairly arbitrary boundary. This makes it more difficult to theorize about it and develop universal concepts concerning ports. Following are the types of ports in accordance with their ownership or administration:

- State ownership
- Autonomous
- Municipal ownership
- Private ownership

This classification might be considered simplistic in many modern ports, but in fact, ownership might consist of a combination of two or the above. Most European ports nowadays will be governed or controlled by a port authority which is a body with juridical status in charge of management of the port according to the rules defined in its constitution.

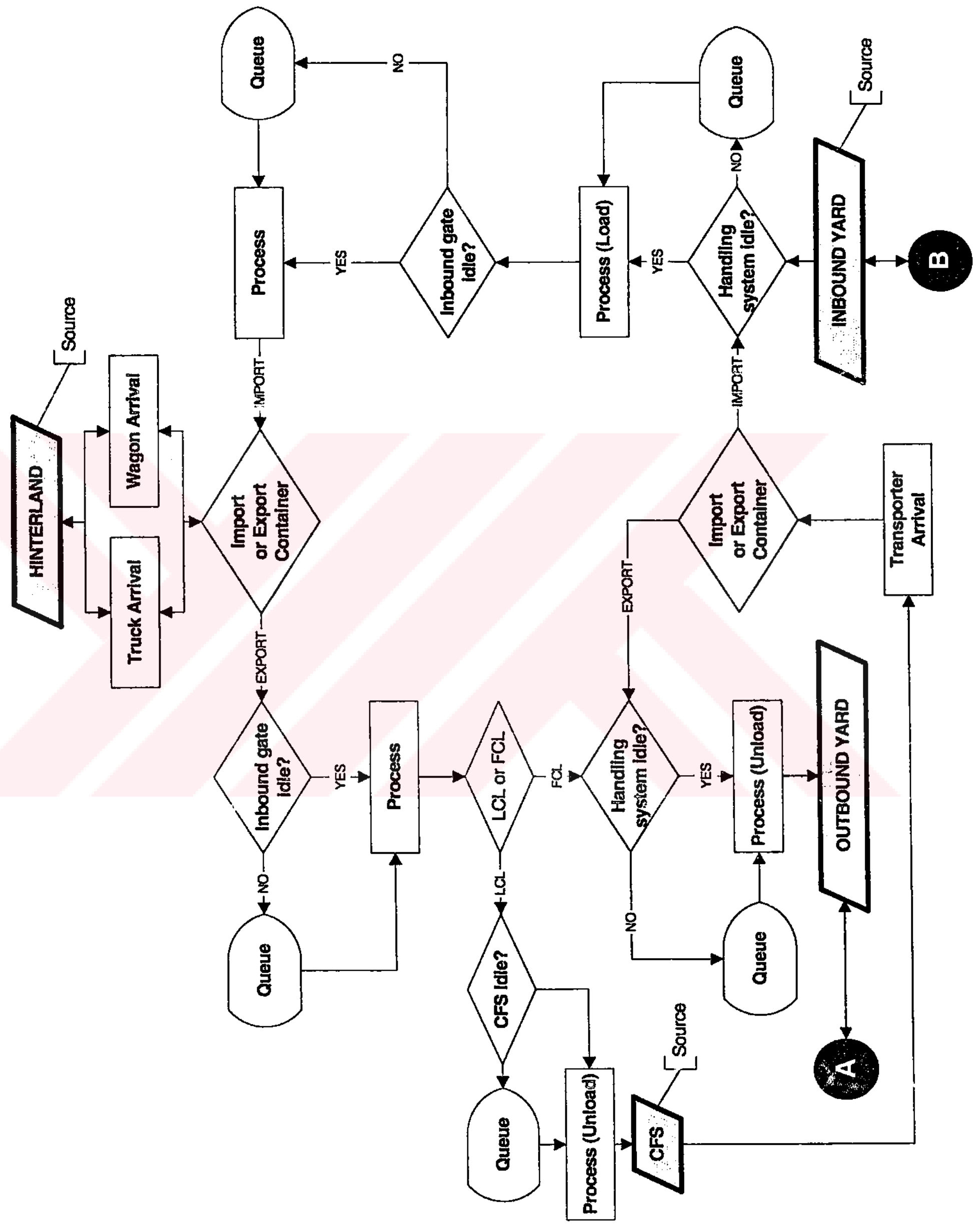


Figure 3.1a Logic diagram of activities between hinterland and storage yards

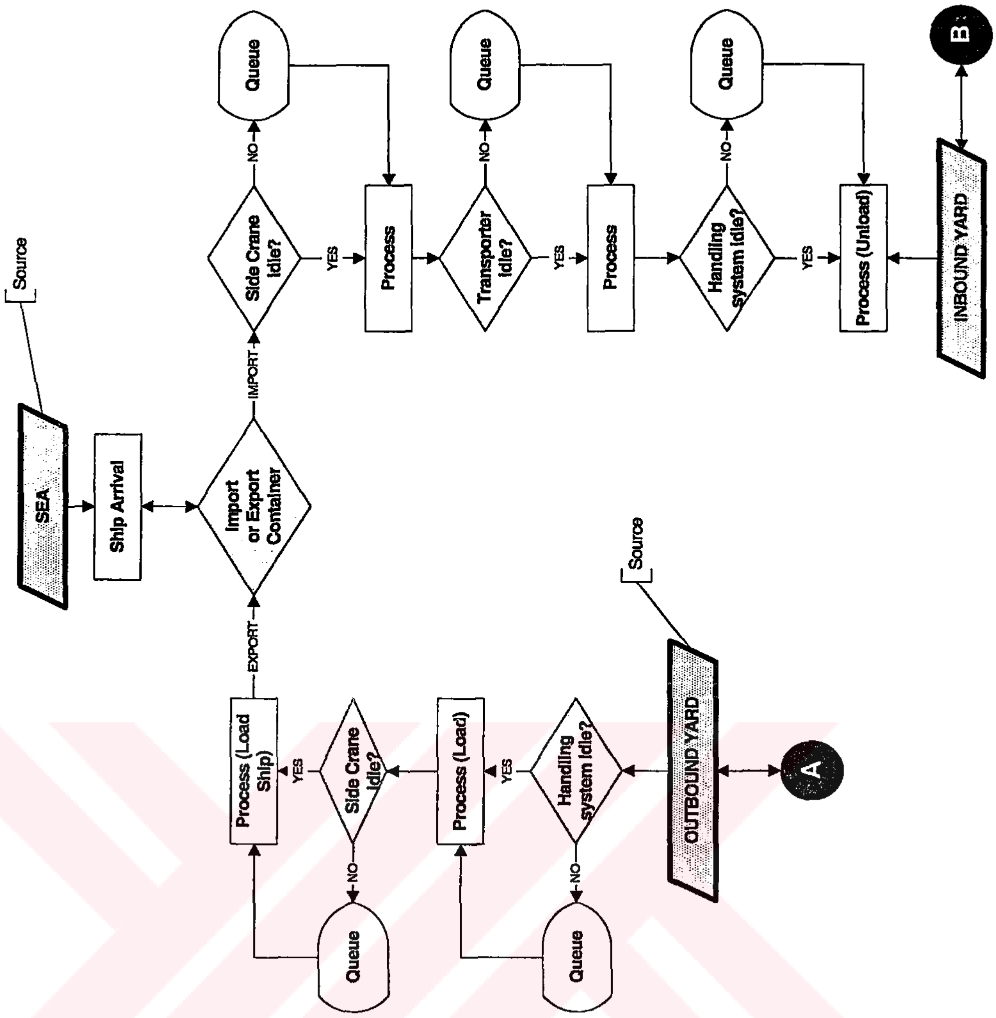


Figure 3.1b Logic diagram of activities between sea and storage yards

3.4 Port Management Objectives

In the past, not many ports had clear and explicit management objectives. However, a port manager now and in the future must be in charge and consider the followings:

1. Cost minimizing ways;

- Minimize payments by users in the port-including ship's time at a port.
- Minimize users' total through-transport costs.

- Minimize port costs.

2. Maximization of benefits.

- They maximize benefits to the owners of the port.
- They maximize benefits to the town, region or country.

Each of these items must be analyzed and solved together for an efficient and profitable port.

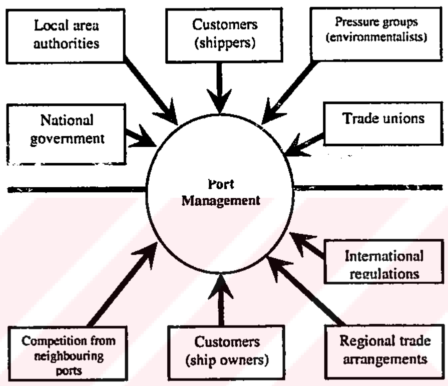


Figure 3.2 Constraint influencing port management (Source: Alderton, 1999)

Port management operates under a great many tight constraints. Figure 3.2 indicates constraints on port management.

CHAPTER FOUR

CONTAINER YARD PLANNING

4.1 General Planning Principles

Container services carry only, at present, a small portion of the general cargo liner traffic between developed and developing countries, but they already handle between 20 and 60 per cent of the cargo in developed countries' ports. Therefore in developing countries port authorities have to consider the probable development towards containerization of their countries' trade. They also have to consider the profound changes in port planning, management and operations which such development brings with it.

Normally, a port has to have a specialized container terminal offering a specified level of service for the large ships to call at. The container throughput must be expected to build up to between 30,000 and 50,000 TEUs in the first three years of operation if the investment is to be justified. If it is less, the port should either provide limited facilities for container feeder ships or adopt the transitional multi-purpose terminal

In principle, container terminals are rapid transit facilities at the interface between land and sea transport. Soon after arriving in the terminal, inbound containers must continue their inland journey to the consignees. Sealed containers' customs processing containers should take place on the premises of the consignees or at inland freight stations relatively near the consignees. Outbound cargo ought to arrive at the terminal as stuffed containers not long before the ship sails. These excellent intentions in regard to reduced storage duration and improved safety of cargo traffic have unfortunately only partly materialized. Like any other cargo, customs processing of containers does only take place in the terminals in many countries. Inland freight stations for stuffing and unstuffing of containers, as well as customs processing near the business premises of consignors and consignees often do not exist. Therefore this has to be done in the terminals. Thus, both full and empty containers remain in storage much longer than intended, and the throughput capacity of terminals, which is inversely proportional to the average storage time for containers (in the container literature this is commonly called dwell time), is greatly reduced.

Primary functions of a container terminal:

1. Furnishing the necessary personnel and container handling equipment to receive, store, and deliver containers.
2. Preparing all the necessary documents for the receiving and delivery of containers and ensure that all port charges, customs duties and freight charges have been paid.
3. Maintaining a status report of all containers received, delivered, and on hand in the terminal for submittal to the steamship lines involved.

4. Maintaining accurate inventory and locations of all containers and equipment.

5. Pre-planning all vessel loading and discharge operations from data supplied by the steamship lines or their agents.

6. Providing the necessary personnel and equipment to service the loading and discharging (stevedore) operations of the vessel.

7. Preparing all cargo plans, hazardous cargo manifest and related documents for delivery to the vessel and steamship line.

8. Maintaining security for all containers and equipment in the terminal.

9. Preparing all reports relative to the terminal functions and vessel operations.

10. Furnishing adequate supervision to ensure proper performance of all operations.

In design of a container terminal in a port it is important to consider if the port is a so-called main port or not. It is also important to consider if it will have a chance to become a main port in the future. If a port is a main port in a main line and feeder system (also called sometimes a "hub-port" a "hub and spokes" system) a terminal for the receipt of main-line vessels for the smaller feeder vessels has to be planned.

Throughput, frequency of calls of the main-line vessels, the distance to the feeder ports etc, are the factors affecting the size of the feeder vessels. The main-line vessels are 3rd or 4th generation container vessels. The standard berth length for a main-line terminal may be taken as 300 m.

For multiple-berth container terminals it is efficient to keep the berths in line. Thus, cranes can be switched conveniently from one berth to the next and small deviations of the straight line may be acceptable.

Figure 4.1 A typical layout of port showing berths and cranes.

Container handling requires much larger land areas behind the berths than general-cargo operations. On the terminal there must be room for:

- Handling zone and tracks for cranes
- Storage yards for containers
- Traffic areas for inland transport and railcars
- Spaces and installations for: weighing, inspection, washing, small repairs, etc
- Administration and maintenance buildings
- Parking for internal and external equipment and cars

Figure 4.2 shows the services above listed.

The modern cranes have a rail span of 30-35 m, with a back reach in the order of 10-15 m. The front rail must be minimum 2.5 m from the berthing line. There must be a two-way traffic lane between the hatch cover area and the first container stack of say: 10 m. Therefore, the total width of the apron is: 50-60 m, depending upon the rail span and the free space required in front of the crane.

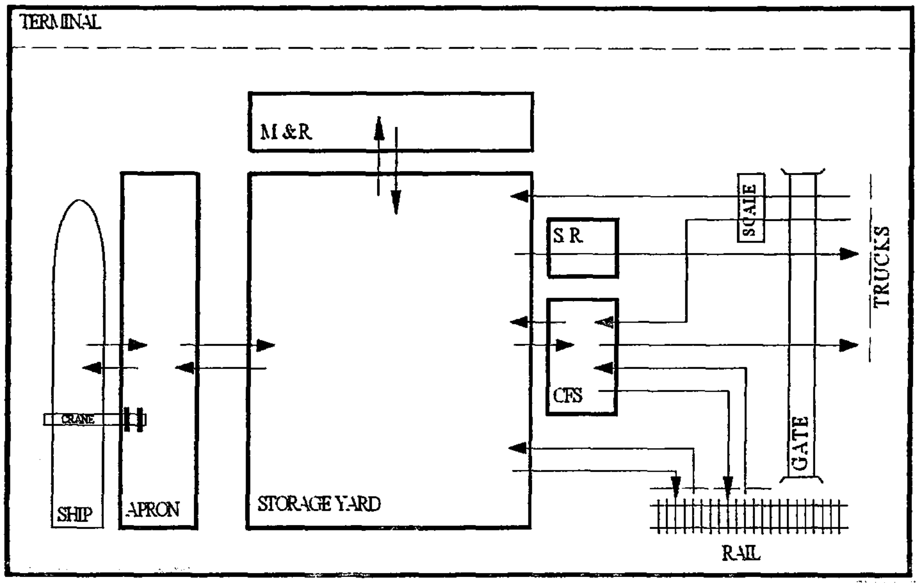


Figure 4.2 A typical container terminal layout showing its sub-services

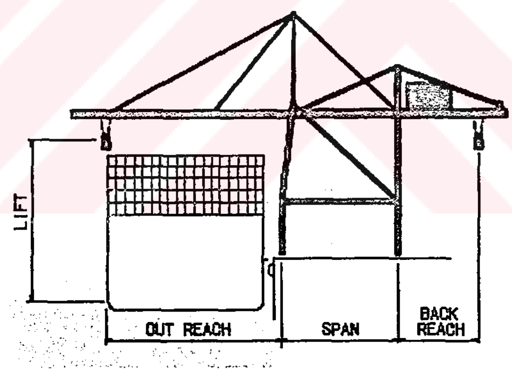


Figure 4.3 Rail span and back reach lengths

The large spans are required because operators want 4 lanes under the crane, two trolleys and automatic guidance for the loading of the containers onto the chassis

The containers are brought from the apron to the stacking area (or vice-versa). Door-to-door concept is the basic idea of the containerization. However, this is not always possible. Several small consignments are packed in one container in many cases.

Therefore so-called "stuffing and stripping"-sheds are required. These sheds are also referred to as Container Freight Stations (C.F.S.). The C.F.S. can be part of the container terminal, but it can also be constructed away from the terminal itself, in the port, or even outside of it.

Several different stacks can be distinguished in the stacking area. There are export-stacks and import-stacks in almost all cases. We usually speak of the export-stack and the import stack. However, the containers have to be separated in several categories. Heavy, medium and light containers, containers with dangerous cargo, reefer containers, 20- and 40-ft's containers, non-standard containers, empties etc, are some of these categories.

Export and import stacks are different from each other. Usually export stacks are stacked higher than import stacks. Export stacks have to be prepared before the ship arrives, so that loading can take place immediately when the ship is ready. The loading takes place in the already known order. Stability calculations have to be also done before the time of loading. "Random access" is preferable for the import-stack. It is not known by the terminal when a certain container will be picked-up. High stacking means that on average many extra moves have to be made for the delivery of the containers. One-high stacking would be ideal, but this requires a lot of space, which may not be available or only at great cost. Import stack is mostly 1 1/2 high depending on handling system.

Export stack is 2, 3 or 4 high. The higher the less area required for a certain throughput, but the more intricate is the operation. Keeping track of the containers must be computerized on large terminals and the high stacking equipment is more expensive. Saying that stacking 4-high instead of 2-high saves 50% on the area required would be a mistake. This is (almost) correct for the stacking area, but this area is only a part of the total terminal.

The required stacking area size depends upon the operational system used, upon the stacking height, but for a large part upon the time the container will stay in the yard, the so-called dwell-time.

4.2 Yard Operations

Yard operations are composed of complicated procedures and vary container characteristics and handling system or the layout of the port. Atkins (1995) summarizes below operation of a typical container port as follows:

The assigning of storage addresses to inbound and outbound containers as they are received is based on a layout pattern established and maintained by a yard control office. Regardless of the storage and handling system employed in a terminal, a certain area in the yard is assigned to export containers, another to imports, and one to empties. A possible exception could he in a full chassis system, where complete random selection is maintained and such segregation is believed to be unnecessary.

4.2.1 Outbound Yard

The export area is usually divided into sections, one section assigned to each vessel that the terminal is currently working. Each vessel section may again be divided into rows or blocks for each port of call, based on the number of containers booked for each port by that steamship line. There may be both 20-foot and 40-foot containers requiring separate rows or blocks for each port of call.

To begin planning storage operations for a particular vessel, the terminal will rely on the steamship line's preliminary booking list for information on the number of each size and type of container booked by port tot that vessel. From the information the terminal will reserve a certain number of addresses in the yard for each port and category. If the vessel is to be loaded utilizing two ship gantry cranes then two separate sections may be established in order to avoid congestion during the loading process

4.2.2 Inbound Yard

As the containers are discharged from the vessel, inbound container storage addresses are assigned. This can be done on a yard plan or simply by the yard clerk recording the container number and the address on a form prepared for this purpose. Containers may either be segregated in various classifications, or stored rotationally in a random fashion as they are discharged from the vessel. For example, containers discharged from a vessel and consigned for local delivery might be stored in one or more rows that are designated for local delivery; all containers scheduled for delivery to a given inland city, moving by railroad on the same train, will be handled in the same manner.

It is usually not known which container will be picked up first, since consignees' trucks arrive at the gate to pick up containers in a random order,. Efficient random selection of containers cannot he achieved unless containers are limited to one-high storage. Space availability in the yard seldom permits one-high storage, so some sorting is anticipated during the delivery procedure.

Some terminals take advantage of the random selectivity of the chassis system by pre-mounting on chassis a certain number of containers that are to be delivered within a short period of time and parking these in a separate area. This is of particular advantage if the top-pick front-end loader system is also in operation, since it requires that containers be taken on a first available basis from a storage row. Containers can thus be block stowed as they are discharged from the vessel and later transferred to chassis with the front-end loader. This system, of course, requires that a supply of over the road chassis be made available to the terminal by the trucking company or the steamship line. As containers are delivered and the rows thin out some consolidation can be made to make room for the containers that will be discharged from the following vessel.

4.2.3 Empty Container Operations

For empty containers, the terminal establishes receiving and delivery operations to ensure that empties are stored in good condition and easily located for loading. Empty containers being returned to the container yard will normally be accompanied by some form of authorization from the steamship company for their return. The receiving clerk makes out an Equipment Interchange Receipt (EIR) and conducts a thorough inspection of the container. If the container is in good condition, the truck driver is directed to the assigned storage area for empties, and the container is unloaded and placed into storage. Empties are usually stored by owner, type, and size. It is not usually necessary to store by specific yard address as a specific container to be loaded is seldom called for by number, but rather by size and type. For this reason, empties can be issued on a first-available basis.

The driver who comes to pick up an empty container must have in authorization for the type and size container requested. The terminal is often instructed to issue a container against a specific booking number by the equipment control section of the steamship line. In this manner, the terminal knows the shipper, vessel booked, and port of destination at the time of issue. If no clear authorization is presented, the steamship company must be contacted to confirm that the driver is to be issued a container. Once the empty is cleared for pick-up an EIR is issued. The driver proceeds to the pick-up area, where the proper type and size of container is loaded on the chassis. When the driver returns to the gate from the storage area, the container's condition may be inspected. The driver signs the EIR as receipt for the equipment and acknowledgment of its condition when received.

4.2.4 General Cargo Operations

The receiving and delivery of general cargo at the container freight station (CFS) and at the general cargo transit shed is basically the same. The difference between the two depends upon the disposition of the cargo. At the CFS, cargo is placed in containers for export and removed from import containers prior to delivery to the consignees. At the general cargo transit shed, cargo is prepared for loading to the vessel as unitized, palletized, or loose cargo. Import cargo is ready for delivery to the consignee upon discharge. The receiving and delivery of cargo, however, is done at the facility to which it is consigned rather than at the gatehouse. Each terminal will have its own procedures, but the basic process and documentation are the same and achieve the same end results for all terminals.

4.2.4.1 Receiving

The delivering driver presents the necessary papers at the entrance gate and is issued a gate pass, which directs the truck to the CFS or the transit shed, depending upon whether the cargo is to be containerized or shipped as general cargo. In some terminals, the initial inspection of delivery documents is made at the gatehouse where the driver is then directed to the appropriate delivery area. At the point of delivery, there is a receiving office where clerk are assigned to receive the cargo and complete the documentation. The same process is followed for both general cargo and containers. The steamship line will have provided the terminal with a booking list identifying the cargo and the shipment prior to its arrival at the terminal. The receiving clerk checks the driver's papers to see that the booking number shown checks against the one on the booking list. The receiving clerk makes out a pile tag entering the name of the vessel on which the cargo is to be loaded the voyage number name of the shipper port of discharge and the present date. The bill of loading or booking number is also included. On the pile tag there is also a place to list the details of the cargo being delivered. This information taken from the driver's delivery papers includes marks and number identifying the shipment number and type of packages a description of the cargo and the measurement and weight (See Figure 3-24). The pile tag is then given to a clerk who directs the driver to a specific location where the cargo will be physically removed from the truck. The receiving clerk must check the cargo as it is discharged from the truck to see that it matches the description on the pile tag and that there is no overage, shortage, or damage. The clerk must also check the identifying marks on the cartons and the port of destination to make certain the right cargo is being delivered.

4.2.4.2 Delivery

Upon arrival at the terminal the truck driver presents a delivery order for the cargo to be picked up. The gate guard or a clerk at the gatehouse directs the driver to the terminal area where the cargo is to be delivered. The delivery order is matched against the inbound container load plan (CLP) and the confirmation from the steamship line that the cargo may he delivered. The clerk also checks to see that the cargo has been cleared through Customs and that all terminal charges and any demurrage due have been paid. A clerk is then assigned to deliver the cargo. As the cargo is loaded to the truck, the clerk counts the number of packages and checks this amount against the delivery order. Any discrepancies are noted and reconciled with the driver.

4.2.5 Container Freight Station

The on-lock CFS is a small terminal within a terminal. It has its own receiving and delivery office and performs its own work. Its sole purpose is to van or de-van cargo. It calls upon yard control in the container terminal to provide empty vans for the loading of cargo and import vans that are to he emptied of cargo at the CFS. Empty containers are returned to yard control for storage, and loaded containers are delivered to the container yard with the same controls as those imposed on outside deliveries.

4.3 Container and Yard Handling Equipments

Container ports have two types of equipment, ones that are used on container storage yards (yard equipments) and others that are used on berths (side equipments).

Yard equipments are charged to handle containers on the yard and transfer containers to the berth and gates or for both activities. Yard handling systems are named by yard equipments. In Table 4.1 main types of handling equipments are listed:

Table 4.1 Main types of handling equipments

Yard Equipments	Yard Gantry Cranes (Rail-Mounted Transtainers and Rubber-Tired Transtainers)
	Straddle Carriers
	Forklifts (Reach Stackers, Front Loaders, Side Loaders) Chassis
	Tractors
	Mobile Cranes
Side Equipments	Bridge
	Gantry

In Appendix C and D, handling equipments and yard layout schemes respectively are explained in detail.

CHAPTER FIVE

YARD OPTIMIZATION METHODS

5.1 Hypotheses Development

In this study, hypotheses below listed were developed.

- To prove that the size of container yard will be optimally determined by applying the mathematical optimization methods used progressively in sizing storage facilities and to develop the proper models and approaches for adaptation of these methods.
- To optimize container yard by selecting the queuing model based on bulk queue system and to realize originally the application of queuing theory

especially in the respect of yard optimization by modifying the container system in bulk.

- To optimize the container yard size by merging the Monte Carlo simulation model with the framework of a yard optimization process and to develop the new yard planning approach in this way.
- To develop original queuing simulation software, Container Yard Optimization CYO, to be able to process effectively the complicated traffic operation not solved by using the mathematical optimization methods and Monte-Carlo simulation.

In next sections of this chapter, these hypotheses will be researched. In review section of conclusion chapter, the theses were discuused.

5.2 Content of Selected Methods

In determining the optimum size of a container yard, some economical and physical factors play an important role. The economical factors can be explained as the costs on waiting ships and trucks, cost of investment, cost of service to be provided for storage, loading, unloading of full and empty containers which are imported and exported. On the other hand, the physical factors are composed of the stacking height and square meter of container base, inbound transportation area and the number of containers stored. Both factors should be processed in accordance with the mathematical optimization method to yield economically and physically the optimum size of the container yard. For the optimization of container yard, three approaches have been utilized in this thesis. These are considered as approach of inventory model, queuing model and simulation.

Among the mathematical optimization methods, first of all, the inventory method is frequently used for the stocks problems of warehouses. The aim of this study is based on minimizing the costs of idle slots or unserved containers from the excessive or defective part of incoming cargo over or under allowed capacity of stock area. Even through this method is rarely used in calculating the container yard; it will provide the basic idea for comparing the results obtained from the other approaches.

In the yard optimization, it is not coincided with the queuing model approach. But this study aims to utilize the queuing theory by assuming the queue system as bulk queues based on moving the containers which arrive and/or is served in-groups. The containers arriving from landside by trucks or wagons and seaside by ships are grouped. They wait in the queue and are served in-groups. Therefore, the assumption in this study considers the queuing system of ships, wagons and trucks carrying the average number of containers. The objectives of utilizing such queuing model are to find out more information about the waiting times of the vehicles and the number of vehicles, waiting in the queue and system, the number of the optimum number of service facility and the busy period. This information will be evaluated by analyzing the costs on service, waiting vehicles and idle slots for the optimization process.

Monte Carlo Simulation aims to solve the objective function composed of terms as ship, truck and wagon arrival and departure and waiting container distribution on the yard. This method considers the probability distributions of sea-born and land-born container departures and the existence probability of containers remaining in a yard in any time together with the probability distributions of sea-born and land-born container arrivals. At first, the monthly-recorded arrival and departure distributions of vehicles are fit to the theoretical distributions. The daily random data is yielded by the mechanism of random data generation. Yard planning problems where the objective function is not available to solve with algebraic methods such as linear, integer and dynamic programming, and conventional mathematics can be solved by Monte Carlo Simulation which is carried out by systematically matching probabilities of conditions to cause vehicle traffic in yard. Each event represented by matching the probabilities to be considered yields the decision variable, the number of container staying at yard. The frequency of decision variables and their probabilities will give the expected number of container to be stayed at yard. The cost analysis will find out the optimum yard capacity by running the developed mathematical model.

Queuing simulation method is preferred for solving the complex queuing problem such as yard optimization. For container yard planning, the probability distributions of land-sea-born container traffic and holding days of containers for both being empty or full containers and export or import containers must be theoretically determined in accordance with the Chi-Square Test of Goodness of Fit. The theoretical arrival and service distributions and populations relating to each container type (e.g. empty/full, export/import) may differentiate from the type to type. The consideration of such complicated situations makes difficulties in selecting and operating queuing model. To derive the analytical formula for any type of queuing model to be dealt with later (e.g. (M/M/c) : (GD/∞/∞) Model, (M/M/c) : (GD/N/∞), $c \leq N$ model, (M/G/1) : (GD/∞/∞) Model) will be quite complex or the arising problem could not be solved analytically. In this situation, the simulation will simplify the analysis of queuing models that were originally quite complex. In addition to this, the types of the handling equipment in yard such as gantry-crane, transtainer, straddle-carrier may cause complicate the problem and make the solution even more difficult. This study aims the analysis of the queue problems which are caused by moving different types of containers in a yard and selecting the different types of handling equipment. For this reason, a software, "Container Yard Optimization", (CYO) has been developed.

5.3 Data Gathering and Testing

The selection of a specific method for analyzing a queuing situation, by simulation or analytical method, is principally determined by the distributions of arrivals and service time. In practice, the determination of these distributions entails observing the queuing system during operation and recording the pertinent data.

The data required for optimization and simulation studies can be obtained from the port authorities, institutions or related ministries. These are present as monthly statistics:

a) Number of arriving, departed and servicing ships, trucks and wagons carrying container,
b) Number of TEU from ships, trucks and wagons,
c) Number of each type of import and export containers,
d) Number of each type of empty and full containers,
e) Number of container staying at yard in the certain day for every month
f) Container storing days at yard corresponding to the certain percentage of total container number in the year.

According to the optimization and simulation methods to be considered in this study, the required data for each method is explained as follows:

Data required for the inventory model;

a.) the data on the numbers of containers staying at yard in a certain day of every month,

b.) data on the numbers of holding or storing days of containers to the yard container capacity

Data required for queuing theory;

a.) data on ship, truck and train arrival times, data on service/storage times of containers,

b.) data on containers arriving in port by seaway, highway and railway.

Data required for Monte Carlo Simulation;

a.) data on container arrival and departed numbers obtained from sea and land-born traffic,

b.) data on number of staying container in the certain day for every month.

In Queuing simulation method;

a.) data on ship, truck and train arrival times, b.) data on service/storage times of containers,

c.) data on containers arriving in port by seaway, highway and railway, the ratio of empty container number to its total

d.) data on number of staying container in the certain day for every month.

The data on ship, truck and train arrival times are generally used by the mentioned three methods except the inventory method. In this study, the amount of containers carried by train is smaller than the others so that the amount of containers by railway is added to the containers carried by highway. The data regarding arrivals and departures is monthly data and taken as observed data. When the probability distribution of them is investigated, it is seen that there is a similarity between the observed arrival distribution of ships and trucks and the theoretical distribution taken as Poisson distribution. If each ship or truck carry same tonnage of cargo like average cargo, is assumed, the distribution regarding the number of containers is also accepted as similar with the distribution of the ship or truck. According to this assumption, both the arrival distribution of ship/truck and container number carried by ship/truck is fits the Poisson distribution. The distribution of observed data is compared to the theoretical distribution and the statistical test by using the Chi-square test of goodness of fit is applied.

The similar process is carried out for representing the service time distribution by considering the data on container storing days at yard corresponding to the certain percentage of total container number in the year. It is seen that the service time distribution fits Erlang distribution for K=2.

5.4. Random Number Generation

A *random number* is a stochastic variable that meets certain conditions (all types of stochastic variables are often called random variables in the statistics literature; in simulation however, a misleading terminology is found). These conditions are;

1. Variable is uniformly distributed over the interval from zero to one

2. A sequence of these variables shows statistical independence.

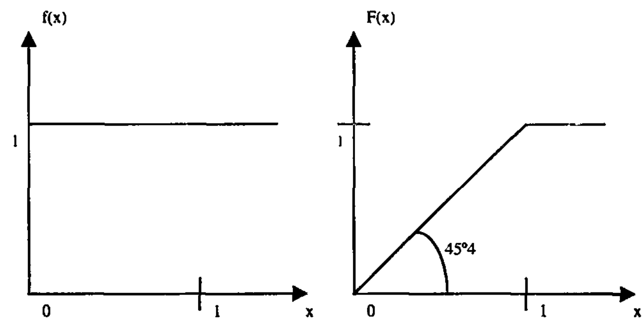


Figure 5.1 Random Numbers x

As Figure 5.1 illustrates, the random number x has a density function (say) *f(x)* such that

$$f(x) = \begin{Bmatrix} 1 & \text{on the interval}[0,1] \\ 0 & \text{elsewhere} \end{Bmatrix} \tag{5.1}$$

This density function corresponds with the cumulative distribution function F(x) shown in Figure 5.1b. So

$$F(x) = \int_0^x f(z)dz = \int_0^x 1dz = x \quad if \quad 0 \le x < 1, \tag{5.2a}$$

$$F(x) = 0 \quad if \quad x < 0, \tag{5.2b}$$

$$F(x) = 1 \quad if x \ge 1. \tag{5.2c}$$

The n elements of the sequence $x_1, x_2, \ldots\ldots x_n$ with $n=2,3,\ldots\ldots$ are statistically independent. So their simultaneous or joint distribution F_n may be written as the product of their marginal distributions $F(x)$, which were given in (5.2a) through (5.2c). So

$$P(x_1 \leq x_1, x_2 \leq x_2, \ldots\ldots x_n \leq x_n) = F_n(x_1, x_2, \ldots\ldots x_n) = F(x_1)F(x_2)\ldots.F(x_n), \tag{5.3}$$

which yields

$$F_n(x_1, x_2, \ldots\ldots x_n) = x_1 x_2 \ldots.x_n \quad if\ \forall x_i : 0 \leq x_i < 1, \tag{5.4a}$$

$$F_n(x_1, x_2, \ldots\ldots x_n) = 0 \quad if\ \exists x_i : x_i < 0, \tag{5.4b}$$

$$F_n(x_1, x_2, \ldots\ldots x_n) = x_2 \ldots.x_n \quad if\ x_i \geq 1, \tag{5.4c}$$

$$x_1 x_3 \ldots.x_n \quad if\ x_2 \geq 1,$$

$$x_1 x_2 \ldots.x_{n-1} \quad if\ x_n \geq 1.$$

Statistical independence implies that knowledge about x_1 does not give any information about x_2. So the conditional distribution equals the marginal distribution:

$$P(x_2 \leq x_2 \ \left| x1 \leq x_1 \right.) = P(x_2 \leq x_2) = F(x_2). \tag{5.5}$$

Symbol r represents the stochastic variable. Random numbers are uniformly and independently distributed over interval [0, 1].

5.4.1 Techniques for Generating Random Numbers

In theory, equation (5.2) and (5.3) is ideal but in practice there are some methods to generate random numbers such as ten-sided die, throwing a coin or some devices. These are practically usable but for computer applications, pseudorandom numbers is used.

5.4.1.1 Pseudorandom Numbers

Digital computer gave rise to number techniques that use a recursive mathematical relation; that is, the number r_i is a function of proceeding numbers r_{i-1}, r_{i-2}...... Because the relation is deterministic, these are not really random: they are called pseudorandom. However, if the mathematical relation is not known and is well chosen, then it is practically impossible to predict the next number.

There are some pseudorandom generation methods such as midsquare, congruential, tausworthe, shuffling etc. To determine the uniformity and independency of generated pseudorandom numbers there are some tests applied which are frequency, correlation, gap, run, poker etc. In practice for simulation applications programmers use some subroutines. (Kleijnen, 1992)

In this study, to simulate ship arrivals, container arrivals by ship, truck and railcar, container waiting days on the stock yard, which are Non-Uniformly distributed, some random number generating routines was used following Dagpunar's (1988) algorithms. In most situations, arrivals have Poisson distribution and Exponential service times but this is true every time and in every problem, so some extra random generator tools such as triangular, normal, chi-square etc was merged in CYO software for changing situations.

5.4.2 Exponential Distribution

The exponential distribution function can be given as

$$F(x) = \int_0^x \alpha e^{-\alpha z} dz = 1 - e^{-\alpha z} \quad \text{with } \alpha > 0 \text{ and } x \geq 0 \tag{5.6}$$

As the information about x usually concerns its expectation and variance. The relation between two moments and parameter α of the exponential distribution:

$$E(x) = \int_0^{\infty} x\alpha e^{-\alpha z} dx = \frac{1}{\alpha} \tag{5.7}$$

$$\mathrm{var}(x) = \int (x - \left(\frac{1}{\alpha}\right)^2 \alpha e^{-\alpha x} dx = \frac{1}{\alpha^2} \tag{5.8}$$

So the mean and standard deviation have the same value as $1/\alpha$.

5.4.3 Distributions Related to the Exponential Distribution

Many distributions can be related to the exponential distributions. So Gamma, Erlang, Chi-Square and some others can figure out this distribution. Here, it will be mentioned about only Poisson distribution which is frequently used distribution function.

5.4.3.1 Poisson Distribution

This distribution is often used in queuing situations. In this study, to simulate ship arrivals, this distribution was used. This distribution can be characterized by below,

$$P(x = k) = \frac{\alpha^k}{k!} e^{-\alpha} \quad \text{with } \alpha>0 \text{ and } k=0,1,\ldots\ldots \tag{5.9}$$

Poisson variables x-$P(\alpha)$ has a mean and variance equal to the parameter α:

$$E(x) = \mathrm{var}(x) = \alpha \tag{5.10}$$

5.5 Optimization Methods

In this thesis, the optimization methods are studied into four groups: inventory method, queuing theory, systematic search approach, and simulation. Increasing the number of design parameters to be computed in detail and existing complex events in port operations require the selection of one among the mentioned methods for obtaining the optimum size of yard.

5.5.1 Inventory Method

5.5.1.1. General

The inventory method is one of the mathematical optimization methods. This aims to compute the number of idle slots and waiting container. By adding the cost analysis, the economical and physical optimization can be done. The determination of optimum size of storage areas plays an important role in port economy. For this aim, container terminals should be planned in accordance with the productivity of handling equipment, the optimum length of quays, and the prevention of idle storage areas

The container traffic variations affect the port economy, the size of storage area, the required handling equipment, berth capacity, port management and operations. A shortage in storage area may occur either by waiting containers before being served because of the container congestion due to insufficient stocking area or unserved and idle container slots which exist because of the excessive capacity of container storage area. Either cases cause a loss in container storage profit or the difficulty in paying the investment cost of idle slots. The optimization methods provide both the required area for storage by minimization of costs for waiting containers and idle slots for port management.

To optimize the container terminal storage yards, the principle of inventory method to be used as optimization method is based on developing a stochastic stock planning model, which is suitable for arrival and service distribution of containers. This model can be developed as deterministic and stochastic process.

The deterministic models suppose that the data on demand, capacity and unit costs (e.g. cost of invested area per square meters, cost of waiting container per day) are known. But this model is valid only if the statistics known. On the other hand, unknown data can be evaluated by stochastic inventory models introducing the probability distributions for the known data. For this reason, the stochastic inventory model can be developed by using the demand data represented by the tested probability distributions, capacity and unit costs.

In a container yard having a certain capacity, if an excessive demand exists surpassing the existing capacity of yard, the containers exceeding this capacity may not be served and the expected income of port management will be lost. On the contrary, the idle container slots will exist and so the profit as much as investment cost of idle slot will not be supplied. The total of both mentioned costs can be defined as the income loss of port. The aim of optimization with the inventory theory is to minimize the total cost from both cases and determine the optimal capacity of the yard. In this study based on minimizing the expenses from idle slots and unserved containers, any income from service and storage of container is taken into consideration.

As it is seen in Figure 5.2, considering variations on load demands on stock yard, sub structures cost will increase if it is built for an excessive demand. If the expected demand is not realized, a portion of the investment will be idle. In this case, the costs of vacancy will increase.

In other way, sizing the yard in a capacity which will not respond to the demand will also cause the decreasing of benefits, in other words, will cause increasing of the revenue losses. So the cost of vacant stock yard and profit loss must be balanced and the total must be as minimum.

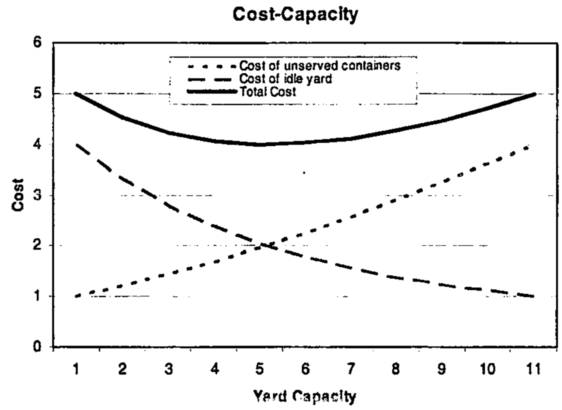


Figure 5.2 Container terminal stock yard capacity-cost function

5.5.1.2 Inventory Model of Container Yard

Capacity of stock yard on container terminals has a very important role in regulating terminal traffic flow. In a considered yard, the container demand recorded at a time i, Q_i and the existence probability of Q_i, P_i, should be calculated for stochastic inventory model as seen in Figure 5.3.

Therefore, stock yard area needed for waiting time, t_o, can be expressed as follows:

$$F = f_0 Q_s t_0 \quad (m^2) \tag{5.11}$$

where Q_s = Daily container capacity of terminal stock yard (TEU/day)

f_0 = Unit area per container box (m^2/TEU)

t_0 = Holding time of each container load in a yard (day)

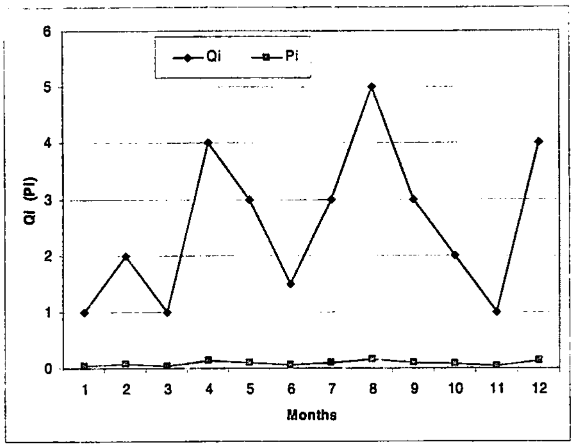


Figure 5.3 The container demand recorded at a time i, Qi and the existence probability of Q_i, P_i,

Daily terminal stocking cost, C_{ss}, based on terminal substructure, investment capital, interest rate and amortization is as follows:

$$C_{ss} = \frac{1}{365} C_{rf} .C.F \tag{5.12}$$

Here,

C = Unit cost of yard (USD/m^2),

C_{rf} = annual amortization rate.

C_{rf} can be calculated by the following formula.

$$C_{rf} = \frac{r.(1+r)^N}{(1+r)^N - 1} \tag{5.13}$$

Here,

r = annual interest rate,

N = life of investment.

Hence the cost of stocking time of container terminal

$$C_{ss} = \frac{1}{365} C_{rf} . C . f_0 . Q_s t_0 \quad (^{USD}/_{Day}) \tag{5.14}$$

can be described. The unit cost of idle slots, C_s, by exclusion of terms regarding on stocking days and daily container capacity of yard from the above-mentioned formula can be written as follows.

$$C_s = \frac{1}{365} C_{rf} . C . f_o \qquad (^{USD}/_{TEU.Day}) \tag{5.15}$$

C_b, terminal profit lost by unit load on terminal stock yard ($^{USD}/_{TEU}$) should be defined in accordance with the applied model. For life of investment, 10 years and annual interest rate, 2%, the annual amortization rate can be obtained as 0.050. For second, third and fourth level stacking, the required area per container is taken respectively as 15 m^2, 10 m^2 and 7.5 m^2 and the unit cost of idle slots can be calculated respectively as 0.255 USD/day.TEU, 0.169 USD/day.TEU and 0.127 USD/day.TEU.

Idle cost of container slots appears by considering unit cost of idle slots and their stocking days if $Q_s > Q_i$ and it is expressed as below.

$$t_o . C_s \sum_{i=1}^{S} (Q_s - Q_i) \tag{5.16}$$

If $Q_i > Q_s$, profit lost on terminal stock yard appears and total cost of unserved container is in the following.

$$C_b \sum_{i=S+1}^{n} (Q_i - Q_s) \tag{5.17}$$

Objective function defining the total cost including the costs of idle slots and unserved containers, C, can be expressed as,

$$C(Q_i, Q_S) = C_s \sum_{i=1}^{S} (Q_s - Q_i).t_i + C_b \sum_{i=S+1}^{n} (Q_i - Q_s) \qquad (5.18)$$

where C_b is unit costs of unserved container composed of loading and unloading, terminal , warehousing and assisting trailer services.

This objective function will produce different results by varying stocking capacity, Q_s, to monthly recorded container numbers, Q_i, existing in a yard and stocking days, t_i. The suitable result is the stocking yard capacity corresponding to the minimum total cost.

In this study, inventory method was coded following the flow chart as in Figure 5.4.

5.5.2 Queuing Theory

In general, the waiting phenomenon is the direct result of *randomness* either in the operation of service facilities or the discipline of the container arrivals. It causes some disruptions in some the systematic working rules of both activities of containers and service facilities. This situation is not desired because of the negative effects on economy and management of the facilities.

The objective is to provide systematic operation of a service facility under random conditions and minimize the container's waiting time. The basic problem in a facility, having a certain level of service and operation discipline, not to remain idle is that how long a container is expected to wait before being serviced. Providing too much service involves excessive costs. On the other hand, not providing enough service capacity causes the waiting line to become excessively long at times. The expected solution can be obtained by investigating the physical, economical and operational properties and the characteristics of containers such as their number, arrival rates and queue disciplines and assembling a reasonable balance between the two conflicting situations.

Queuing theory involves the mathematical study of queues, or waiting lines. A number of queuing or waiting line models that account for a variety of service operations. The models developed are basically applications of probability theory and stochastic processes.

In queuing models, for port problems, container arrivals and service times are characterized in terms of probability distributions normally referred to as *arrivals* and *service time distributions*. These distributions may represent situations where containers arrive and are served *individually* (e.g., containers on the yard or waiting ships to be serviced). In other situations, containers may arrive and/or be served in-groups (e.g., railway convoy). This case is normally referred to as *bulk queues*.

Although the patterns of arrivals and departures are the main factors in the analysis of queues, some factors also play an important role in the structure of the models. The first factor is the manner of choosing container from the waiting line to start service. This is referred to as the *service discipline*. The discipline seen frequently is the FCFS rule (first come, first served). LCFS (last come, first served) and SIRO (service in random order) may also arise in practical situations. The specific service discipline which regulates the selection of customers (container for the port problems) from a waiting line before being served may be put in *priority queues*. As the second factor, the design of the facility and the execution of service may require more than one server (e.g., handling equipments). In this case, all servers offer the same service and the facility is said to have *parallel servers*. On the other hand, the waiting lines in a facility including a number of series stations (e.g., processing of a product on a sequence of machines) are normally known as queues in series or *tandem queues*. The most general design of a service facility comprising both series and parallel processing station is defined as *network queues*.

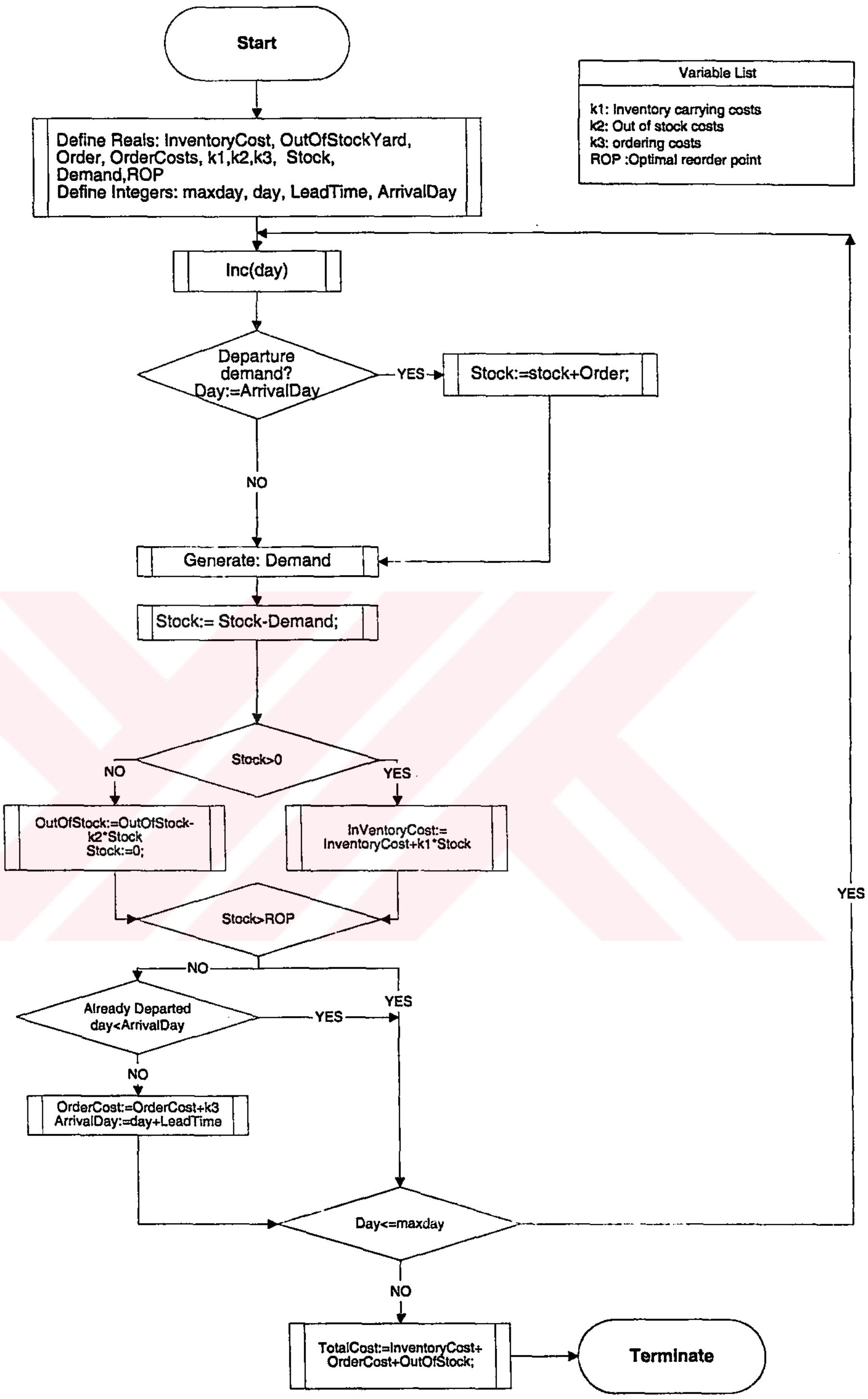


Figure 5.4 Flow chart of inventory model

The third factor concerns admissible *queue size.* In certain situations, only a limited number of containers may be allowed, possibly because of space limitation (e.g., car spaces allowed in a drive-in bank). Once the queue fills to capacity, newly arriving containers are denied service and may not join the queue.

The fourth factor deals with the nature of the source from which calls for service (arrivals of containers) are generated. The calling source may be capable of generating a finite number of containers or (theoretically) infinitely many containers. A finite source exists when an arrival affects the rate of arrival of new containers.

The basic elements of a queuing model depend on the following factors:

1. Arrivals distribution (single or bulk arrivals).
2. Service-time distributions (single or bulk service).
3. Number of servers or channels (finite or infinite situations of tandem, parallel, or network stations).
4. Queue discipline (FCFS, LCFS, SIRO) and service priority.
5. Calling source or customer population (finite or infinite).

The variant using schemes of the mentioned elements exist the queuing model. Each model can be designed separately from each other. Figure 5.5 shows the selection pattern of queuing models.

In any queuing model, the suitable parameters for container number, number of channels, queue discipline can be chosen, but arrival and service distributions can not be easily determined without defining the theoretical probability distributions representing the real arrival-time and service-time distributions of containers. Data regarding arrivals and departures is gathered by measuring the time between successive arrivals, and the service time of each arrival. The real probability distributions from these data are produced and tested by using the Chi-square test of goodness of fit to obtain the specific theoretical distribution.

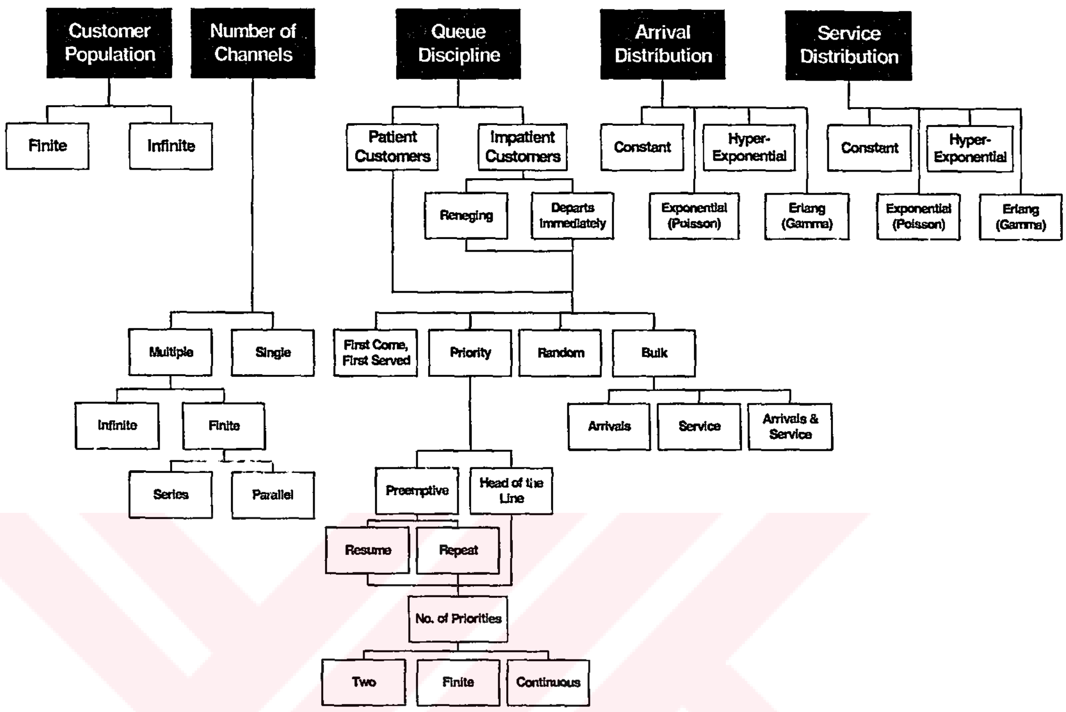


Figure 5.5 Queuing model selecting

The standard notation described easily was initially devised by D. G. Kendall [1953] in the form *(a/b/c)* and is known in the literature as the Kendall notation. Later, Lee [1966] added the symbols *d* and *e* to the Kendall notation. Study will use this Kendall-Lee notation by use of the symbol *f* representing the capacity of calling source.

$$(a/b/c):(d/e/f)$$

where the symbols *a*, *b*. *c*, *d*. *e*, and *f* stand for basic elements of the model as follows:

a : arrivals distribution

b : service time (or departures) distribution

c : number of parallel servers (c = 1, 2

d : service discipline (e.g., FCFS, LCFS, SIRO)

e : maximum number allowed in *system* (in queue ± in service)

f : size of calling source

The standard notation replaces the symbols *a* and *b* for arrivals and departures by the following codes:

M : Poisson (or Markovian) arrival or departure distribution (or equivalently exponential interarrival or/service-time distribution)

D : constant or deterministic interarrival or service time

E_k : *Erlangian* or gamma distribution of interarrival or service time distribution with parameter *k*

GI : general independent distribution of arrivals (or interarrival time)

G : general distribution of departures (or sevice time)

The notations representing the selected queuing model are defined as follows:

$$(M/D/10):(GD/N/\infty)$$

Here we have Poisson arrivals, constant service time, and 10 parallel servers in the facility. The service discipline is general *(GD)* in the sense that it could be *FCFS, LCFS, SIRO*, or whatever procedure the servers may use to decide on the order in which customers are chosen from the queue to start service. Regardless of how many customers arrive at the facility, the system *(queue + service)* can hold only a maximum of *N* customers: all others must seek service elsewhere. Finally, the source generating the arriving customers has an infinite capacity.

There are a number of queuing models with combined arrivals and departures. The characteristics of each model will be summarized in terms of the extended Kendall notation explained earlier.

a) (M/M/1) : (GD/∞/∞) Model : In this model, there is one server, with no limit on the capacity of either the system or the calling source. Arrivals and departures are Poisson with rates λ and μ.

b) (M/M/1) : (GD/N/∞) Model : The only difference between this model and (M/M/1) : (GD/∞/∞) is that the maximum number of customers allowed in the system is N (maximum queue length = N-1). This means that once N customers are in the system and all new arrivals either balk or not are not permitted to join the system. The result is that the effective arrival rate λ_{eff} at the facility becomes less than the rate λ at which arrivals are generated from the source.

c) (M/G/1) : (GD/∞/∞)- The Pollaczek-Khintchine Formula : This model is poisson arrival rate λ. General service time distribution with mean *E(t)* and variance *var(t)*. Steady–state conditions prevail with $\rho=\lambda\, E(t)<1$.

d) (M/M/c) : (GD/∞/∞) Model : In this model arrivals occur at the rate λ and a maximum of c customers can be serviced simultaneously. The average service time per customer is $1/\mu$. Both arrivals and departures occur according to the Poisson distributions.

e) (M/M/c) : (GD/N/∞), c ≤ N model : This queuing situation differs from (M/M/c) : (GD/∞/∞) in that a limit N is set on the capacity of the system (i.e. maximum queue size = N-c). In terms of the ($M_n/M_n/1$) : (GD/∞/∞) model, λ_n and μ_n. for the current model are given.

f) (M/M/∞) : (GD/∞/∞), - Self-Service Model : In this model, the number of servers is unlimited because himself or herself is also the server. This is the normally the case in the self-service facilities.

g) (M/M/R) : (GD/K/K), R<K – Machine Servicing Model : This model assumes that R repairmen are available for servicing a total of K machines. Since a broken machine cannot generate new calls while in service, the model is an example of a finite calling source.

Under *steady-state conditions*, the following basic measures of performance for (M/M/c) : (GD/∞/∞) Model is defined.

P_n : (steady-state) probability of a customers in system
L_s : expected number of customers in system
L_q : expected number of customers in queue
W_s : expected waiting time in system (in queue + in service)
W_q : expected waiting time in queue

The mentioned parameters can be expressed as follows:

$$p_n = \begin{cases} \left(\dfrac{\rho^n}{n!}\right) p_o & o \le n \le c \\ \left(\dfrac{\rho^n}{c^{n-c} c!}\right) p_o & n > c \end{cases} \tag{5.19}$$

$$p_0 = \left\{ \sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!(1 - \rho/c)} \right\}^{-1} \quad \text{(M/M/c):(GD/∞/∞)} \tag{5.20}$$

where

$$\frac{\rho}{c} < 1 \quad or \quad \frac{\lambda}{\mu c} < 1 \tag{5.21}$$

Also,

$$L_s = \sum_{n=0}^{\infty} np_n \tag{5.22}$$

$$L_q = \sum_{n=c}^{\infty} (n-c)p_n \tag{5.22}$$

A strong relationship exists between L_s and W_s (also L_q and W_q) so that either measure is automatically determined from the other. Specifically, given the arrival rate λ can be written as follows;

$$L_s = \lambda W_s \tag{5.24}$$

$$L_q = \lambda W_q \tag{5.25}$$

The equations hold under rather general conditions that do not restrict the distribution of arrivals or service time. However, in the special case where customers arrive at the rate λ but not all arrivals can join the system (this can happen, for example, when there is a limit on the maximum number in system), the equations must be modified by redefining λ to include only those customers that actually join the system. Thus letting

$$\lambda_{eff} = \begin{pmatrix} \textit{effective arrival} \\ \textit{rate for those who} \\ \textit{join the system} \end{pmatrix}$$

According to the effective arrival rate;

$$L_s = \lambda_{eff} W_s \tag{5.26}$$

$$L_q = \lambda_{eff} W_q \tag{5.27}$$

terms can be defined. In general,

$$\lambda_{eff} = \beta\lambda_s \qquad (for\ 0 < \beta < 1) \tag{5.28}$$

meaning that only a portion of those arriving can actually join the system. However, we can determine λ_{eff} in terms of L_s and L_q in the following manner.

By definition

$$\begin{pmatrix}\text{expected waiting} \\ \text{time in system}\end{pmatrix} = \begin{pmatrix}\text{expected waiting} \\ \text{time in queue}\end{pmatrix} + \begin{pmatrix}\text{expected service} \\ \text{time}\end{pmatrix} \tag{5.29}$$

Given that μ is the service rate, the expected service time is $1/\mu$ and we get

$$W_s = W_q + \frac{1}{\mu} \tag{5.30}$$

Multiplying both sides by λ, we get

$$L_s = L_q + \frac{\lambda}{\mu} \tag{5.31}$$

The relationship also holds when λ is replaced by λ_{eff} so that we can determine λ_{eff} from knowledge of L_s, and L_q as

$$\lambda_{eff} = \mu(L_s - L_q) \tag{5.32}$$

In all the queuing models developed, all the basic measures of performance in the following order can be expressed.

$$L_q = \frac{\rho^{c+1}}{(c-1)!(c-\rho)^2} p_0 = \left[\frac{c\rho}{(c-\rho)^2} \right] p_c \tag{5.33}$$

$$L_s = L_q + \rho \tag{5.34}$$

$$W_q = \frac{L_q}{\lambda} \tag{5.35}$$

$$W_s = W_q + \frac{1}{\mu} \tag{5.36}$$

In most queuing models, the computation of p_n is usually simple. In contrast, the computation of the waiting-time distribution may be quite complex. Thus the computation of W_s and W_q via L_s and L_q is usually more convenient and straightforward.

5.5.2.1 The Queuing Model Selecting

In general, queuing model is selected according to the mentioned basic elements: arrivals distribution, service-time distributions, number of servers, queue discipline and customer population.

In this study, the containers traffic to port can be separated into the land and sea-born traffic. Land-born traffic is composed of two subgroups: highway and railway. Other is of course known as seaway traffic. The containers transported by highway are also inclusive of those transported by railways which are in negligible number. The land-born containers is carried by trucks which have the four containers (TEU) loading capacity. On the other hand, the average number of container per ship is assumed. Customers dealt with in the queue system are *the ships and trucks loaded with containers as in the bulk queue system.* Therefore, the traffic arrivals include both ship and truck. If the containers are taken as customers, the individual arrivals of containers will be processed. On the contrary, if the ships and trucks as is taken as customers, *the bulking arrivals* as preferred in this study will be considered for determining the arrival distribution type.

The arrival distributions of ships and trucks carrying land-born containers are investigated separately and their distribution is found as fit to the Poisson distribution by the Chi-square method. However, the arrival rate of ships and trucks are calculated separately. If the capacity of yard is available to store, the containers arriving in port are handled. Each container slots serve for a handled container. In a yard, the number of container slots will of course be more than one. This means that each container slot is taken as server or channel and able to present a parallel service. This study considers *parallel server system*. If there is any congestion related to the container storage in yard, the ships and trucks are waited outbound of port. In this situation, the labor force is lost during the working day, at least, for the ships and trucks. The queuing modeling has to include the cost of this labor force loss. In this study, the waiting cost of ships and trucks are taken into consideration. In bulk queue system, the customers waiting mean, in fact, containers waiting. The cost of containers waiting will be calculated to the container capacity loaded for each ship and truck. The amount of waiting costs for either ships and trucks or containers does not change even if the bulk system in-container groups is preferred for individual containers.

For service rate and distribution type, there are two systems: individual and bulk system. Both system yields same service rate so that *the individual service system* is taken into consideration for defining the service time distribution type and calculating the service cost. After handled the containers, the inbound service required for the containers is presented individually. However, the service cost for loading, unloading, terminal, warehousing and assisting trailer services. Both land and sea-born containers utilize the same service possibilities. Therefore, the service time distribution of land and sea oriented containers is determined by testing in form of Erlang distribution for K=2. Instead of the service time distribution of containers based on individual system, the distribution related to ships and trucks in bulk system may be thought. If the labor force losses of the ships and trucks do not considered, the cost of service will be stable. This study employs the cost of service on individual system.

The port management does not undertake any responsibility in coordinating and scheduling ship or truck arrivals. Ships and trucks will be served in accordance with *the First Come-First Served queue discipline.* Ship-to-ship, truck-to-truck and ship-to-truck relation are independent from each other. The population of ships and trucks is considered as *infinite* because the rate at which the arrival source generates the ships and trucks, is not appreciably affected by the number of ships and trucks in the queue system (both in queue and service). According to the mentioned operating principles of a container yard, the basic elements of queuing model elements can be in short described as: *Poisson type arrival time distribution for bulk arrivals, Erlang type service time distribution for individual service, infinite and parallel number of servers, First Come-First Served (FCFS) queue discipline, infinite customer population.* These elements are coded as: **(M/M/c):(GD/∞/∞)**

In order to calculate easily the defined queuing parameters, the queuing software is developed by using the mentioned algorithm in Figure 5.6. The application of queuing theory in case study is carried out and the required parameters is satisfactorily obtained in accordance with the (M/M/c):(GD/∞/∞) queuing model algorithm and the assumptions of the proposal model.

To eliminate the decision variables which are not available economically in the optimization process, cost analysis including cost of investment, cost of service, cost of waiting ship or trucks and total cost is carried out. These costs are as follows:

$$RSA = RA_4.S.AV \quad (5.37)$$

$$COST_I = RSA.C_{SP}.CL_4.365 \quad (5.38)$$

$$COST_S = C_S.(TC - L_q.165) \quad (5.39)$$

$$COST_{WS} = W_q.TC.C_{WS} \quad (5.40)$$

$$TOC = COST_I + COST_S + COST_{WS} \quad (5.41)$$

Here, the cost parameters are taken as the unit slot area for 4-level stacking height; RA_4, the total required yard area; RSA, cost of investment; $COST_I$, cost of service; $COST_S$, cost of waiting ship or trucks; $COST_{WS}$, total cost; TOC, number of server; S, the annual amortization rate for 4-level stacking; CI_4, cost of slot per square meters, C_{SP}, unit cost of service; C_S, total number of container; TC, length of queue; L_q and waiting time of containers; W_q. For sea-born traffic, average ship load; 165, average number of trucks; 4 and C_{SP}=124 USD/m^2.

5.5.3 Monte Carlo Simulation

5.5.3.1 General

A distinct difference exists between the mathematical optimization and simulation models. In a mathematical optimization model, optimization problem is expressed in terms of explicit functions of the decision variables. The optimization problem is then solved to yield the values of the decision variables that optimize (maximize or minimize) the model's objective function. In this respect, the optimum values of decision variables (together the optimum objective value) represent the output of the mathematical optimization problem.

Constraints on this function do not exist. This objective function yields the value by using some input values. It may not be possible to express explicitly what this value is optimum without searching other outputs. For this purpose, Monte Carlo simulation (MCS) is carried out by considering the traffic loading of yard to be existed by matching all probabilities. To yield the traffic, MCS utilizing the probability distributions of arrivals, departures and staying containers takes into account all the intervals of a probability. For the combination process of the matched probability distributions, the container number staying at yard, calculated from objective function will be taken as one trial. The frequency and occurrence probability of each trial is then calculated.

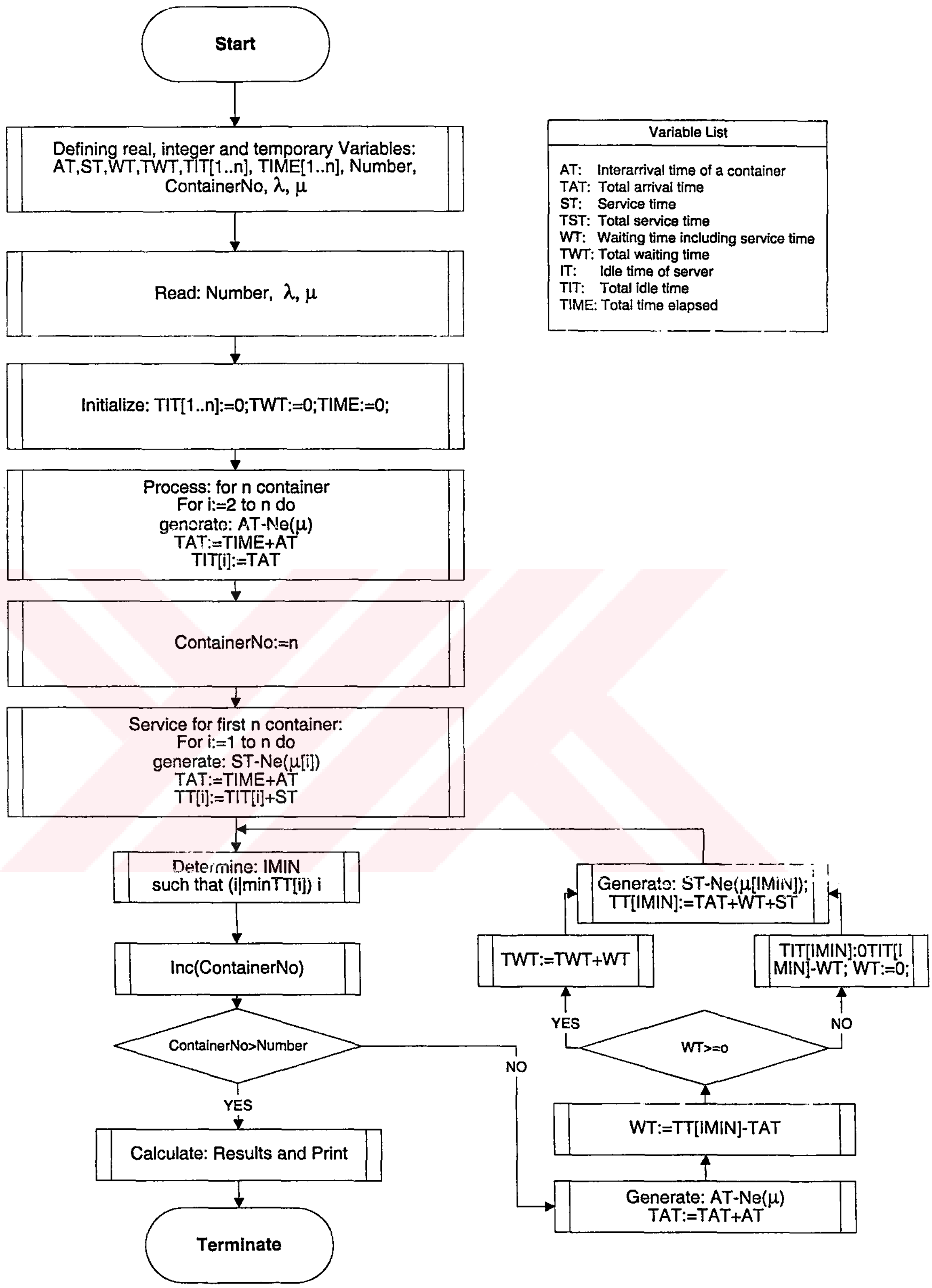


Figure 5.6 Flow chart of queuing theory

The optimum number of containers staying at yard is determined by minimum value of total cost to cause the excessive and defective container numbers obtained from evaluating their occurrence probabilities by the predetermined yard capacity.

In this study, the objective function is firstly written by considering the numbers of arriving ships, trucks and wagons, the average TEU's carried by each of these vehicles and, the number of containers staying at yard at any time as buffer.

$$W = (S_A)(O_A) - (S_L)(O_L) + 2(T_A) - 2(T_L) + 2(V_A) - 2(V_L) + Z \qquad (5.42)$$

W : Container number at the time w probability confirmed.
S_A : Number of ship arrivals.
O_A : Average container arrivals per ship.
S_L : Number of ship departures.
O_L : Average container departure per ship.
T_A : Number of truck arrivals.
T_L : Number of truck departures.
V_A : Number of wagon arrivals.
V_L : Number of wagon departures.
Z : Number of containers on the yard at the present time.

The container numbers to be departed by wagon is included to the number of truck departures because the number of wagon departures is so small. It is considered that each truck and wagon carry only two TEU.

The terms in objective function are composed of constant (average number of container in ship, truck and wagon) and variable parameters (number of containers arriving, departed and staying). The constant parameters are known but the variable parameters must be assigned by MCS.

5.5.3.2 Methodology of Monte Carlo Simulation

1. *Determining the theoretical probabilities:* at first, the relation between the observed distributions of arrivals, departures of ships, trucks and wagons and the theoretical distribution of them is tested by the Chi-square test of Goodness of Fit.

2. *Generating the random number*: by using mechanism of random number generation, the daily arrivals of ships, trucks and wagons from monthly statistics is re-generated in accordance with the related theoretical distributions and the arrival probabilities from arrival statistics of each vehicle is calculated. However, there is the requirement about probability distribution of container staying at yard in a time.

3. *Writing the objective function:* the container inputs and outputs to yard, and the number of container at yard are balanced by setting objective function.

4. *Determining the ship, truck and wagon arrival and departure numbers:* an interval of a deterministic probability distribution corresponds to the numbers related to arrival or departure of that transport system is selected. The similar process is carried out for another probability distribution. A probability interval selected from all distributions is matched with others by using MCS. The combination process of the matched probability distributions represents one event or trial in system. The relating container numbers corresponding to the considered probability is taken.

5. *Calculating the container number at yard by objective function*: the function yields the container yard numbers as the decision variables in optimization problems. According to each event or trial to be coincided with in yard, the relating container number staying at yard is then calculated by using objective function.

6. *Yielding the new yard container numbers by increasing the number of trial*: the similar process is followed and new decision variables are yielded.

7. *Calculating the frequency and probability of decision variables*: the frequencies and occurrence probabilities of the calculated container number for each event or trial can be computed by using the developed software in the way of algorithm presented.

8. *Analyzing the costs of idle and unserved containers:* the mentioned costs are analyzed by determining the numbers of idle and unserved containers to be obtained by relating between the considered capacity of yard and the calculated container yard capacity.

9. *Optimizing the decision variables:* Cost analysis restricts the decision variables and the optimum container yard number is found by minimizing the total cost.

İf ($W_o > W_i$) then

$$M_j = C_y \times \sum_{i=1}^{j} P_{wi} \times W_{fi} \tag{5.43}$$

where j : number of W occured under determined capcity

M_j : Cost of idle investment

C_y : Cost of investment per container

P_{wi} : Probability of occurrence under determined capacity.

W_o : Determined capacity

W_i : Container number occurred under capacity and ($W_{fi} = W_o - W_i$)

If {$W_o < W_k$} then

$$M_k = C_s \sum_{k=j+1}^{n} P_{wk} \times W_{Ek} \tag{5.44}$$

where k : Container number occurred over determined capacity

M_k : Cost of lost benefit

C_s : Revenue for one container serviced and stored

P_{wk} : Probability of occurrance over capacity.

W_o : Determined capacity

W_k : Container number occurred over capacity and $(W_{Ek} = W_k - W_o)$

So, the total cost is $\{M = M_j + M_k\}_{\min}$

The developed software for this part of study assists for solving optimization problem by using the MCS. Each trial of the arrival and departure probability distribution is randomly changed to yield traffic loading of yard. The software, MCS is executed and the number of containers slots staying at yard required for optimization problem is calculated. At the end of the trials, the frequency and probability for number values of containers in yard taken as the decision variables are determined so that the costs can be computed as presented in previous case (see Figure 5.7).

5.5.4 Queuing Simulation to New Developed Software (Container Yard Optimization, CYO)

Simulation models developed to analyze the behavior of systems as a function of time can be classified into two groups: Discrete and Continuous simulations. A typical example of discrete simulation is a waiting line system in which customers either joins a queue or enters service and then leaves the service facility after the service is completed. The continuous case is exemplified by the flow of liquid in a pipeline or by the growth of world population. In this study, the discrete simulation modeling is taken into consideration.

Simulation models, on the other hand, are not constructed in framework of a classical optimization process. A simulation model merely measures the output of the system for predetermined values of decision variables. This means that the values of decision variables are considered part of the input data. When the optimization study by utilizing simulation model is carried out, the changing values of decision variables in a random manner are processed to be able to calculate their costs. The optimum decision variable can be found by taking as the value corresponding to minimum total cost.

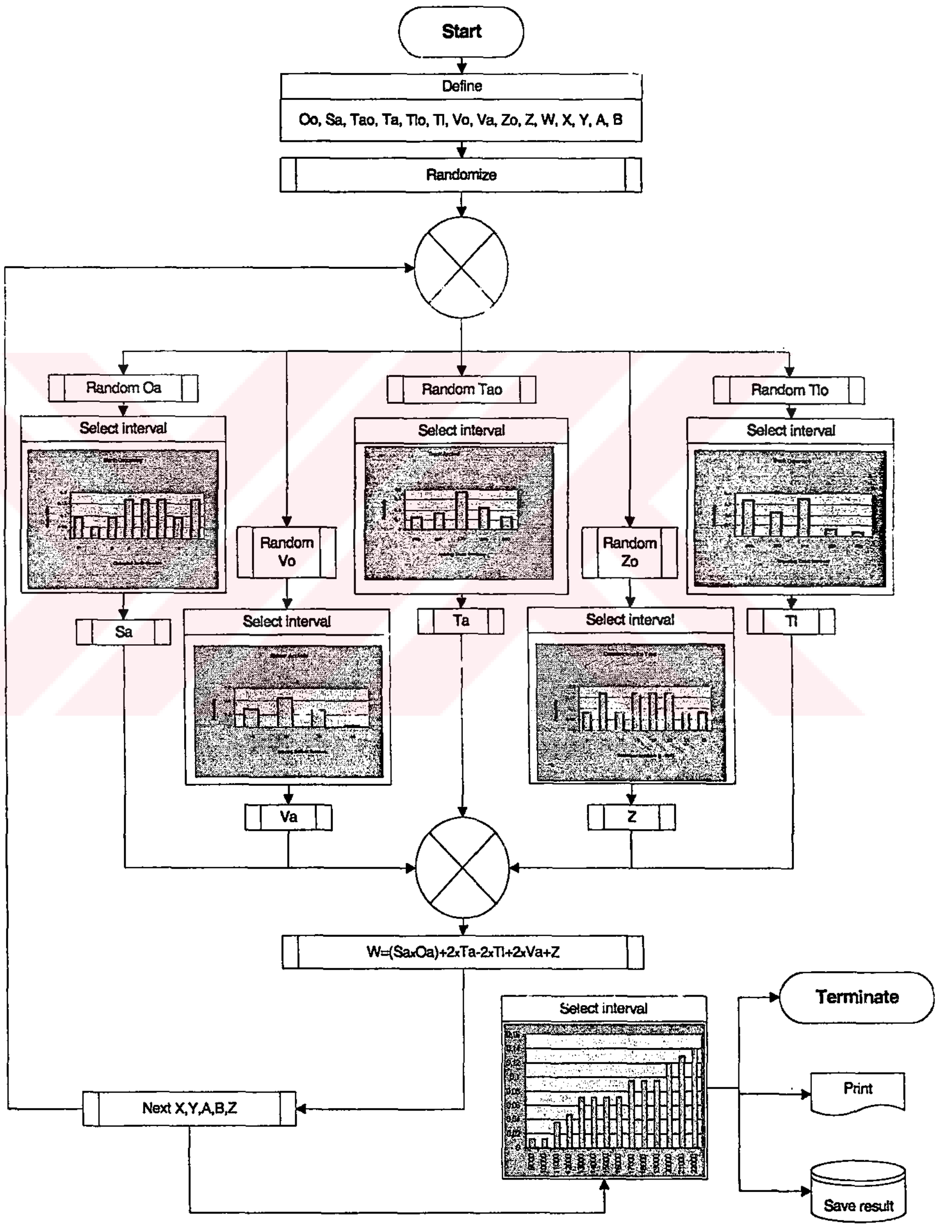


Figure 5.7 Flow chart of optimization process by using MCS

The queuing model can be complicated by considering the movement of containers carried by ships, trucks and railcars and flow of empty/full containers in yard together with import/export containers require several number of probability distribution to be matched and tested by theoretical distributions. Such queue system has to investigate probability distributions of the arrivals and departures of empty/full containers, probability distributions of the arrivals and departures of import/export containers, storing or holding days of containers staying at yard and types of handling equipment.

Even if the probability processes of this queue system can be solved, the queuing modeling, including the combination of many differentiated probability distribution in the process, and especially the derivation of the analytical formula are rather complex and may be dissolved. In this case, queuing simulation method is preferred for solving computationally such complex queuing problem.

In this study, the software based on queuing simulation, Container Yard Optimization, CYO is developed. Even if the queuing model is much more complex, the expected solution of it with the simulation is carried out.

5.5.4.1 Software Development

Software CYO was developed on Windows XP operating system and was not tested on other systems. It is possible that it will not run under Windows 98, NT, Millennium except for Windows 2000 and XP due to used visual effect and components. Because that CYO is a Windows application, it has characteristics of any windows application except for menu. The program was not designed as usual windows and menu system to stand simple. To do so, it was designed by tabs containing sub tabs. Every group of activity was spread on one tab, its sub characteristics on sub tabs.

The application has a core executer, input modulo and output modulo. Core component that make runs the program also checks and initialize data given as in Figure 5.8a and 5.8b. For detailed usage, CYO manual in Appendix B explains the phases to use and shows its images.

As all visual applications have, CYO has visual elements as check boxes, edit boxes, buttons etc, too. Program variables have default values the designer initiated using its knowledgebase if it is not filled by user.

Program was developed using a high level visual development environment. CYO's codes has object-oriented base so variables were defined as record types of Pascal.

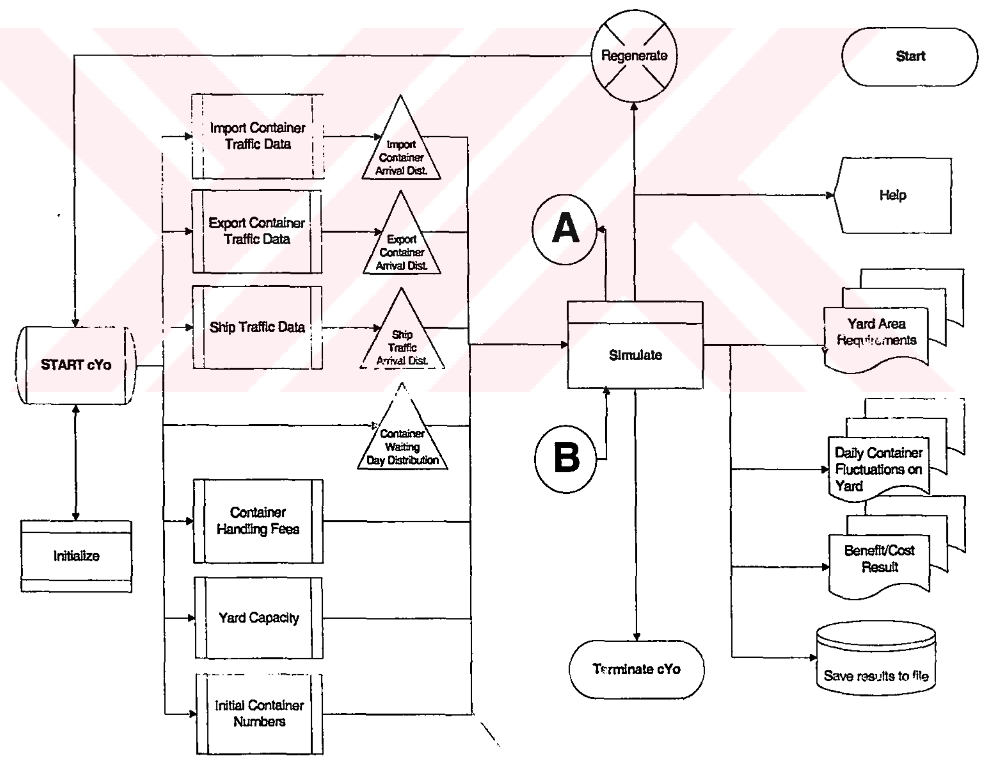


Figure 5.8a Flow chart of CYO showing input, output and executing functions.

A typical port has elements; yard, ship, container, berth, handling equipment. Some characteristics of each element were defined:

```
Type
ImEx                      =(Imported,Exported);

Containers =              record
ArrivalDayToPort          :Integer;
ArrivalDay                :Integer;
LeaveDay                  :Integer;
WaitingDay                :Integer;
Benefit                   :Real;
Empty                     :Boolean;
TEUEquivalent             :Byte;
ImportOrExport            :ImEx;
                          end;

Ships =                   record
IncomingNumber            :Integer;
IncomingContainerNumber   :Integer;
OutgoingContainerNumber   :Integer;
ArrivalDay                :Integer;
LeaveDay                  :Integer;
WaitingDay                :Integer;
                          end;

Berths =                  record
HourlyHandlingCapacity    :Byte;
                          end;

Gates =                        record
GateIncomingContainerNumber    :Integer;
GateOutgoingContainerNumber    :Integer;
                                end;

StorageYards =            record
TotalCapacity             :Extended;
IncomingYardCapacity      :Extended;
OutgoingYardCapacity      :Extended;
ExInitialTEU              :Integer;
ImInitialTEU              :Integer;
DailyTEUNumber            :Integer;
ExDailyTEU20              :Integer;
ExDailyTEU40              :Integer;
ExDailyEmtyTEU20          :Integer;
ExDailyEmtyTEU40          :Integer;
ExDailyTEUTotal           :Integer;
ImDailyTEU20              :Integer;
ImDailyTEU40              :Integer;
ImDailyEmtyTEU20          :Integer;
ImDailyEmtyTEU40          :Integer;
ImDailyTEUTotal           :Integer;
DailyWaitingDay           :Array[1..365] of Real;
DailyWeight               :Real;
                          end;
```

Each ship of given annual ship traffic, after distributing monthly and daily by a distribution function, has a arrival day to port (not berthed), arrival day to berth (starting service) and departure day. Annual sea born containers are first distributed by any distribution function user selected and then attached to these ships. So daily sea born incoming containers varies with ship number arrived in that day. But containers arrived by truck and railcar were distributed directly by any distribution selected. The data of İzmir Port used in case study verifies this assumption.

For recorded container, arrived in a day; an arrival day, a waiting day by a distribution and a departure day adding its waiting day to its arrival day due to birth source (sea born or land born) was attached. ArrivalDayToPort property of container varies with ship arrival.

```
For i:=1 to ExConIndex do begin
        Inc(Sayac);
        If Sayac>100 then begin Sayac:=0;
        RandomHarmanla(Sender);                    end;
        ExportContainer[i].WaitingDay:=RandomBeklemeSuresi[Sayac];
        ExportContainer[i].LeaveDay:=ExportContainer[i].ArrivalDay+ExportContainer[i].WaitingDay;      end;
```

This procedure is applied to both import and export containers.

Next procedure is profit computation of each container serviced. Each container is priced due to its condition that means if it is full or empty. Every service has a fee. So due to the condition of being full or empty, export or import and time waited on the yard. Code below is for import containers. Service fees table is given in Figure 6.4. Port tariff varies port to port. Given tariff in the table is for İzmir Port.

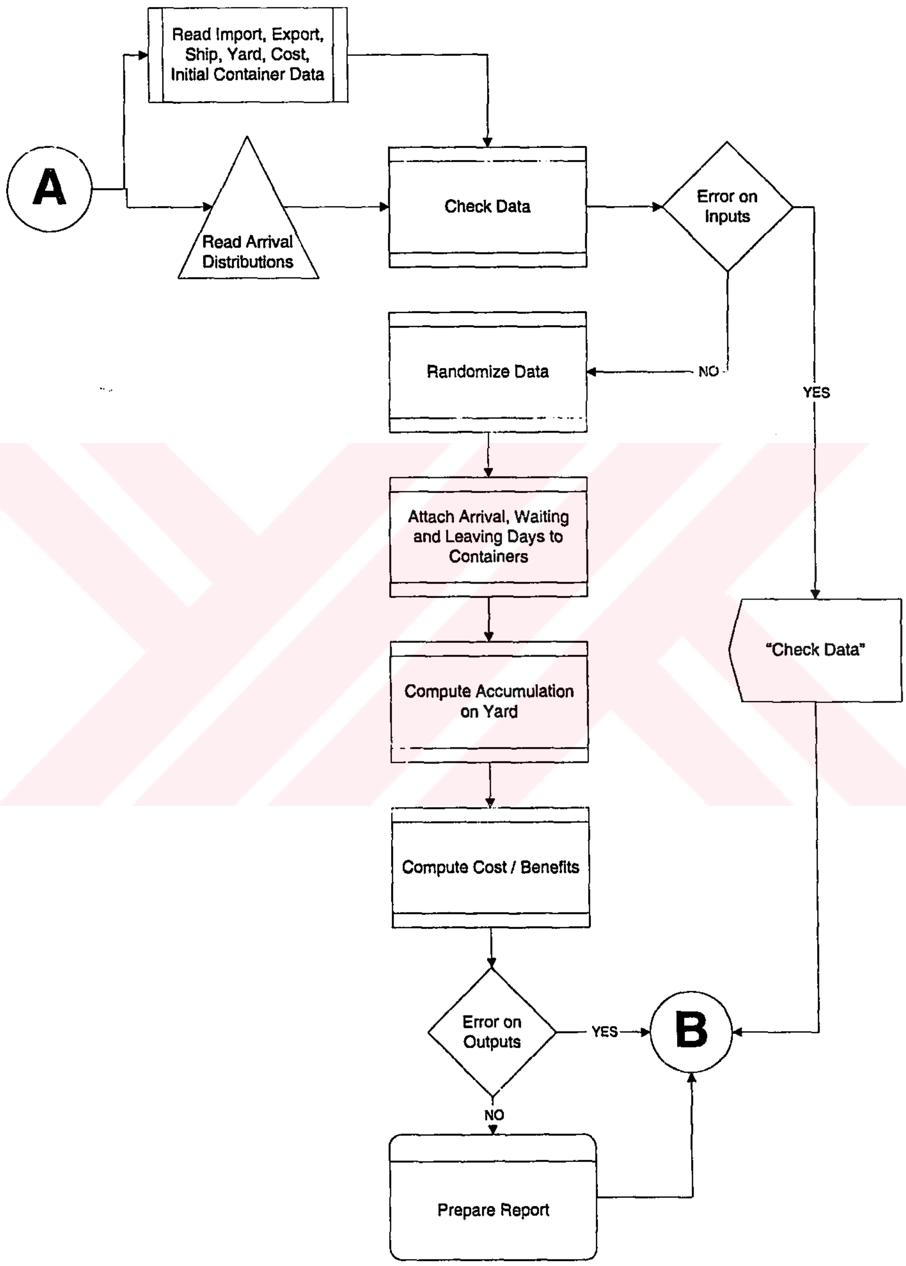


Figure 5.8b Flow chart of CYO showing input, output and executing functions (continued).

```
For i:=1 to ImConIndex do begin
        if  (i mod 10000)=0 then DigitSayac.Value:=i;
        If ImportContainer[i].Empty=False then begin
        If ImportContainer[i].WaitingDay in [0..ImDFP1.Value]
        then ImportContainer[i].Benefit:=ImLF.Value+ImTF.Value+ImportContainer[i].WaitingDay*ImFP1.Value;
        If ImportContainer[i].WaitingDay in [ImDFP1.Value+1..ImDFP1.Value+ImDFP2.Value]
        then ImportContainer[i].Benefit:=ImLF.Value+ImTF.Value+ImDFP1.Value*ImFP1.Value+(ImportContainer[i].WaitingDay-ImDFP1.Value)*ImFP2.Value;
        If ImportContainer[i].WaitingDay in [ImDFP1.Value+ImDFP2.Value+1..ImDFP1.Value+ImDFP2.Value+ImDFP3.Value]
                then ImportContainer[i].Benefit:=ImLF.Value+ImTF.Value+ImDFP1.Value*ImFP1.Value+ImDFP2.Value*ImFP2.Value+(ImportContainer[i].WaitingDay-
                                ImDFP1.Value-ImDFP2.Value)*ImFP3.Value;
        end
                else
                begin
         If ImportContainer[i].WaitingDay in [0..ImDEP1.Value]
                then ImportContainer[i].Benefit:=ImLE.Value+ImTE.Value+ImportContainer[i].WaitingDay*ImEP1.Value;
         If ImportContainer[i].WaitingDay in [ImDEP1.Value+1..ImDEP1.Value+ImDEP2.Value]
                then ImportContainer[i].Benefit:=ImLE.Value+ImTE.Value+ImDEP1.Value*ImEP1.Value+(ImportContainer[i].WaitingDay-ImDEP1.Value)*ImEP2.Value;
         If ImportContainer[i].WaitingDay in [ImDEP1.Value+ImDEP2.Value+1..ImDEP1.Value+ImDEP2.Value+ImDEP3.Value]
                then ImportContainer[i].Benefit:=ImLE.Value+ImTE.Value+ImDEP1.Value*ImEP1.Value+ImDEP2.Value*ImEP2.Value+
        (ImportContainer[i].WaitingDay-ImDEP1.Value-ImDEP2.Value)*ImFP3.Value;
               end;
            ImBenefitTotal.Value:=ImBenefitTotal.Value+ImportContainer[i].Benefit;
        end;
```

CYO disaggregates import and export containers, emptiness and fullness. So processes are applied due to the property of container.

Main phase is the accumulation computation section. This is also disaggregated for import and export containers. In this section, total container number in a day is calculated by ArrivalDay and LeaveDay property of containers. Procedure here is adding arriving containers and subtracting leaving container including waiting containers and checks the total. If yard capacity is over, then ArrivalDay property of containers is increased coming. This applies also to ships. If container's ArrivalDatToPort and ArrivalDay property differs, the difference is multiplied by cost. Code procedure for above mentioned calculation is as below;

```
For i:=1 to 365  do BEGIN
          DigitSayac.Value:=i;
If i=0 then      TempBirikim:=Yard.ImDailyTEUTotal else TempBirikim:=GunSonuBirikim[i-1];
For j:=1 to ImConIndex do begin
           If ImportContainer[j].ArrivalDay=i then Inc(TempBirikim);
           If ImportContainer[j].LeaveDay=i   then Dec(TempBirikim);            end;
For j:=1 to ImInConIndex do begin
//               If ImportInitialContainer[j].ArrivalDay=i then Inc(TempBirikim);
                 If ImportInitialContainer[j].LeaveDay=i   then Dec(TempBirikim);       end;

If TempBirikim>ImYardCapacity.Value then
 BEGIN
  OGunIslenenKonteynerSayisi:=ImYardCapacity.Value-TempBirikim;
  KuyruktakiKonteynerSayisi:=TempBirikim-ImYardCapacity.Value;
  For j:=ImDayBegin[i] to ImDayBegin[i]+OGunIslenenKonteynerSayisi do  begin
                                     ImportContainer[j].ArrivalDay:=i;
                                     end;
  For j:=ImDayBegin[i]+OGunIslenenKonteynerSayisi+1 to ImDayEnd[i] do  ImportContainer[j].ArrivalDay:=i+1;

  If OGunIslenenKonteynerSayisi>ConPerShip[i]  then begin  Dec(ShipQueueDaily[i],(OGunIslenenKonteynerSayisi div ConPerShip[i]));
                               Inc(ShipQueueDaily[i+1],(Ship[i].IncomingNumber-(OGunIslenenKonteynerSayisi div ConPerShip[i])));
                               DeMoorageCostDaily[i]:=ShipQueueDaily[i]*DeMoorageCost.Value;end
                      else      DeMoorageCostDaily[i]:=ShipQueueDaily[i]*DeMoorageCost.Value;

 END else  BEGIN
 DeMurrageCostDaily[i]:=0;
 ShipQueueDaily[i]:=0;
 ImCapacityUnder[i]:=ImYardCapacity.Value-TempBirikim;  ImCapacityOver[i]:=0;  END;
```

```
If i=0 then begin  GunBirikimEmpty:=Yard.ImDailyEmtyTEU20; GunBirikimFull:=Yard.ImDailyTEU20;end
     else begin  GunBirikimEmpty:=GunBasiBirikimEmpty[i];GunBirikimFull:=GunBasiBirikimFull[i];end;

For j:=1 to ImConIndex do begin
          If ImportContainer[j].ArrivalDay=i then If ImportContainer[j].Empty=True then Inc(GunBirikimEmpty)
                                                      else Inc(GunBirikimFull);
          If ImportContainer[j].LeaveDay=i   then If ImportContainer[j].Empty=True then Dec(GunBirikimEmpty)
                                                      else Dec(GunBirikimFull);            end;

For j:=1 to ImInConIndex do begin
          If ImportInitialContainer[j].LeaveDay=i   then If ImportContainer[j].Empty=True then Dec(GunBirikimEmpty)
                                                      else Dec(GunBirikimFull);            end;
GunSonuBirikim[i]:=GunBirikimEmpty+GunBirikimFull;
GunBasiBirikim[i+1]:=GunSonuBirikim[i];
GunBasiBirikimEmpty[i+1]:=GunBirikimEmpty;
GunBasiBirikimFull[i+1]:=GunBirikimFull;

ImCapacityUnderTotal:=ImCapacityUnderTotal+ImCapacityUnder[i]*ImCostUnder.Value;
DeMoorageCostTotal:=DeMoorageCostTotal+DeMoorageCostDaily[i]; end;
For i:=1 to 365  do Val(ImGridYardWaitings.Cells[3,i],TempArray[i],Code);
InConMax.Value:=MaxIArray(TempArray);
InConMin.Value:=MinIArray(TempArray);
```

Routine for the export containers is the same except that waiting ship is replaced by truck or railcar.

Next step is the yard area calculation. CYO for the computation of area determines the maximum container number scanning daily numbers of all year for inbound and outbound yard. Considering the layout of each handling system and handling equipment, CYO calculates the total area to be required for the maximum container number. Routine for this calculation is below;

```
For i:=1 to 6 do begin
          N:=Round(CopyInConMax.Value*(100+(100-
TrmSpinEdit(FindComponent('Im'+IntToStr(i)+'7')).Value)) /100);
          DigitSayac.Value:=i;
          lx:=TrmSpinEdit(FindComponent('Im'                +
IntToStr(i)+'6')).Value/100;
          ly:=TrmSpinEdit(FindComponent('Im'                +
IntToStr(i)+'5')).Value/100;
          a:=        TrmSpinEdit(FindComponent('Im'        +
IntToStr(i)+'3')).Value;
          b:=        TrmSpinEdit(FindComponent('Im'        +
IntToStr(i)+'2')).Value;
c:= TrmSpinEdit(FindComponent('Im' + IntToStr(i)+'4')).Value;
```

```
          TB:=(N div (a*b*c));
          KR:=Round((N mod (a*b*c))/(a*b));
          TrmSpinEdit(FindComponent('Im'                +
IntToStr(i)+'9')).Value:=KR;
          TrmSpinEdit(FindComponent('Im'                +
IntToStr(i)+'1')) Value:=TB;
          RequiredArea:=(a*c)*ACon*TB+(a*KR)*ACon+
          TB*( (a-1)*lx*(c*z+(c-1)*ly) +   (c-1)*ly*(a*x+(a-1)*lx) -  (a-
1)*(c-1)*lx*ly   ) +
          ( (a-1)*lx*(KR*z+(KR-1)*ly) + (KR-1)*ly*(a*x+(a-1)*lx) - (a-
1)*(KR-1)*lx*ly   );
          TmxFlatFloatSpinEdit(FindComponent('Im'         +
IntToStr(i)+'8')).Value:=Round(RequiredArea);
end;
```

The last routine is for cost-benefit analysis. CYO calculates the optimum yard capacity trying new capacities. To do so, it increases the capacity from limit boundary to upper boundary the user defined simulation parameters page of itself. For every capacity, above routines are reapplied and minimum cost point is determined.

The flow chart of CYO's was drawn completely in Appendix A.

CHAPTER SIX

CASE STUDY: İZMİR PORT

6.1 Information for İzmir Port

This part of study includes the description of İzmir Port and the present container statistics.

İzmir port was constructed by Ministry of Transportation, General Directorate of Railways, Ports and Airports Construction (DLH in Turkish) and has been operated by Ministry of Transportation, General Directorate of State Railways (TCDD in Turkish). The administration, management and operation of İzmir Port is belonging to Republic of Turkey and referred as state port. The information about İzmir Port is presented as follows:

Location and Description of the Port: City of Izmir is situated in the eastern coast of the Aegean Sea. Izmir is the third largely populated city of Turkiye and it is a business center. The port has a vast agricultural and industrial hinterland. It is the port for the Aegean Region's industry and agriculture and it plays a vital function in the country's exports. The port is also connected with state railway and highway network.

Pilotage is compulsory for vessels entering or leaving the port. Pilotage and towage services are provided by the Turkish Maritime Organization (TDI).

Sea Crafts comprise one floating crane of 100 tons capacity and 2 mooring boats.

Handling Equipment: Operations at the quays are carried out by 5 gantry cranes of 40 tons capacity. The operations at the container yard are carried out by 19 rubber tired transtainers and 20 reach stackers of 40 tons capacity together with 23 empty container forklifts of 10 to 42 tons capacity. Reefer facilities for refrigerated containers are also available. The capacity of container washing facility is 20 TEU per day.

Container Terminal: The container terminal of İzmir port has seven berths which have an alongside depth of 13 m. The total length of berths is 1050 m. Terminal covers as area of 152.000 m^2 and holding capacity is 7047 TEU.

Bulk Cargo Facilities: Two reinforced concrete grain silos belonging to The Agricultural Products Office (TMO) of having a total 70.000 tons capacity are available and there is a conveyor system connection with the quay.

Passenger Facilities: As İzmir is very close to the tourism and historical places on the Aegean coast, the port has substantial passenger traffic.

Position: Latitude : 38° 25' 00" N

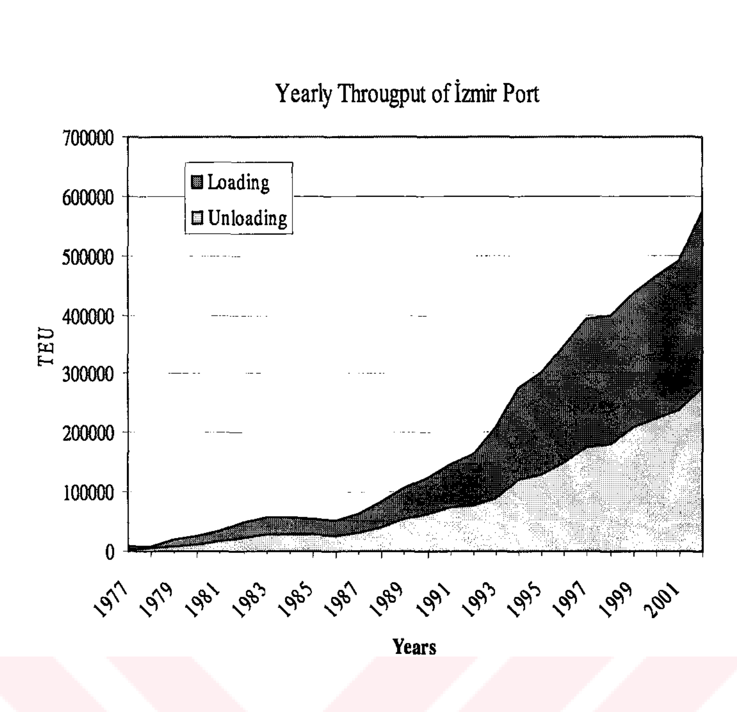
Longitude : 27° 04' 30" E

Port Working Hours:

Administrative : 08:30 – 17:30

Operational : 3 shifts (08:00-16:30, 16:30-00:30, 00:30-08:00) 24 hours a day

Container traffic of İzmir Port between 1977 and 2002 years is given in Figure 6.1.



Years	Unloading	Loading
1977	3773	3936
1978	4735	4795
1979	9995	10403
1980	12388	12419
1981	17936	17770
1982	24379	24704
1983	28354	28375
1984	28152	28432
1985	27642	27106
1986	26095	26471
1987	30947	31331
1988	41196	41416
1989	53678	51957
1990	61754	61087
1991	73306	73046
1992	78440	85730
1993	90289	118552
1994	119133	156299
1995	129461	171333
1996	150231	195695
1997	174696	217000
1998	179837	220357
1999	208076	227894
2000	223150	241305
2001	237587	253690
2002	275410	297821

Figure 6.1 Annual throughputs of İzmir Port

6.2 Data on Ships, Cargo and Trucks

Port is connected by highway and railway. The container traffic employs all transportation system. Total number of land-born containers is 432 818. The import and export container numbers are respectively 233 414 and 197 526. The full and empty containers for export are approximately 96 and 4 as percentage. Similarly, total number of sea-born containers is 573 231. The container numbers for the import and export are respectively 275 410 and 297 821. The percentages of full and empty container for import are approximately 38 and 62. Table 6.1, 6.2 and 6.3 give the detail information about sea and land-born traffic.

Table 6.1 Sea-Born Traffic Data of İzmir Port (Year 2002)

Months	Ship Number	Unloading						Loading					
		Full		Empty		TEU	Tons	Full		Empty		TEU	Tons
		20'	40'	20'	40'			20'	40'	20'	40'		
January	128	2 433	2 572	4 895	2 981	18 434	109 130	7 484	6 117	299	247	20 511	261 510
February	130	2 144	2 789	4 983	3 637	19 979	113 941	8 066	5 976	543	240	21 041	255 091
March	154	2 464	3 302	5 802	3 641	22 152	127 717	9 407	7 320	322	92	24 553	323 436
April	134	2 757	3 555	5 755	3 107	21 836	131 994	8 577	6 369	685	295	22 590	291 694
May	137	3 195	4 042	5 188	3 147	22 761	147 288	9 775	7 093	673	477	25 588	314 437
June	139	3 112	3 544	4 965	2 028	19 221	128 596	8 939	6 464	623	469	23 428	296 133
July	144	2 783	3 517	6 748	3 288	23 141	134 481	9 252	6 702	378	346	23 726	303 882
August	134	2 737	3 541	6 404	3 847	23 917	134 659	9 514	7 932	168	298	26 142	329 575
September	146	2 828	3 472	8 203	4 726	27 427	143 348	11 336	8 501	341	220	29 119	386 303
October	152	3 160	3 812	7 498	4 456	27 194	145 779	12 351	9 024	257	310	31 276	421 021
November	139	2 836	3 358	7 000	4 217	24 986	139 939	10 291	8 018	287	158	26 930	366 728
December	135	2 548	2 993	7 028	4 400	24 362	127 364	9 185	6 349	386	324	22 917	305 741
Total	**1 672**	**32 997**	**40 497**	**74 469**	**43 475**	**275 410**	**1 584 236**	**114 177**	**85 865**	**4 962**	**3 476**	**297 821**	**3 855 551**

Table 6.2 Land-Born Traffic Data of İzmir Port (Year 2002)

	Import By Truck				Import By Wagon				Export By Truck				Export By Wagon			
	Full		Empty		Full		Empty		Full		Empty		Full		Empty	
Months	20	40	20	40	20	40	20	40	20	40	20	40	20	40	20	40
January	3386	4799	858	324	2	474	130	8	980	1398	2621	2824	0	92	0	30
February	3996	5143	1124	179	5	233	184	0	819	1530	2428	3383	0	19	0	27
March	3900	5855	1350	326	0	761	95	0	1083	2355	3458	4248	0	19	0	84
April	3822	5752	1529	271	0	616	286	68	1324	2455	3273	3441	0	49	0	98
May	4029	5767	1871	561	0	252	194	48	1528	2564	3059	3525	0	37	0	4
June	3753	5398	1420	433	2	505	203	0	1517	2158	2407	2730	0	52	0	5
July	4000	5951	1310	396	0	358	0	0	1408	2453	3044	3440	0	121	0	25
August	3964	6592	1243	387	0	386	94	0	1395	2327	3357	4052	0	70	0	0
September	5342	6586	1494	354	0	1099	74	32	1362	2230	3878	4150	0	89	0	0
October	6124	7356	1003	363	0	847	184	2	1470	2183	4141	4266	20	103	0	0
November	5080	7342	1102	299	0	464	84	0	1302	2355	3920	4776	10	0	0	0
December	3961	5568	997	387	22	473	167	0	1250	2068	3800	4440	0	0	0	0
Total	**51357**	**72109**	**15301**	**4280**	**31**	**6468**	**1695**	**158**	**15438**	**26076**	**39386**	**45275**	**30**	**651**	**0**	**273**

Table 6.3 Daily Ship Traffic Data of İzmir Port (Year 2002)

Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
January	1	5	4	3	3	6	4	5	2	0	6	7	4	5	3	6	4	7	3	6	4	5	2	2	4	5	4	7	4	5	2	**128**
February	2	5	6	5	4	5	3	5	4	6	6	7	5	4	5	7	3	5	2	6	3	6	5	4	6	4	5	2				**130**
March	2	6	7	5	3	5	6	6	3	6	5	6	5	6	5	4	4	4	5	6	7	3	5	4	5	4	6	5	7	5	4	**154**
April	3	5	4	6	4	5	2	7	4	5	2	6	4	5	3	5	4	5	4	7	4	5	4	5	4	3	6	4	5	4		**134**
May	4	6	2	5	4	7	4	5	4	6	4	3	5	3	5	4	5	2	5	4	7	4	5	4	5	4	5	1	6	4	5	**137**
June	4	6	5	5	3	5	2	2	4	5	7	7	1	5	4	7	6	5	4	2	6	5	4	5	3	7	4	5	6	5		**139**
July	4	6	1	4	6	7	5	4	7	4	6	4	6	5	3	0	5	4	5	4	5	3	5	2	6	5	6	4	7	6	5	**144**
August	3	5	1	5	4	0	6	5	4	5	3	6	4	2	7	5	4	5	4	2	7	5	4	5	4	6	4	3	4	6	6	**134**
September	6	5	3	4	5	6	4	6	7	5	6	5	4	5	7	1	4	6	4	2	4	5	7	6	4	6	4	6	4	5		**146**
October	4	6	7	5	4	6	4	6	5	2	5	6	3	6	4	5	4	6	5	4	7	3	6	4	6	5	6	4	5	5	4	**152**
November	4	5	3	6	2	4	4	3	6	5	3	5	6	7	4	5	6	5	6	5	6	4	7	3	4	7	2	1	5	6		**139**
December	5	3	1	6	4	5	6	5	4	2	4	5	3	5	4	7	4	5	4	3	2	5	4	5	4	5	6	5	4	6	4	**135**
Total																																**1672**

The land and sea-born traffic data including empty and full container numbers of import and export cargo by the transportation systems are presented in tables above. These raw data will be processed by the optimization methods.

6.3 Port Tariff of İzmir Port

TCDD has the responsibility to decide how much port tariff will be applied in state ports. Port tariff includes unit cost of containers loaded and unloaded for import and export, unit cost of warehousing or storage which changes by staying days of containers and terminal services.

Table 6.4 Port Tariff for A 1 TEU Container (in USD)

Container	Warehousing						Shifting	Limbo	Terminal	Loading	Unloading
	Day	Import	Day	Export	Day	Transit					
Empty	0-5	0	0-5	0	0-5	0					
	6-20	3	6-20	3	6-	2	40	50	15	35	35
	21-	3	21-	3							
Full	0-15	7	0-5	0	0-5	0					
	16-30	12	6-15	6	6-20	4	85	110	35	70	95
	31-	12	16-	10	21-	6					

In inventory model, the cost of service is taken as 39.64 USD/TEU. This is calculated by considering the annual service cost earned per TEU in Haydarpaşa Port operated by TCDD. The daily amortization rate of investment cost is found as 0.3 USD/TEU.day for square meters of container area, approximately 124 USD, economic life of port, 10 years and interest rate 3%.

6.4 İzmir Port Data Gathering and Testing

The data on arrival and departure of ships and trucks is fit to the Poisson distribution according to the Chi-square method. But this process is not carried out for wagons which are negligible amount of traffic. The number of containers carried by wagons is included to the number of containers by trucks. The monthly statistics of sea and land-born containers are yielded as daily statistics according to the Poisson distribution.

Table 6.5 Random Generated Daily Ship Arrivals

Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
January	7	7	11	3	5	6	5	2	3	2	6	4	2	3	5	2	8	4	8	8	3	5	5	4	4	3	4	6	8	5	1	149
February	4	4	4	3	5	3	1	4	3	6	6	1	9	5	3	3	6	2	4	7	11	2	4	8	4	8	5	4	-	-	-	129
March	7	3	4	3	7	5	2	5	4	6	7	3	8	4	4	5	1	7	3	5	4	6	3	3	4	5	5	6	4	4	3	140
April	8	3	6	8	0	5	6	6	4	3	7	8	5	1	4	7	5	3	4	6	6	4	4	3	7	8	6	5	6	6	-	154
May	5	3	4	1	8	1	4	7	4	4	3	7	6	4	2	8	0	8	6	2	1	6	9	6	4	6	6	2	3	4	7	141
June	4	1	6	6	4	6	7	12	3	8	5	3	1	3	1	5	4	5	4	9	2	5	2	5	4	4	4	4	3	7	-	137
July	5	2	3	1	3	8	4	4	7	8	5	9	4	4	7	4	10	4	2	4	5	6	8	2	8	3	3	4	4	3	1	145
August	4	7	3	7	2	4	4	4	4	3	8	3	5	2	5	3	5	2	5	7	3	3	3	7	6	6	2	7	2	5	3	134
Sept.	1	5	8	6	3	5	4	3	5	3	9	4	9	4	5	5	7	5	5	3	4	5	6	2	5	5	1	2	2	5	-	136
October	7	3	3	3	6	5	5	7	2	2	8	5	10	2	5	3	4	6	6	5	3	0	2	3	3	1	3	6	3	6	4	131
Nov.	2	5	4	4	3	6	0	5	2	4	7	5	5	2	4	7	5	2	4	6	8	2	2	4	3	4	7	5	4	6	-	127
Dec.	9	2	7	3	2	3	2	3	4	5	6	7	1	5	4	5	6	4	5	6	8	4	5	4	5	4	6	4	5	6	6	146
Total																																1669

Table 6.6 Random Generated Daily Wagon Arrivals (Year 2002)

Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Jan.	21	36	22	25	31	28	30	23	33	17	23	24	27	28	24	26	33	33	36	33	22	20	29	25	31	30	24	23	33	20	35	845
Fe.	31	32	36	27	31	26	26	24	32	38	33	38	22	36	29	33	33	22	26	34	20	27	29	27	33	30	37	29	-	-	-	841
March	12	23	20	22	16	23	20	24	9	20	20	14	12	19	13	15	17	16	19	18	19	16	11	22	15	10	19	16	10	8	14	512
April	14	7	15	9	15	15	15	9	12	11	11	14	7	13	10	8	11	11	11	8	8	13	8	10	15	11	15	16	12	14	-	348
May	35	27	33	28	28	40	26	31	31	34	33	32	20	32	32	35	24	28	29	33	26	28	36	37	30	34	28	26	23	28	22	929
June	21	17	15	19	14	12	13	23	13	7	16	17	19	12	14	14	16	8	13	13	16	17	14	10	17	18	26	18	18	23	-	473
July	23	31	26	30	23	21	29	36	35	24	28	33	21	32	21	28	28	27	26	19	27	19	24	30	22	36	24	24	31	27	26	831
August	26	28	33	18	25	24	23	17	27	18	16	33	27	18	20	20	20	20	30	22	27	19	19	23	26	26	31	31	22	19	30	738
Sep.	21	22	23	15	18	18	18	19	19	18	23	18	24	12	19	12	19	12	15	21	20	23	15	20	23	13	11	13	19	16	-	539
Oct.	10	5	10	14	10	13	12	7	17	11	11	8	13	7	16	18	17	8	11	15	13	10	9	12	13	14	11	14	12	13	12	366
Nov.	16	14	21	9	18	20	20	14	14	13	9	19	19	14	12	11	15	18	12	14	19	14	11	10	9	20	24	13	14	23	-	459
Dec.	22	19	17	22	19	11	24	16	26	21	21	20	28	31	22	16	16	22	20	23	21	21	25	15	14	22	18	15	15	18	16	616
Total																																7497

Table 6.7 Random Generated Daily Truck Arrival and Departures (Year 2002)

	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Truck Arrival	January	311	312	292	292	297	296	297	312	312	292	312	312	292	296	292	312	312	312	292	311	293	292	292	312	293	312	292	292	312	300	312	9358
	February	288	288	308	308	288	296	292	294	288	288	308	301	303	308	294	302	308	294	288	308	298	302	308	308	304	289	300	299	-	-	-	8360
	March	309	297	313	317	297	305	297	317	317	297	301	317	311	317	297	317	297	310	316	317	313	317	297	297	297	297	317	304	317	317	297	9536
	April	305	305	303	285	305	305	290	285	303	304	305	288	288	285	285	298	285	285	285	289	285	303	305	285	290	289	298	288	305	298	-	8829
	May	303	293	299	294	290	310	296	310	310	290	290	290	290	310	303	298	290	290	310	310	310	310	290	310	290	310	300	294	310	290	290	9280
	June	305	301	305	305	285	305	285	302	305	285	305	285	285	292	305	305	298	305	291	305	305	305	297	287	305	300	305	305	303	285	-	8956
	July	285	294	305	286	285	305	305	305	291	285	305	303	289	297	293	285	285	298	285	298	297	295	296	285	299	304	285	294	285	294	286	9104
	August	298	294	303	285	305	302	305	298	286	296	295	305	305	290	300	305	295	285	301	305	302	285	301	305	297	285	285	285	285	303	305	9196
	September	295	293	289	294	285	305	285	285	285	285	296	305	285	292	305	305	305	305	285	305	294	285	291	305	305	291	292	293	305	305	-	8855
	October	325	305	305	306	325	313	305	305	317	320	306	305	324	305	305	325	325	305	325	315	305	308	305	312	325	305	312	307	309	305	325	9684
	November	325	305	325	305	321	307	325	313	325	325	325	322	305	322	310	305	317	316	305	305	317	317	305	317	305	325	319	325	311	325	-	9474
	December	285	305	305	285	289	285	305	299	285	296	305	285	305	285	299	285	285	305	302	295	305	305	285	285	285	286	285	305	285	285	285	9086
	Total																																109718
Truck Departures	January	263	256	256	270	271	264	256	265	269	271	276	256	276	256	262	265	260	256	276	276	276	276	271	256	276	263	264	269	275	276	276	8278
	February	255	257	270	250	270	253	250	250	262	250	256	270	259	250	252	255	270	265	266	270	253	270	255	270	270	266	262	269	-	-	-	7295
	March	281	290	290	289	271	286	270	290	290	278	287	288	270	270	271	286	280	270	280	280	270	270	290	290	270	270	270	283	272	280	278	8660
	April	270	283	270	270	280	270	270	287	290	270	289	290	270	282	290	270	278	289	270	290	290	270	290	290	270	278	278	290	280	290	-	8404
	May	273	273	273	253	254	273	262	253	253	253	253	273	253	273	273	253	273	273	270	273	253	265	271	255	253	271	270	253	253	269	261	8161
	June	280	280	260	280	260	280	279	280	265	280	279	280	260	277	260	280	280	280	265	276	273	280	266	272	260	265	276	260	260	279	-	8173
	July	274	276	258	259	261	261	278	278	259	268	278	278	266	266	258	258	263	278	278	278	273	278	258	260	266	258	266	258	270	278	278	8316
	August	265	272	283	285	274	285	277	285	277	276	268	275	285	282	279	277	285	266	282	279	277	273	285	265	285	278	265	283	270	285	265	8588
	September	259	270	270	254	251	270	260	270	250	269	250	270	259	270	250	261	255	250	250	270	270	266	270	250	262	250	260	257	270	250	-	7813
	October	272	290	290	270	290	290	270	270	290	285	270	278	270	290	284	290	282	270	270	270	277	290	290	283	290	287	281	290	286	280	290	8735
	November	259	258	255	250	270	270	270	254	253	270	254	270	268	265	250	269	263	261	270	270	270	270	263	250	250	250	270	250	257	250	-	7829
	December	266	266	266	266	280	286	266	271	286	277	266	266	282	272	269	285	270	286	270	279	286	277	274	268	266	278	286	266	266	270	286	8498
	Total																																98750

Table 6.8 Ship Arrival, Truck Arrival, Wagon Arrival and Truck Departure Frequencies

	Ship Arrival														Truck Arrival							Wagon Arrival					Truck Departure					
Months	0	1	2	3	4	5	6	7	8	9	10	11	12	Total	280	290	300	310	320	330	Total	10	20	30	40	Total	250	260	270	280	290	Total
January	0	1	4	5	5	6	3	2	4	0	0	1	0	31	0	12	5	14	0	0	31	0	12	16	3	31	0	13	8	10	0	31
February	0	2	2	5	8	3	3	1	2	1	0	1	0	28	0	11	9	8	0	0	28	0	4	19	5	28	8	8	12	0	0	28
March	0	1	1	7	8	6	3	4	1	0	0	0	0	31	0	0	13	6	12	0	31	10	21	0	0	31	0	0	12	8	11	31
April	1	1	0	4	5	4	8	3	4	0	0	0	0	30	1	15	7	7	0	0	30	23	7	0	0	30	0	0	11	7	12	30
May	1	3	3	3	7	1	6	3	3	1	0	0	0	31	0	14	6	11	0	0	31	0	4	22	5	31	12	3	16	0	0	31
June	0	3	2	4	8	5	3	2	1	1	0	0	1	30	0	9	6	15	0	0	30	13	16	1	0	30	0	7	6	17	0	30
July	0	2	3	5	9	3	1	2	4	1	1	0	0	31	0	17	9	5	0	0	31	0	12	16	3	31	0	12	8	11	0	31
August	0	0	5	8	5	5	2	5	1	0	0	0	0	31	0	10	13	8	0	0	31	0	17	14	0	31	0	0	10	13	8	31
September	0	2	3	4	4	11	2	1	1	2	0	0	0	30	0	17	2	11	0	0	30	6	24	0	0	30	10	8	12	0	0	30
October	1	1	4	9	2	5	5	2	1	0	1	0	0	31	0	0	0	20	4	7	31	26	5	0	0	31	0	0	9	7	15	31
November	1	0	6	2	8	6	3	3	1	0	0	0	0	30	0	0	0	12	9	9	30	17	13	0	0	30	10	7	13	0	0	30
December	0	1	3	3	7	7	6	2	1	1	0	0	0	31	0	17	5	9	0	0	31	2	25	4	0	31	0	0	18	6	7	31
Total	4	17	36	59	76	62	45	30	24	7	2	2	1	365	1	122	75	126	25	16	365	97	160	92	16	365	40	58	135	79	53	365

Table 6.9 Container Numbers Counted At Yard on a Day of Every Month and Their Probabilities (Year 2002)

Months	Box Number	TEU
January	5 140	8 620
February	5 670	9 253
March	6 320	10 140
April	6 885	10 814
May	7 540	11 725
June	8 654	13 245
July	9 947	15 042
August	11 076	16 614
September	11 816	17 156
October	12 241	17 945
November	12 864	19 227
December	13 004	20 145
Average		14 161

Interval	Frequency
8001-9000	1
9001-10000	1
10001-11000	2
11001-12000	1
12001-13000	0
13001-14000	1
14001-15000	0
15001-16000	1
16001-17000	1
17001-18000	2
18001-19000	0
19001-20000	1
20001-21000	1

Table 6.10 Costs in the Situation of 2, 3 and 4 Level Stacking

	2 Level stacking (C_s=39.64 \$ and C_v=0.255 \$)			3 Level stacking (C_s=39.64 \$ and C_v=0.169 \$)			4 Level stacking (C_s=39.64 \$ and C_v=0.127 \$)		
Stock Yard	M_j(\$)	M_k (\$)	$M=M_j+M_k$ (\$)	M_j(\$)	M_k (\$)	$M=M_j+M_k$ (\$)	M_j(\$)	M_k (\$)	$M=M_j+M_k$ (\$)
15000	25092,12	130257,04	159174,16	25092,12	130257,04	157884,16	25092,12	130257,04	157254,16
17500	63007,78	62433	129903,28	63007,78	62433	128398,28	63007,78	62433	127663,28
17800	68799,184	55535,64	128873,824	68799,184	55535,64	127343,024	68799,184	55535,64	126595,424
17900	70729,652	53236,52	128530,672	70729,652	53236,52	126991,272	70729,652	53236,52	126239,472
18000	**72660,12**	**50937,4**	**128187,52**	**72660,12**	**50937,4**	**126639,52**	**72660,12**	**50937,4**	**125883,52**
18100	74967,168	49014,86	128597,528	74967,168	49014,86	127040,928	74967,168	49014,86	126280,728
18200	77274,216	47092,32	129007,536	77274,216	47092,32	127442,336	77274,216	47092,32	126677,936
18300	79581,264	45169,78	129417,544	79581,264	45169,78	127843,744	79581,264	45169,78	127075,144
18500	84195,36	41324,7	130237,56	84195,36	41324,7	128646,56	84195,36	41324,7	127869,56
19000	95254,92	31712	131811,92	95254,92	31712	130177,92	95254,92	31712	129379,92
20000	122566,88	16252,4	143919,28	122566,88	16252,4	142199,28	122566,88	16252,4	141359,28
22500	212054,18	0	217791,68	212054,18	0	215856,68	212054,18	0	214911,68

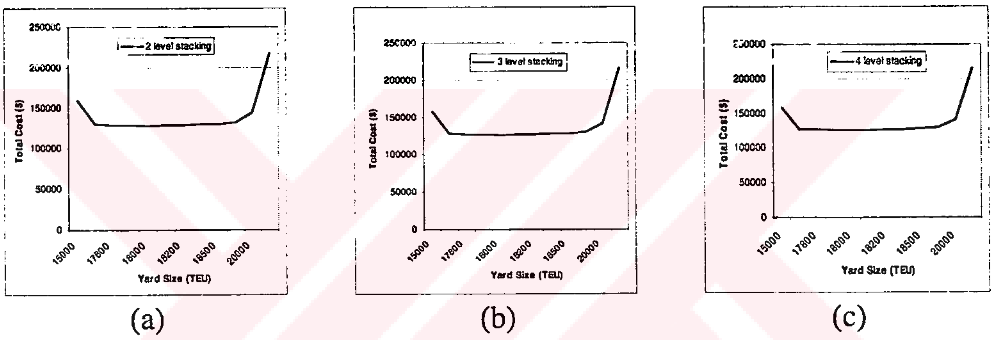


Figure 6.2 Minimum cost in the situation of a) 2, b) 3 and c) 4 level stacking

6.5 Inventory Model Application

Inventory model was applied to data presented Table 6.9 and results are given in Table 6.11 and Figure 6.4.

Table 6.11 Result of Inventory Modeling

Legend		
	C_b: Cost of service (USD/TEU)	Q_{FTA}: Cumulative of Q_F
	C_S: Amortization rate of investment (USD/day.TEU)	Q_{FTE}: Cumulative of unserved container number
	Q_s: Daily container capacity	C_{GID}: Cost of unserved container
	T: Container storing day per TEU	C_{GEL}: Cost of idle slots
	Q: Container number staying at yard at a time	C_T: Total cost
	Q_F: Idle container slot number under capacity	

	C_b=39.64 $, C_s=0.3 $																				
	Q_s=14000, T=7			Q_s=15000, T=8			Q_s=16000, T=9			Q_s=17000, T=10			Q_s=18000, T=11			Q_s=19000, T=13			Q_s=20500, T=14		
Q_I	Q_F	Q_{FTA}	Q_{FTE}	Q_F	Q_{FTA}	Q_{FTE}	Q_F	Q_{FTA}	Q_{FTE}	Q_F	Q_{FTA}	Q_{FTE}	Q_F	Q_{FTA}	Q_{FTE}	Q_F	Q_{FTA}	Q_{FTE}	Q_F	Q_{FTA}	Q_{FTE}
8620	5380	5380	0	6380	6380	0	7380	7380	0	8380	8380	0	9380	9380	0	10380	10380	0	11880	11880	0
9253	4747	10127	0	5747	12127	0	6747	14127	0	7747	16127	0	8747	18127	0	9747	20127	0	11247	23127	0
10140	3860	13987	0	4860	16987	0	5860	19987	0	6860	22987	0	7860	25987	0	8860	28987	0	10360	33487	0
10814	3186	17173	0	4186	21173	0	5186	25173	0	6186	29173	0	7186	33173	0	8186	37173	0	9686	43173	0
11725	2275	19448	0	3275	24448	0	4275	29448	0	5275	34448	0	6275	39448	0	7275	44448	0	8775	51948	0
13245	755	20203	0	1755	26203	0	2755	32203	0	3755	38203	0	4755	44203	0	5755	50203	0	7255	59203	0
15042	-1042	20203	-1042	-42	26203	-42	958	33161	0	1958	40161	0	2958	47161	0	3958	54161	0	5458	64661	0
16614	-2614	20203	-3656	-1614	26203	-1656	-614	33161	-614	386	40547	0	1386	48547	0	2386	56547	0	3886	68547	0
17156	-3156	20203	-6812	-2156	26203	-3812	-1156	33161	-1770	-156	40547	-156	844	49391	0	1844	58391	0	3344	71891	0
17954	-3954	20203	-10766	-2954	26203	-6766	-1954	33161	-3724	-954	40547	-1110	46	49437	0	1046	59437	0	2546	74437	0
17945	-3945	20203	-1471[illegible]	-2945	26203	-9711	-1945	33161	-5669	-945	40547	-2055	55	49492	0	1055	60492	0	2555	76992	0
19227	-5227	20203	-19938	-4227	26203	-13938	-3227	33161	-8896	-2227	40547	-4282	-1227	49492	-1227	-227	60492	-227	1273	78265	0
Q_{FTA}	20203			26203			33161			40547			**49492**			60492			78265		
Q_{FTE}	-19938			-13938			-8896			-4282			**-1227**			-227			0		
C_{GID}	832768.6			615389.5			442172.1			291379.5			**211961.9**			244917.1			328713		
C_{GEL}	554960			594600			634240			673880			**713520**			753160			812620		
C_T	1387729			1209990			1076412			965259.5			**925481.9**			998077.1			1141333		

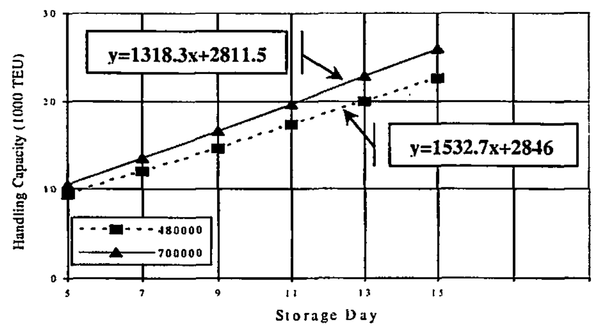


Figure 6.3 Handling capacities versus of storage day of İzmir Port

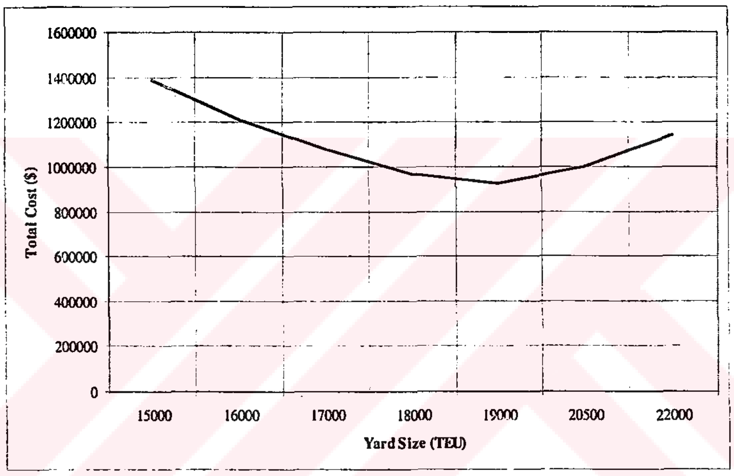


Figure 6.4 Capacity-Cost relation of İzmir Port

6.6 Result of Queuing Model Application on İzmir Port

Queuing model was applied to land-born and sea-born data of İzmir Port presented at raw data table. Results are listed in Table 6.12 and 6.13 and drawn in Figure 6.5.

Table 6.12 Results of Queuing Modeling (Land-Born Traffic)

Legend		
	S: Number of server	**L:** Arrival rate of trucks (TEU/day)
	L_s: Lenght of system	**M:** Service rate of containers (TEU/day)
	L_q: Lenght of queue	**S:** Number of server
	W_s: Waiting trucks in system	**C_S:** Cost of service (USD/TEU)
	W_q: Waiting trucks in queue	**C_{WS}:** Cost of waiting container (USD/day)
	SH: Stacking level	**SH:** Stacking level
	$COST_{WS}$: Cost of waiting trucks (USD)	**CI_4:** Amortization rate of investment (USD/day.TEU)
	$COST_I$: Cost of investment (USD)	**RA_4:** Required container area (m^2)
	$COST_S$: Cost of service (USD)	**TOC:** Total cost (USD)
	RSA: Required container area (m^2)	**C_T:** Number of container

L	M	S	C_S	C_{WS}	SH	CI_4	RA_4	C_T
162.09	83682	1937	39.64	25	4	0.3	7.5	233414

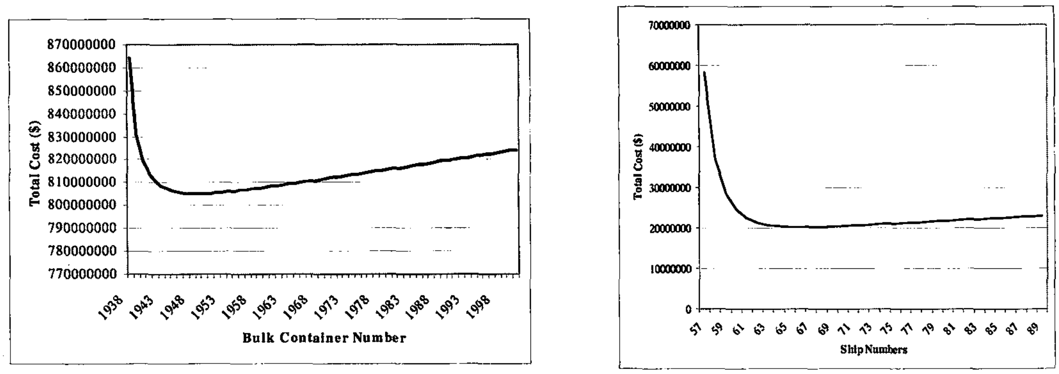
S	L_S	Lq	W_S	Wq	SH	RSA	$COST_I$	$COST_S$	$COST_{WS}$	TOC
1940	2498,6	562	15,4	3,46	4	58200	790239600	9163479	20200000	819622200
1942	2224,9	288	13,7	1,78	4	58260	791054300	9206872	10400000	810628000
1944	2105,9	169	13,0	1,04	4	58320	791869000	9225749	6080810	807175600
1946	2042,7	106	12,6	0,65	4	58380	792683600	9235765	3806574	805726000
1948	**2006,1**	**69**	**12,4**	**0,43**	**4**	**58440**	**793498400**	**9241563**	**2490211**	**805230100**
1950	1983,8	47	12,2	0,29	4	58500	794313000	9245099	1687406	805245500
1952	1969,7	33	12,2	0,20	4	58560	795127700	9247342	1178142	805553200
1954	1960,4	23	12,1	0,14	4	58620	795942400	9248813	844209	806035400
1956	1954,2	17	12,1	0,11	4	58680	796757100	9249805	618790	806625700
1958	1949,8	13	12,0	0,08	4	58740	797571800	9250493	462646	807284900
1960	1946,8	10	12,0	0,06	4	58800	798386400	9250981	351972	807989400
1962	1944,5	8	12,0	0,05	4	58860	799201100	9251333	271899	808724300
1964	1942,9	6	12,0	0,04	4	58920	800015800	9251593	212893	809480300
1966	1941,7	5	12,0	0,03	4	58980	800830500	9251788	168691	810250900
1968	1940,7	4	12,0	0,02	4	59040	801645100	9251936	135088	811032100
1970	1940,0	3	12,0	0,02	4	59100	802459800	9252050	109202	811821100
1972	1939,4	2	12,0	0,02	4	59160	803274500	9252139	89020	812615700
1974	1939,0	2	12,0	0,01	4	59220	804089200	9252209	73115	813414500
1976	1938,7	2	12,0	0,01	4	59280	804903900	9252265	60458	814216600
1978	1938,4	1	12,0	0,01	4	59340	805718500	9252309	50296	815021100
1980	1938,1	1	12,0	0,01	4	59400	806533200	9252346	42070	815827600
1982	1938,0	1	12,0	0,01	4	59460	807347900	9252375	35363	816635600
1984	1937,8	1	12,0	0,01	4	59520	808162600	9252399	29857	817444900
1986	1937,7	1	12,0	0,00	4	59580	808977300	9252419	25310	818255000
1988	1937,6	1	12,0	0,00	4	59640	809791900	9252436	21532	819065900
1990	1937,5	1	12,0	0,00	4	59700	810606700	9252450	18379	819877500
1992	1937,4	0	12,0	0,00	4	59760	811421300	9252462	15733	820689500
1994	1937,4	0	12,0	0,00	4	59820	812236000	9252471	13504	821502000
1996	1937,3	0	12,0	0,00	4	59880	813050700	9252480	11618	822314800
1998	1937,3	0	12,0	0,00	4	59940	813865300	9252487	10017	823127900
2000	1937,2	0	12,0	0,00	4	60000	814680100	9252493	8653	823941200

Table 6.13 Results of Queuing Modeling (Sea-Born Traffic)

Legend		
	S: Number of server	**L:** Arrival rate of ships (TEU/day)
	L_s: Lenght of system	**M:** Service rate of ships (TEU/day)
	L_q: Lenght of queue	**S:** Number of server
	W_s: Waiting ships in system	**C_S:** Cost of service (USD/TEU)
	W_q: Waiting ships in queue	**C_{WS}:** Cost of waiting containers (USD/day)
	SH: Stacking level	**SH:** Stacking level
	RSA: Required container area (m^2)	**CI_4:** Amortization rate of investment (USD/day.TEU)
	$COST_I$: Cost of investment (USD)	**RA_4:** Required container area (m^2)
	$COST_S$: Cost of service (USD)	**TOC:** Total cost (USD)
	$COST_{WS}$: Cost of waiting ships (USD)	**C_T:** Total cost (USD)

L	M	S	C_S	C_{WS}	SH	CI_4	RA_4	C_T
4.64	0.0837	57	39.64	25	4	0.3	7.5	233414

S	L_S	Lq	W_S	Wq	SH	RSA	$COST_I$	$COST_S$	$COST_{WS}$	TOC
57	82.3	26.8299	17.7323	5.7823	4	70538	7723857	10741770	39812660	58278290
58	67.9	12.4079	14.6241	2.6741	4	71775	7859363	10836100	18411920	37107380
59	61.9	6.4946	13.3497	1.3997	4	73013	7994869	10874770	9637222	28506860
60	59.1	3.6302	12.7324	0.7824	4	74250	8130376	10893510	5386795	24410680
61	57.6	2.1273	12.4085	0.4585	4	75488	8265882	10903340	3156733	22325950
62	56.7	1.2943	12.2290	0.2790	4	76725	8401388	10908790	1920661	21230840
63	56.3	0.8118	12.1250	0.1750	4	77963	8536894	10911940	1204659	20653490
64	56.0	0.5218	12.0625	0.1125	4	79200	8672400	10913840	774310	20360550
65	55.8	0.3420	12.0237	0.0737	4	80438	8807907	10915020	507495	20230420
66	**55.7**	**0.2276**	**11.9991**	**0.0491**	**4**	**81675**	**8943413**	**10915760**	**337726**	**20196900**
67	55.6	0.1532	11.9830	0.0330	4	82913	9078919	10916250	227370	20222540
68	55.6	0.1040	11.9724	0.0224	4	84150	9214425	10916570	154377	20285370
69	55.5	0.0710	11.9653	0.0153	4	85388	9349932	10916790	105423	20372140
70	55.5	0.0487	11.9605	0.0105	4	86625	9485438	10916930	72241	20474610
71	55.5	0.0334	11.9572	0.0072	4	87863	9620944	10917030	49572	20587550
72	55.5	0.0229	11.9549	0.0049	4	89100	9756450	10917100	34004	20707560
73	55.5	0.0157	11.9534	0.0034	4	90338	9891957	10917150	23280	20832390
74	55.5	0.0107	11.9523	0.0023	4	91575	10027460	10917180	15885	20960530
75	55.5	0.0073	11.9516	0.0016	4	92813	10162970	10917210	10791	21090960
76	55.5	0.0049	11.9511	0.0011	4	94050	10298480	10917220	7290	21222980
77	55.5	0.0033	11.9507	0.0007	4	95288	10433980	10917230	4894	21356110
78	55.5	0.0022	11.9505	0.0005	4	96525	10569490	10917240	3262	21489990
79	55.4	0.0015	11.9503	0.0003	4	97763	10704990	10917240	2157	21624390
80	55.4	0.0010	11.9502	0.0002	4	99000	10840500	10917250	1415	21759160
81	55.4	0.0006	11.9501	0.0001	4	100238	10976010	10917250	920	21894180
82	55.4	0.0004	11.9501	0.0001	4	101475	11111510	10917250	593	22029360
83	55.4	0.0003	11.9501	0.0001	4	102713	11247020	10917250	379	22164650
84	55.4	0.0002	11.9500	0.0000	4	103950	11382530	10917250	239	22300020
85	55.4	0.0001	11.9500	0.0000	4	105188	11518030	10917250	150	22435430
86	55.4	0.0001	11.9500	0.0000	4	106425	11653540	10917250	93	22570880
87	55.4	0.0000	11.9500	0.0000	4	107663	11789040	10917250	57	22706350
88	55.4	0.0000	11.9500	0.0000	4	108900	11924550	10917250	35	22841840
89	55.4	0.0000	11.9500	0.0000	4	110138	12060060	10917250	21	22977330

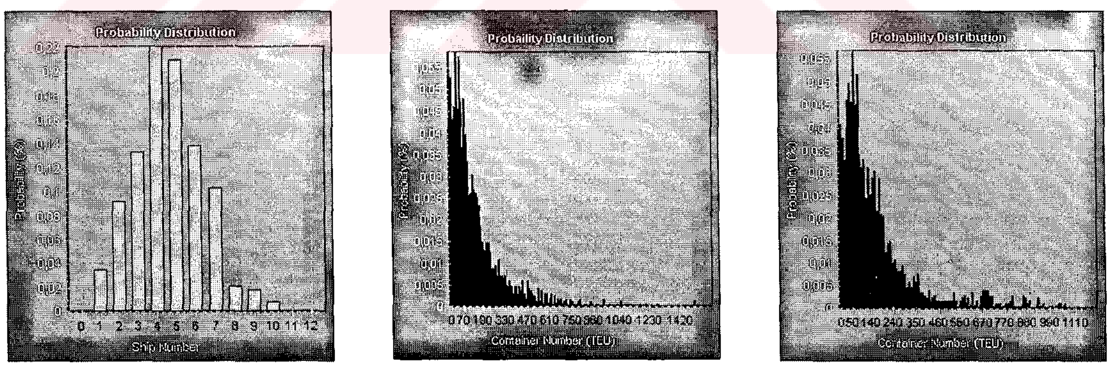


(a) (b)

Figure 6.5 Minimum bulk container numbers related to a) land-born data and b) sea-born data

6.7 Monte Carlo Simulation

For the application of Monte Carlo simulation of İzmir Port presented in Figure 6.6 were used.



(a) (b) (c)

Figure 6.6 Incoming and outgoing container and ship traffic probabilities; a) ship arrival, b) incoming container by ship, c) outgoing container by ship

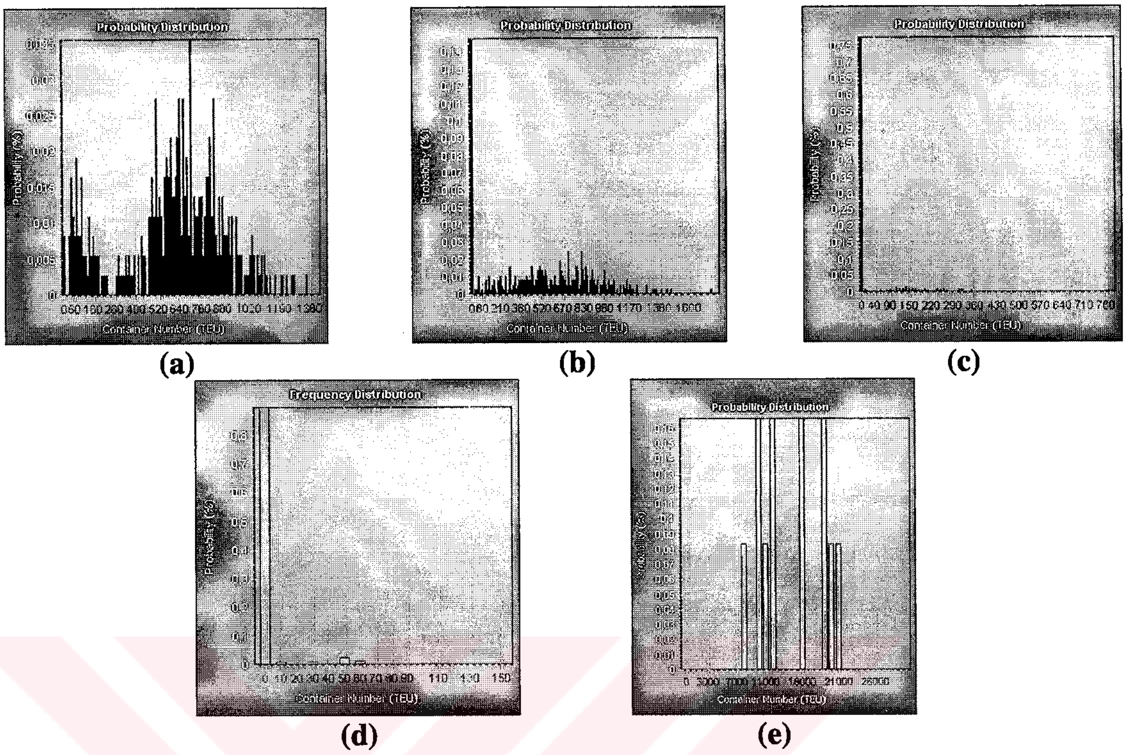


Figure 6.7 Incoming and outgoing container traffic probabilities; a) incoming container by truck, b) outgoing container by truck, c) incoming container by wagon, d) outgoing container by wagon, e) container numbers counted at yard.

Cost analysis was applied for 2, 3 and 4-level stacking using 0.255, 0.169 and 0.127 USD respectively as a cost of idle slot and 39.64 USD as a cost of an unserved container.

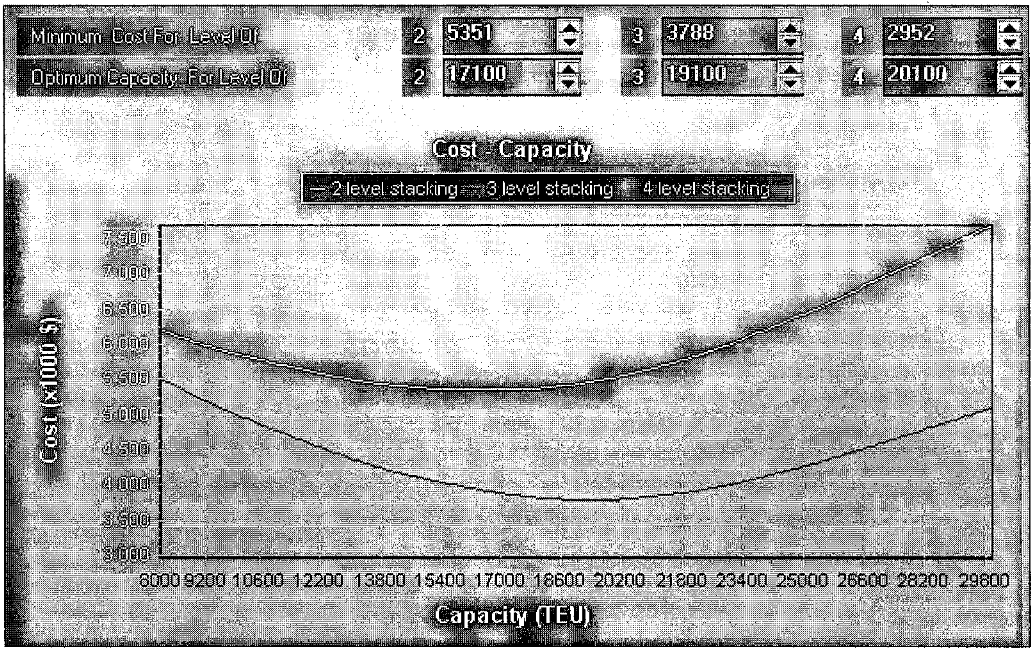


Figure 6.8 Cost and capacity relation for 2, 3 and 4-level stacking

For 2-level stacking, a yard capacity of 17100 TEU, for 3-level stacking, a yard capacity of 19100 TEU and for 4-level stacking, a yard capacity of 20100 TEU minimized the total cost.

6.8 Results on Simulation of CYO

6.8.1 Input Data for cYo

cYo generates ship daily arrivals for a given yearly ship traffic. It can be generate using different distribution functions such as Poisson, Erlang, triangular, normal etc. Below data was generated using Poisson distribution tool for 1672 ships in a year.

Table 6.14 Randomized daily incoming traffic generated by cYo using Poisson distribution

	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Monthly Total	Annual Total
Ship traffic for a given 1672 ship number in a year	1	0	1	7	3	3	5	3	2	4	4	2	4	2	7	1	3	8	4	6	3	5	7	6	3	2	3	4	3	6	3	4	118	1644
	2	3	8	4	7	10	5	8	7	1	3	3	5	1	5	1	7	6	7	6	5	3	6	5	9	6	13	3	6				153	
	3	3	2	6	4	7	4	5	8	5	3	0	5	10	6	6	3	2	7	6	5	7	5	3	2	5	3	7	2	3	5	9	148	
	4	3	2	3	3	5	4	3	2	5	6	6	2	2	2	2	6	6	4	5	4	6	4	4	7	7	2	2	2	2	3		114	
	5	5	3	5	3	4	7	3	3	5	5	7	3	4	3	6	6	5	6	4	5	5	7	5	2	4	4	2	1	5	5	2	134	
	6	8	7	6	8	3	6	6	4	5	2	3	8	4	2	10	3	1	2	7	5	6	2	5	1	3	8	5	4	4	7		145	
	7	4	4	4	2	7	6	3	8	4	2	7	4	3	6	5	2	5	8	5	3	4	3	3	5	11	5	5	5	2	6	2	143	
	8	3	7	6	4	9	2	1	3	0	4	4	4	2	4	4	4	5	6	5	3	4	5	7	5	3	5	5	7	4	4	5	134	
	9	6	4	3	6	7	6	7	3	6	3	3	6	4	9	3	1	3	7	4	7	6	9	3	4	7	1	3	1	5	4		141	
	10	0	2	6	3	4	5	3	2	3	2	5	3	6	5	5	7	1	3	7	5	1	2	2	4	4	2	0	4	6	5	3	110	
	11	7	2	4	2	4	5	3	6	5	4	1	11	3	1	2	2	6	9	2	3	6	10	4	1	5	6	8	5	5	13		145	
	12	6	6	7	11	6	6	1	4	3	2	5	3	7	8	1	7	8	4	5	4	4	6	5	3	5	4	9	2	10	1	5	159	
Import sea-born traffic for a given 275410 TEU in a year	1	0	201	1407	603	603	1005	603	402	804	804	402	804	402	1407	201	603	1608	804	1206	603	1005	1407	1206	603	402	603	804	603	1206	603	804	23718	279240
	2	420	1120	560	980	1400	700	1120	980	140	420	420	700	140	700	140	980	840	980	840	700	420	840	700	1260	840	1820	420	840				21420	
	3	481	320	961	641	1122	641	801	1282	801	481	[illegible]	801	1602	961	961	481	320	1122	961	801	1122	801	481	320	801	481	1122	320	481	801	1442	23713	
	4	604	403	604	604	1007	805	604	403	1007	1208	1208	403	403	403	403	1208	1208	805	1007	805	1208	805	805	1409	1409	403	403	403	403	604		22954	
	5	885	531	885	531	708	1239	531	531	885	885	1239	531	708	531	1062	1062	885	1062	708	885	885	1239	885	354	708	708	354	177	885	885	354	23718	
	6	1266	1108	950	1266	475	950	950	633	791	317	475	1266	633	317	1583	475	158	317	1108	791	950	317	791	158	475	1266	791	633	633	1108		22951	
	7	663	663	663	332	1161	995	498	1327	663	332	1161	663	498	995	829	332	829	1327	829	498	663	498	498	829	1824	829	829	829	332	995	332	23716	
	8	531	1239	1062	708	1593	354	177	531	0	708	708	708	354	708	708	708	885	1062	885	531	708	885	1239	885	531	885	885	1239	708	708	885	23718	
	9	977	651	488	977	1139	977	1139	488	977	488	488	977	651	1465	488	163	488	1139	651	1139	977	1465	488	651	1139	163	488	163	814	651		22949	
	10	0	431	1294	647	862	1078	647	431	647	431	1078	647	1294	1078	1078	1509	216	647	1509	1078	216	431	431	862	862	431	0	862	1294	1078	647	23716	
	11	1108	317	633	317	633	791	475	950	791	633	158	1741	475	158	317	317	950	1424	317	475	950	1583	633	158	791	950	1266	791	791	2058		22951	
	12	895	895	1044	1641	895	895	149	597	447	298	895	447	1044	1193	149	1044	1193	597	746	597	597	895	746	447	746	597	1342	298	1492	149	746	23716	
Export land-born traffic for a given 233000 TEU in a year	1	617	627	636	636	635	636	626	625	636	616	616	622	636	636	616	633	636	624	616	635	616	636	636	636	622	616	616	631	636	616	625	19446	232851
	2	703	703	703	703	703	683	683	703	703	683	683	703	697	691	689	683	703	703	683	700	703	683	692	687	693	703	703	683				19452	
	3	616	633	616	616	624	616	616	636	636	616	616	624	636	636	621	616	636	616	616	616	636	636	622	616	621	618	636	622	635	636	636	19372	
	4	644	649	655	637	637	641	657	657	637	657	637	637	657	645	648	657	657	642	652	637	657	645	637	637	654	657	646	637	645	637		19392	
	5	616	636	636	636	616	616	636	616	616	616	616	636	636	616	636	616	634	631	636	616	636	636	635	625	636	636	616	618	636	628	636	19451	
	6	657	637	653	637	637	637	642	652	657	657	657	657	638	637	641	637	657	637	640	637	649	648	649	637	637	642	657	647	652	639		19361	
	7	618	636	636	636	631	628	636	616	616	636	626	636	616	636	616	622	616	636	619	636	636	636	619	636	616	636	616	618	621	616	636	19434	
	8	616	616	616	616	635	616	636	616	636	620	625	628	616	636	616	636	616	636	636	621	626	616	636	616	622	622	636	617	632	636	625	19373	
	9	637	637	642	646	638	645	637	637	657	650	644	657	657	653	642	637	657	652	637	656	657	637	655	637	645	657	657	637	657	657		19414	
	10	636	616	636	616	625	617	636	633	616	621	616	626	627	616	630	633	616	631	636	636	616	636	622	636	630	629	627	636	636	629	633	19449	
	11	657	642	637	657	637	657	657	637	656	657	657	637	637	638	657	637	657	653	657	657	640	637	637	654	657	645	647	657	657	637		19449	
	12	616	616	636	616	616	616	621	626	616	619	616	616	616	616	636	616	618	632	616	616	619	616	636	621	616	636	627	623	636	616	616	19258	

6.8.2 Output Data of cYo

Table 6.15 Daily outgoing traffic to hinterland and sea after cYo run

	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Monthly Total	Annual Total
Import sea-born traffic	January	0	37	68	97	132	170	206	255	301	334	385	440	443	460	498	505	543	572	578	566	591	580	595	606	592	603	617	613	603	613	12603	222249
	February	622	637	630	650	631	650	646	675	643	667	664	680	678	674	679	684	680	692	687	698	677	696	690	697	684	692	692	690			18785	
	March	687	689	692	683	672	680	664	661	670	653	643	650	642	644	634	640	625	641	629	633	624	625	640	617	630	623	630	627	623	618	19389	
	April	622	624	633	619	637	635	626	652	625	644	626	645	640	648	641	648	641	641	649	651	643	645	650	651	638	646	651	645	650	642	19208	
	May	641	657	642	636	642	645	636	643	631	638	629	631	636	627	629	626	625	626	633	627	621	625	636	627	624	636	626	632	631	618	18976	
	June	626	642	626	625	640	628	640	634	633	638	642	639	648	637	640	652	641	652	632	647	648	648	636	651	642	648	645	649	634	647	19210	
	July	640	644	650	641	646	636	637	638	637	641	638	630	638	634	630	628	632	623	622	631	635	628	629	630	619	633	624	627	634	624	18999	
	August	628	619	633	615	625	626	624	622	625	624	622	628	619	618	628	624	624	622	632	618	628	624	624	630	619	634	623	624	627	628	18737	
	Sep.	624	626	621	637	625	630	628	636	637	532	636	633	650	632	646	640	643	646	642	651	644	640	650	648	654	639	644	648	656	647	19185	
	October	652	641	651	639	648	644	641	640	629	652	634	626	638	628	628	628	634	626	626	628	619	534	627	627	621	635	621	640	621	630	19008	
	Nov.	628	631	627	637	633	631	637	632	635	653	645	634	655	635	643	648	648	647	643	648	643	653	643	650	641	649	649	650	654	643	19265	
	Dec.	646	643	649	644	638	643	644	634	644	624	632	631	625	623	630	620	639	612	625	620	623	619	620	620	627	621	624	615	625	624	18884	
Export land-born traffic	January	0	0	12	94	112	136	220	233	268	350	388	400	509	493	504	543	556	637	669	731	698	707	784	820	816	803	839	830	816	833	14801	266556
	February	838	850	817	761	808	841	836	858	832	763	761	842	770	747	778	680	658	705	652	683	703	696	627	686	686	703	812	770			21163	
	March	754	782	754	802	832	856	792	804	791	780	781	766	769	835	809	781	769	771	789	829	768	847	854	815	780	730	761	794	828	746	23769	
	April	745	697	716	765	706	746	747	672	671	746	764	752	744	748	714	749	749	742	743	822	771	767	777	793	885	948	897	828	831	796	23031	
	May	839	837	802	796	783	707	726	743	732	771	771	730	720	719	744	791	814	779	813	828	826	829	865	850	852	851	843	781	758	774	23674	
	June	758	764	734	746	809	766	759	836	819	786	807	769	805	795	769	811	793	750	737	739	717	741	736	669	677	653	662	686	727	702	22522	
	July	711	697	677	686	700	762	773	680	723	745	735	784	776	722	797	785	720	753	800	746	760	824	709	718	797	774	779	831	815	735	22515	
	August	794	747	851	870	768	817	784	743	810	769	723	747	726	641	650	682	590	668	716	673	692	691	673	711	781	735	775	796	789	788	22201	
	Sep.	848	859	864	792	798	832	864	859	840	835	840	807	833	842	848	831	789	745	779	762	815	828	817	797	778	802	768	818	807	751	24448	
	October	754	673	627	708	685	686	693	669	651	677	635	671	703	746	714	750	809	744	812	901	895	859	851	799	794	830	767	710	789	791	22371	
	Nov.	717	779	712	748	757	642	690	733	751	680	690	634	733	752	689	676	641	647	702	644	676	697	749	653	675	710	740	814	784	704	21159	
	Dec.	822	900	839	906	931	954	1005	971	914	905	894	876	832	859	829	753	796	796	743	803	813	735	727	775	698	762	753	779	736	796	24902	

Table 6.16 Sample randomized container arrival day, departure day and waiting day recorded at each 1000 container

	Incoming Containers				Outgoing Containers			
Con. No	Arrival Day to Port	Arrival Day to Yard	Waiting Day	Departure Day	Arrival Day to Port	Arrival Day to Yard	Waiting Day	Departure Day
1000	3	3	7	10	2	2	4	6
2000	4	4	4	8	4	4	7	11
3000	6	6	6	12	5	5	7	12
4000	7	7	29	36	7	7	15	22
5000	9	9	7	16	8	8	17	25
6000	10	10	11	21	10	10	6	16
7000	12	12	9	21	12	12	8	20
8000	13	13	3	16	13	13	15	28
9000	14	14	5	19	15	15	13	28
10000	16	16	14	30	16	16	15	31
11000	17	17	7	24	18	18	26	44
12000	18	18	5	23	20	20	10	30
13000	19	19	10	29	21	21	13	34
14000	20	20	7	27	23	23	5	28
....	....	....	....	....	....	....	....	....

Table 6.17 Revenue from container handled and serviced

	Import Containers			Export Containers		
Container No	Empty or Full	Waiting Day	Revenue($)	Empty or Full	Waiting Day	Revenue($)
1000	Full	4	105.00	Full	7	179.00
2000	Empty	7	56.00	Full	4	158.00
3000	Full	7	117.00	Full	6	172.00
4000	Empty	15	80.00	Full	29	403.00
5000	Full	17	185.00	Full	7	179.00
6000	Full	6	111.00	Full	11	207.00
7000	Empty	8	59.00	Full	9	193.00
8000	Full	15	165.00	Full	3	151.00
9000	Empty	13	74.00	Full	5	165.00
10000	Full	15	165.00	Full	14	228.00
11000	Full	26	275.00	Full	7	179.00
12000	Empty	10	65.00	Full	5	165.00
13000	Full	13	153.00	Full	10	200.00
14000	Empty	5	50.00	Full	7	179.00
15000	Full	2	105.00	Full	7	179.00
....	....	....	....	....	....	....

Table 6.18 Daily container numbers on inbound and outbound container yards and related cost-benefit values

Yard	Day	Full	Empty	Total	Over Capacity (TEU)	Under Capacity (TEU)	Cost of Containers Over Capacity (USD)	Cost of Containers Under Capacity (USD)
Inbound Yard	1	1940	3384	5324	7176	0	0	2152,8
	2	1862	3383	5245	7255	0	0	2176,5
	3	2344	3400	5744	6756	0	0	2026,8
	4	2510	3407	5917	6583	0	0	1974,9
	5	1856	3376	5232	7268	0	0	2180,4
	6	2208	3387	5595	6905	0	0	2071,5
	7	1988	3373	5361	7139	0	0	2141,7
	8	1886	3363	5249	7251	0	0	2175,3
	......	....	....	....	....	....	....	....
	114	5601	3481	9082	3418	0	0	1025,4
	115	6110	3496	9606	2894	0	0	868,[illegible]
	116	5583	3478	9061	3439	0	0	1031,7
	117	5100	3467	8567	3933	0	0	1179,9
	118	4689	3453	8142	4358	0	0	1307,4
	119	4280	3434	7714	4786	0	0	1435,8
	......	....	....	....	....	....	....	....
Outbound Yard	1	8036	567	8603	1403	0	35075	0
	2	7987	786	8773	1573	0	39325	0
	3	7037	958	7995	795	0	19875	0
	4	6879	1151	8030	830	0	20750	0
	5	5484	1285	6769	0	431	0	129,3
	6	5036	1443	6479	0	721	0	216,3
	7	4401	1574	5975	0	1225	0	367,5
	8	4222	1703	5925	0	1275	0	382,5
	......	....	....	....	....	....	....	....
	237	3733	2473	6206	0	994	0	298,2
	238	3730	2464	6194	0	1006	0	301,8
	239	3739	2468	6207	0	993	0	297,9
	240	3737	2463	6200	0	1000	0	300
	241	3744	2461	6205	0	995	0	298,5
	242	3742	2471	6213	0	987	0	296,1
	......	....	....	....	....	....	....	....

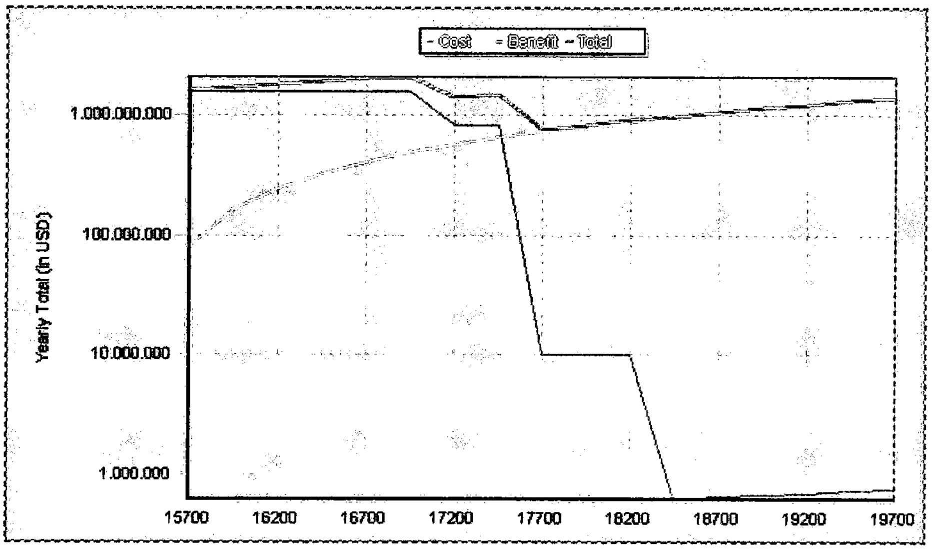


Figure 6.9 Graph of optimum yard capacity

CHAPTER SEVEN

CONCLUSION

7.1 Methods Survey

There are many well known advanced methods used for optimization problems and cost analysis. Most of these methods are subject of operations research science and have been applied to many problems, especially to technical problems. Among others, for the solution of port problems, queuing and simulation methods are used most frequently. Simulation that is one of these is being applied to almost many problems. Unfortunately, as all others have, these methods have also advantages and disadvantages and are preferred considering the problem characteristics.

The inventory model, one of these methods used in the study, is preferred only to solve roughly the optimum size problem of yard. This method is based on taking statistics on buffer (container number staying at yard) of a day in a month and use the average stocking day for the process. In fact, the buffer at yard demonstrates the seasonal variation and the average stocking day never represents the real situation of each container. It does not consider costs revealing the loading and unloading operations of empty or full containers and stocking in separate. This method use only the average service cost of containers.

The queuing models are well known. But in this study, the bulk type queue model is used for yard optimization because the containers carried by ships, trucks and wagons move in-groups. The bulk queue system is solved by superposing queuing systems on the trucks, wagons and ships. Such system is not coincided in literature yet. The queuing modeling considers the unique type container except for containers to be loaded or unloaded and empty or full type containers. If considered, the arrival and service time distributions of each type container and their populations will be complicated even if the queue discipline and number of server does not change. The distributions must be coded in accordance with the queue notations. If not, the complex queue system will exist.

Monte Carlo Simulation is generated to solve yard optimization problem. This method is based on yielding the extreme traffic conditions according to the arrival and departure probability distributions of transportation systems. By using Monte Carlo simulation within their distributions, the occurrence possibility of each event and frequencies can be calculated. The number of containers at yard corresponding to the considered probability can be computed by the generated objective function based on the balance of container traffic at yard. Before applying this approach, all distribution by Poisson distribution is generated randomly. This mentality in yard operations is achieved successfully.

Simulation method is the combination of processes replicating the real world considering a set of assumptions and conceived models of reality. Experimental and theoretical simulation may be performed. Theoretical simulation, in practice, is usually performed numerically. Numerical simulation, as with the experimental methods, may be used to obtain simulated data. For engineering purposes simulation may be applied to predict or study the performance and/or response of a system. The simulation process, with a prescribed set of values for the system parameters, yields a specific measure of performance or response. Through repeated simulations, the sensitivity of the system performance to variation in the system parameters may be examined or assessed. Simulation, by this procedure, may be used to appraise alternative designs or determine optimal designs. Simulation, as with most other techniques, has its advantages and disadvantages. The major advantage is that simulation theory is relatively straightforward. Simulation methods, in general, are easier to apply than analytical methods. Whereas analytical models may require us to make many simplifying assumptions, simulation models have few such restrictions, thereby allowing much greater flexibility in representing the real system. Once a model is built, it can be repeatedly to analyze different policies, parameters, or designs. However, it must be emphasized that simulation is not an optimizing technique. It is most often used to analyze "what if" types of questions. Optimization with simulation is possible, but it is usually a time consuming process.

7.2 Thesis Methods

In this study, the queuing system of the container yard was simulated to produce daily container variations of yard and cost analysis was applied to these data. We called this model as Container Yard Optimization, CYO. Other methods above mentioned, as queuing, inventory and systematic search method, were also applied to port data with combination of cost-benefit analysis and CYO model result was checked by the results of these methods.

Queuing simulation is generated to solve complex queuing models not to be able to solve with the queue modeling. Container types are very important in cost analysis and determination of probability distributions. Each type container flow produces the probability. These probabilities must be coded in queue system. If the code is not suitable for theoretical form of probability distribution of observed data, the queuing system could not be represented by any code. In this complex situation, the solution will be obtained by using the queuing simulation. This is the because of developing CYO. The application of this software is successfully carried out in case study. Manual of the software is presented in Appendix B. Time series of import and export containers and empty and full containers are presented by this software. The numbers of containers at yard, buffer, containers under capacity, and containers over capacity at a time can be obtained. The cost analysis will be then carried out easily.

7.3 Hypothesis Review

Mathematical optimization methods are selected as Inventory and Queuing Theory. First method is easily applied to determine the optimum size of yard. Data evaluation and mathematical modeling are processed successfully. Second method especially requires the bulk type queuing model in order to solve the yard container operation. Other types of queuing models are not used conveniently for yard operation.

Bulk queue system includes the bulk container records from incoming ships, trucks and wagons. Arrival and service time distributions of each vehicle is firstly determined and formulated. Especially, bulk queuing models can yield reasonable outputs in yard optimization.

Monte-Carlo simulation can be effectively used together with optimization process by merging. The developed software can respond to some limited requests.

The Container Yard Optimization software yields the reasonable and satisfactory results for whole costs and container types.

7.4 Macro and Micro Aspects

From the study, some macro and micro aspects can be extracted.

7.4.1 Macro Aspects

- CYO is able to give daily traffic and container stock yard numbers. This can be used in any decision session.
- Port revenues containing handling, warehousing etc could be calculated by CYO if the distribution of waiting days of containers on the yard is exactly known.
- By queuing method, queue size of waiting ships and containers transported by truck and wagon so the cost of unserved ships and containers could be calculated.
- The most popular and frequently used distribution function generators were included to CYO and MCS. These functions will solve the modeling traffic data of any port.
- CYO was able to calculate the required yard area as square meter using pick container numbers in a year. But this tool can be used for any other purposes or container numbers.
- By MCS, if the number of random data set is extended enough, all possibilities of daily traffic number and so the minimum and maximum container numbers on the yard can be achieved. Frequencies of all yard container numbers and pick numbers can help to determine the handling equipment number considering unit handling time.
- Yard area calculation tool of CYO is able to calculate also yard blocks after the determination of block stack level, row and lane number.

7.4.2 Micro Aspects

- Inventory model gave about 19000 TEU yard size minimizing the cost function.

- By application of Monte Carlo simulation on İzmir Port data of 2002 year, result showed that 17100, 19100 and 20100 TEU respecting 2, 3 and 4 level stacking on the yard minimizes port cost function.
- Using the same data of İzmir Port for 2002 year, queuing model showed that about 18682 TEU of yard size minimized the cost function.
- Using the same data of İzmir Port for 2002 year, Container Yard Optimization, CYO result showed that about 17700 TEU of yard size minimized the cost function.

7.5 Recommendations for Future Studies

The study covers and gives the daily container numbers on the yard and revenues. To do this, effort is the modeling of the terminal realistically. But there are more to do. Below are author remarks to do in the future studies;

- Study focuses on container storage yards but optimization of container freight station can be also studied using similar manner in the future studies.
- Berth simulation was studied in the past using queuing method ad simulation techniques but can be combined with yard simulation in this manner
- Cost of handling equipments was not included into cost-benefit analysis. It can be done for different equipment types and layout schemes.
- Queuing simulation is realized only one trial. This may not be enough to obtain the reliable outputs. More trials should be done from aspect of software reliability. For the results of each trial, the frequencies and probabilities should be calculated and each curve of probability distribution should be matched. Finally, the number of trials required should be determined.
- It is assumed in the study that handling equipment does not cause a queue in the queue system. The effect of handling equipments can be analyzed.
- Seasonal variations on container traffic and ship coming to the port can be researched.

- In the study, traffic data of one-year were used in the methods. Including the traffic forecast yard size respecting future traffic can be researched.
- Study is limited to container terminals so other terminals, such as bulk, liquid etc, also can be analyzed and terminal stack size can be determined.
- Standard 1 TEU container type and size was used as traffic unit and size of the 1 TEU is decided by the user in the CYO interface. This is because that data achieved form many ports does not contain detailed information on container types and sizes but just TEU equivalent. In the situation of detailed information, other non-standard container sizes and types can be determined in the methods used.
- For the modeling of traffic data, just a few probability distributions, such as Poisson, Erlang etc, could be analyzed. For the future studies, it is possible that other probability distribution functions, such as Gamble, Binomial, Gauss, Lognormal, Weibull etc, can be tried for exact fit to real data modeling.
- Cost of demurrage and waiting trucks was determined and used after personal interviews with the sector people and from some articles. This of course changes from country to country or from port to port. For the future studies, a more realistic value and its affect as a parameter can be examined.
- For the case study, distribution of container waiting days on the yard was Erlang. This decision was taken by interviews with some port staff and some non-official raw data because there is no study on this data. But author predicts that this may change from port to port or depends on port ownership and port traffic characteristics.

7.6 Conclusion

In this study, the main objective is to determine optimally yard in a container port. In first step, the inventory method, well known especially in management and industry, is firstly essayed in yard planning of port. This method especially requires recorded container data staying at yard for the certain day of each month. The optimum container capacity must be within recorded data because of the obligation in obtaining both of unserved container cost and idle slot cost. This causes the limitation in determining the optimum container capacity in a yard. In addition to this handicap, costs of the empty and full container operations and handling costs of import and export containers are not considered separately. Therefore, the requirement of the different method to respond to these handicaps happens.

In second step, the applicability of queuing model is essayed to eliminate these handicaps. When the container operations in a port are investigated, it is seen that the bulk container system should be preferred. This requires the bulk queuing model for optimizing a yard. This process is subjected as first application in yard planning. The application process is implemented successfully. But the mentioned costs and the probability of different container situations are not taken into consideration because queuing model exists complex operation not to be solved by using queuing theory. And it is decided that the complex queuing models can be only solved with simulation.

In third step, the Monte-Carlo simulation is used for calculating the frequencies of different numbers of containers at yard in a day. This does not mean that the optimum container capacity is determined. Because that the simulation process does not produce the optimum decision variables. For these requirements, the optimization process must merge with the simulation model. In this study, this process is developed originally and the optimum container number staying at yard can be calculated successfully. But, the costs relating to different container operations are not included to the simulation process.

Finally, new software to eliminate the above mentioned handicaps is originally produced. It is based on queuing simulation model and called as Container Yard Optimization, CYO. Whole yard operations and costs are included in detail.

In this study, popular four operations research methods used for many engineering problems as well as optimization problems were used and coded by high-level programming language. Considering all advantages and disadvantages of these methods, the software, CYO, was developed by simulating container yard queue in which each container slot behaves as a server. Results of the CYO were checked by other methods. All tools were applied to data of 2002 belonging to İzmir Port. Result of this study is highly reasonable and similar. For İzmir Port data, a container yard size of 18000 TEU minimized the cost function.

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APPENDICES

Appendix A: Flow Chart of Container Yard Optimization Program (cYo)

In this appendix, the flow chart of the cYo software is presented in pieces. Program is composed of some components needed in the program. These components are random number generators, data checker, printing tool, area calculator, benefit calculator and simulator. The flow chart of each random number generator tool by any distribution function was presented separately. There are many distribution functions in statistics but in this study, just Triangular, Normal, Exponential, Erlang and Poisson distribution functions was used as random number generation function. The reason to choose these functions is their popularity and being frequent functions met in the port operations and problems. As a matter of fact that, in the study, the distribution of ship arrivals is Poisson, container numbers exported or imported by ships is Erlang, container numbers imported or exported by trucks is the superposition of Erlang and Poisson (or Normal) distribution.

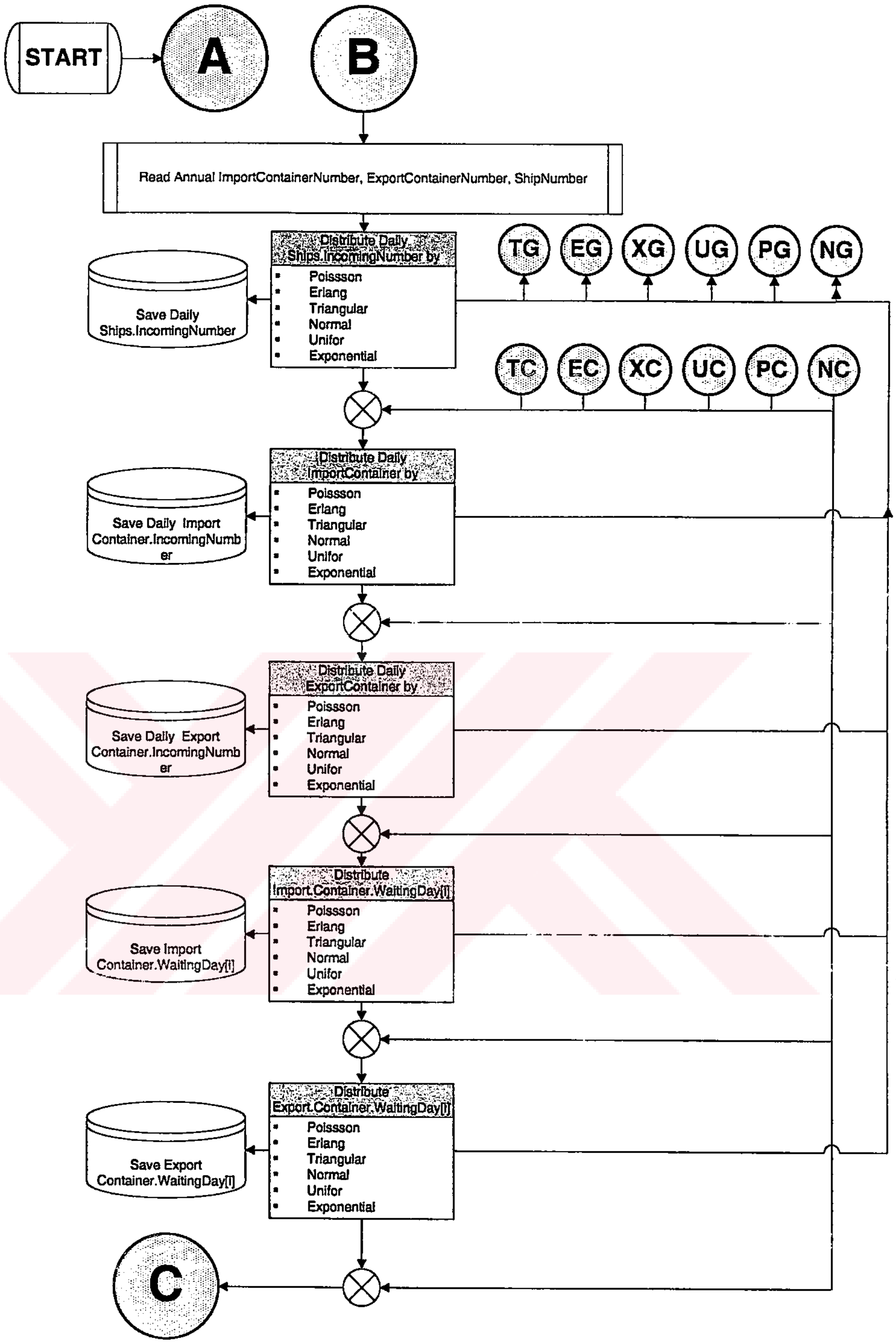


Figure A.1a Flow chart of cYo

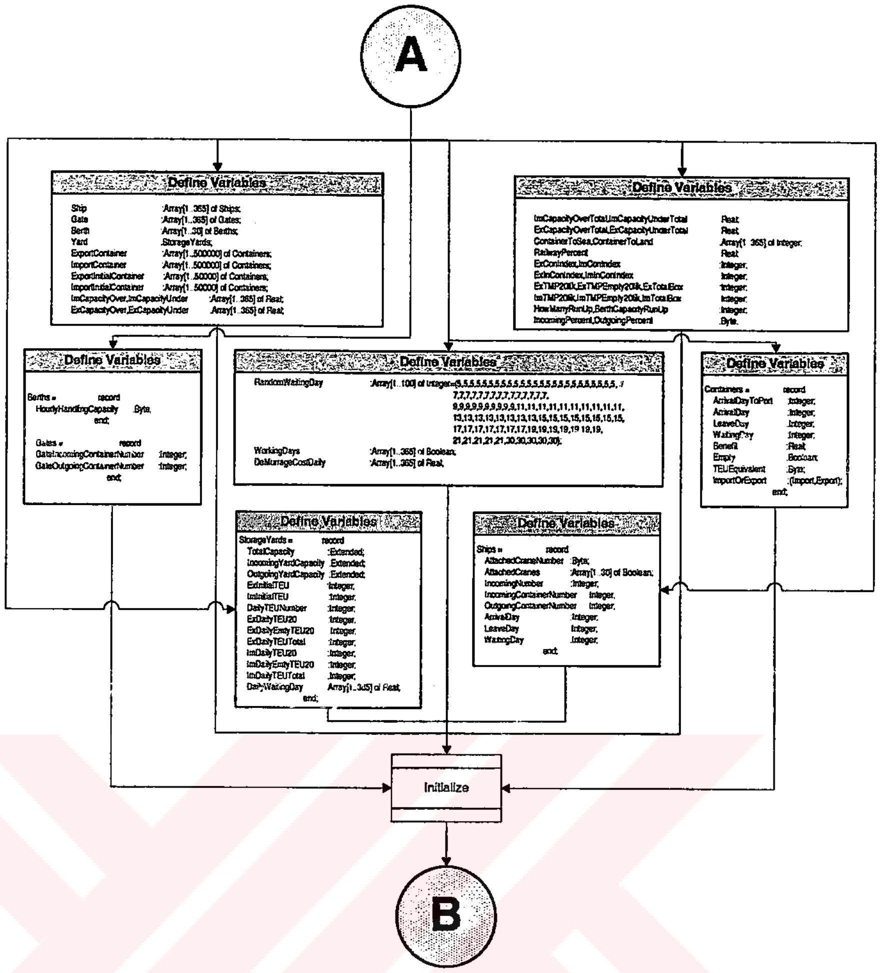


Figure A.1b Flow chart of cYo (Variable definitions)

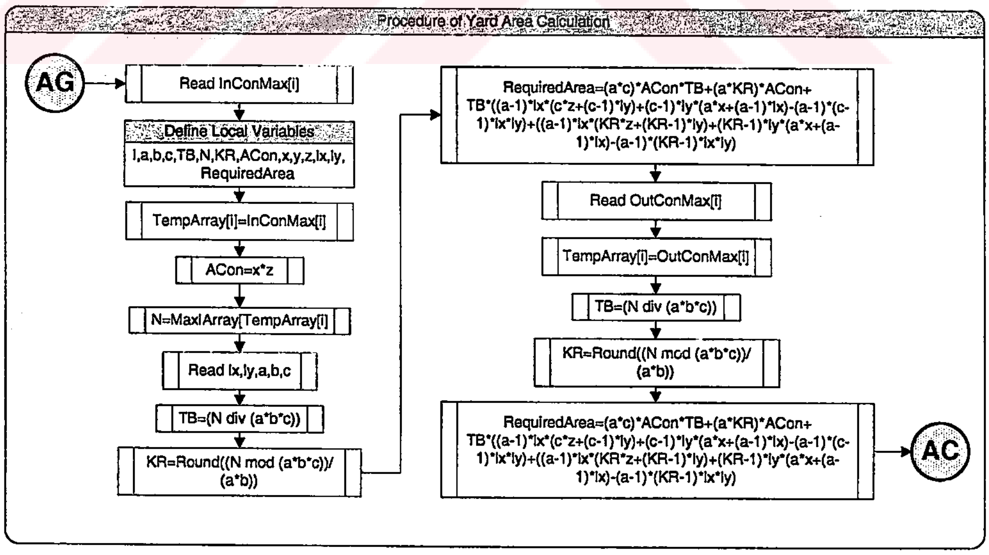


Figure A.1c Flow chart of cYo (Yard area calculation procedure)

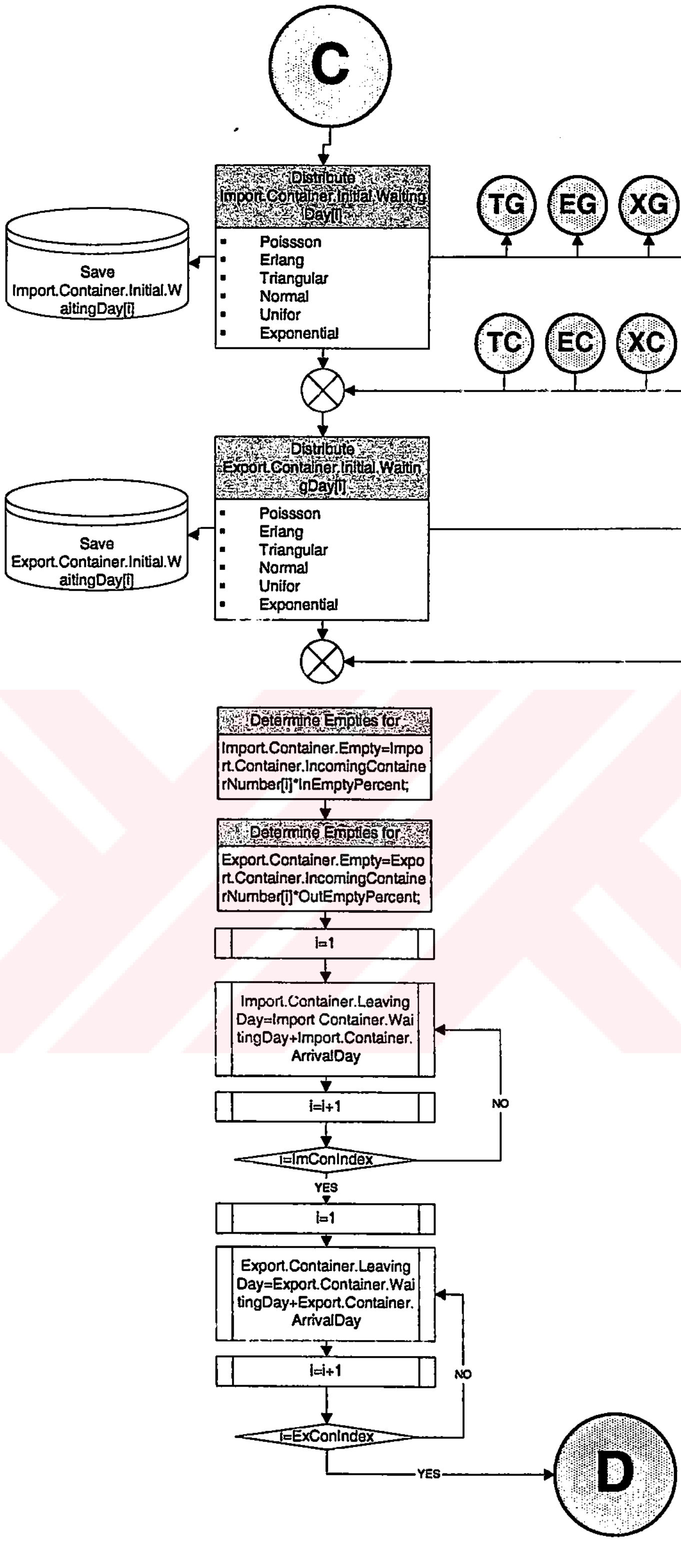


Figure A.1d Flow chart of cYo

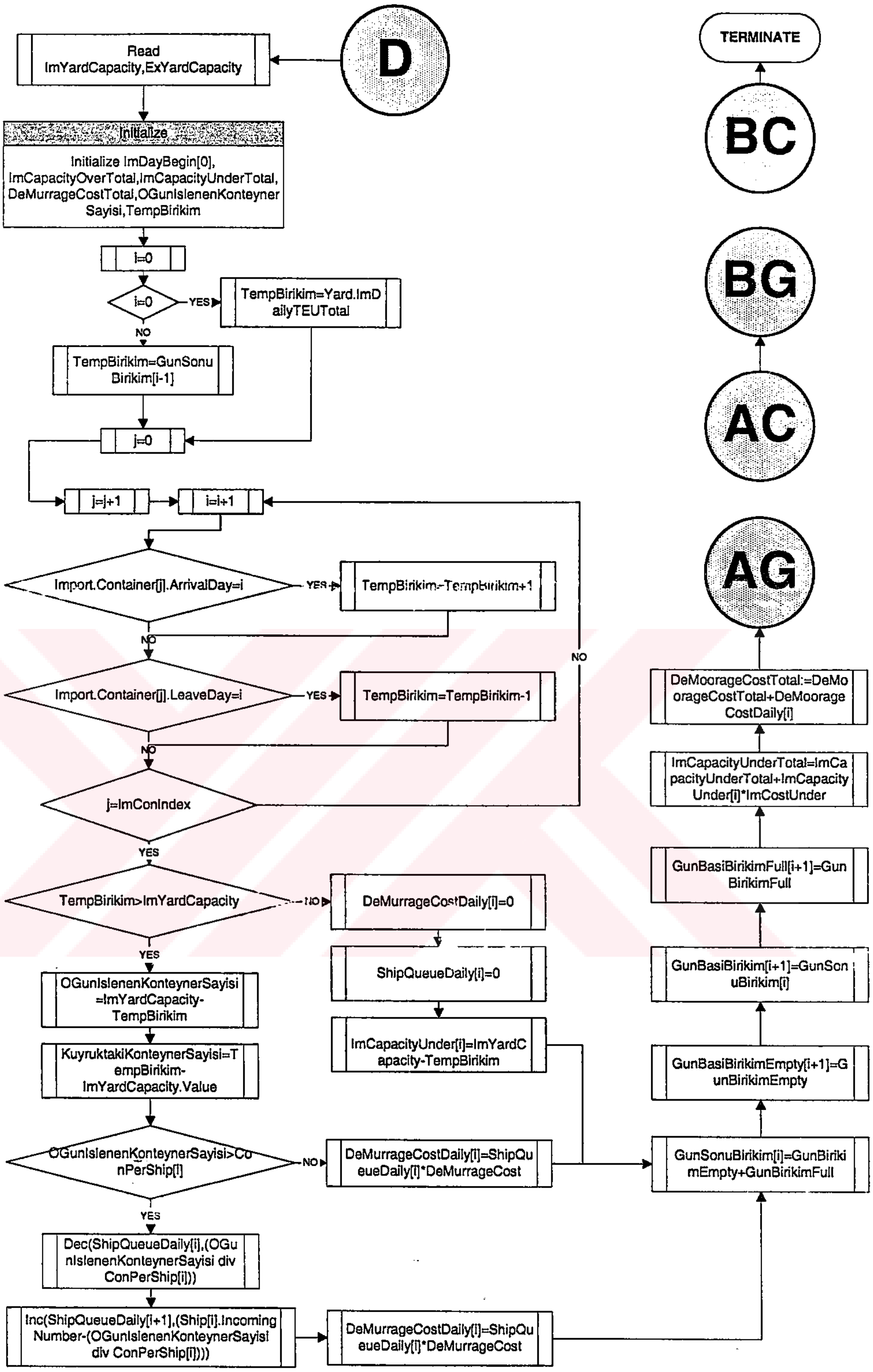


Figure A.1e Flow chart of cYo

Figure A.1f Flow chart of cYo (Revenue calculation phase)

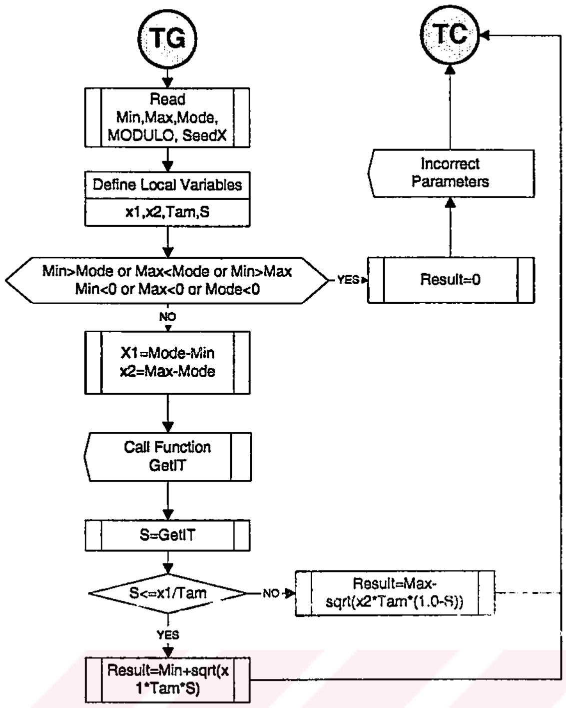


Figure A.1g Flow chart of cYo (Triangular distribution function)

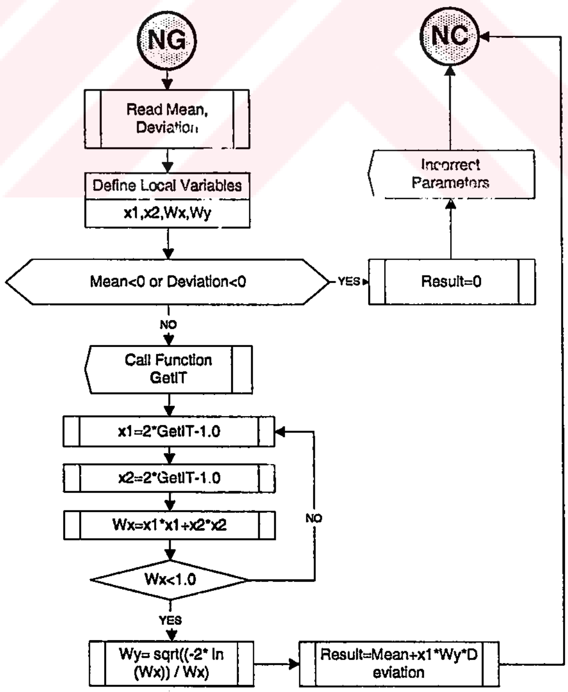


Figure A.1h Flow chart of cYo (Normal distribution function)

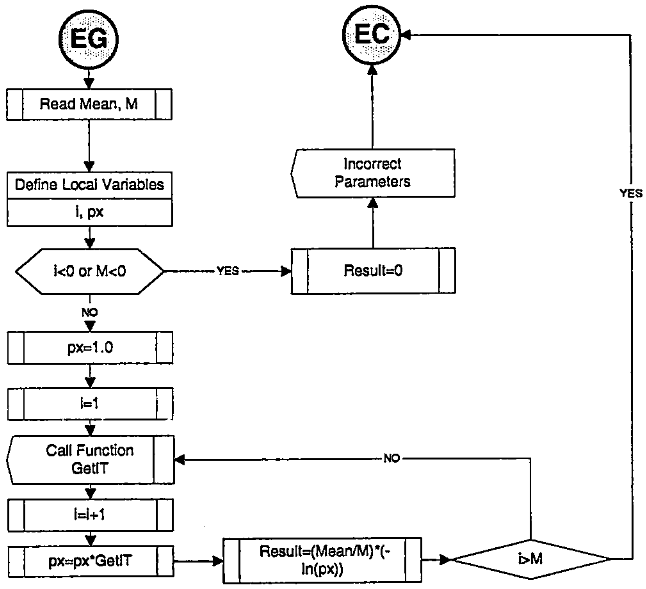


Figure A.1i Flow chart of cYo (Erlang distribution function)

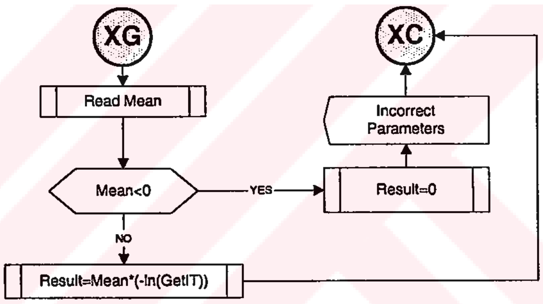


Figure A.1j Flow chart of cYo (Exponential distribution function)

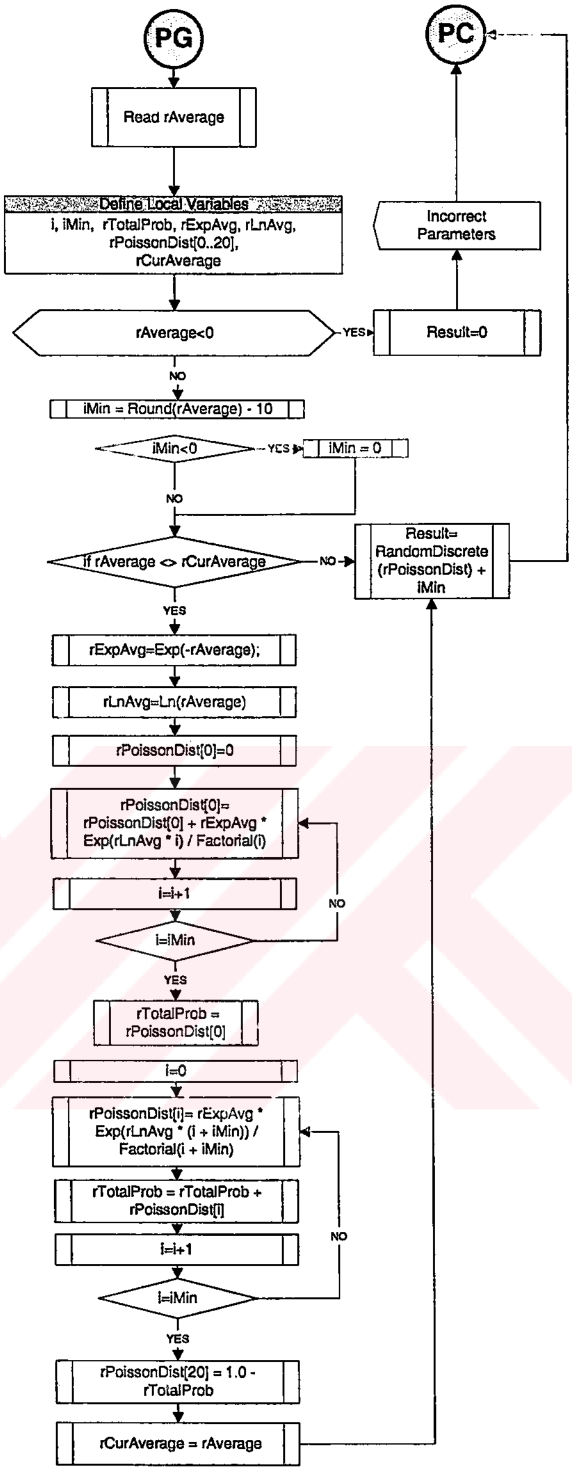


Figure A.1k Flow chart of cYo (Poisson distribution function)

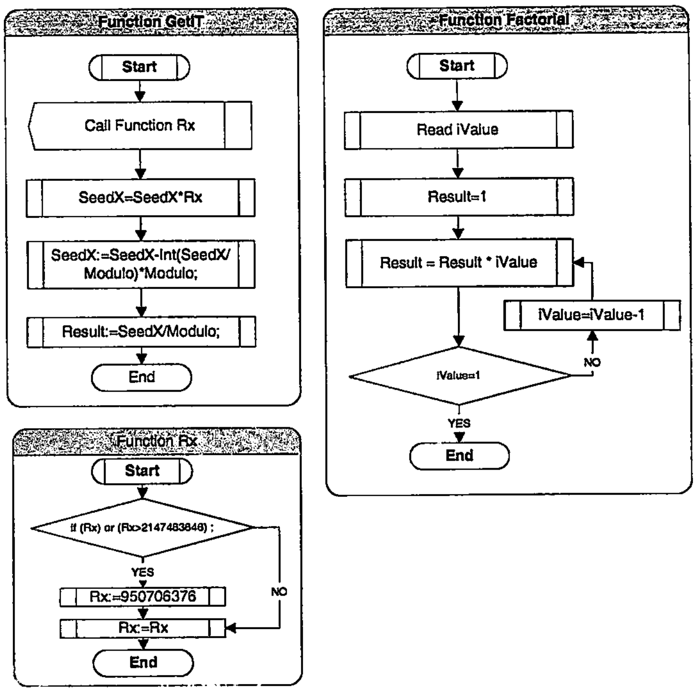


Figure A.1l Flow chart of cYo (Sub-functions)

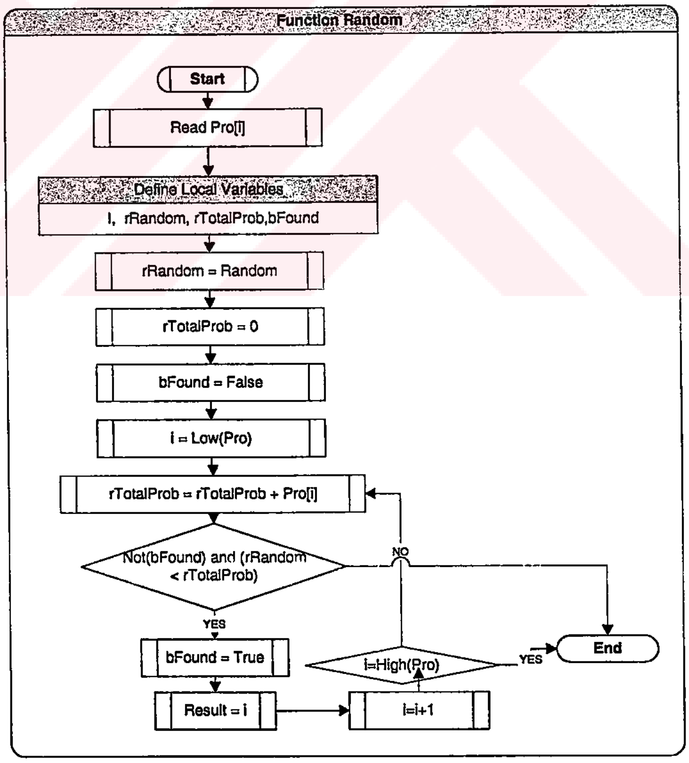


Figure A.1m Flow chart of cYo (Sub-functions)

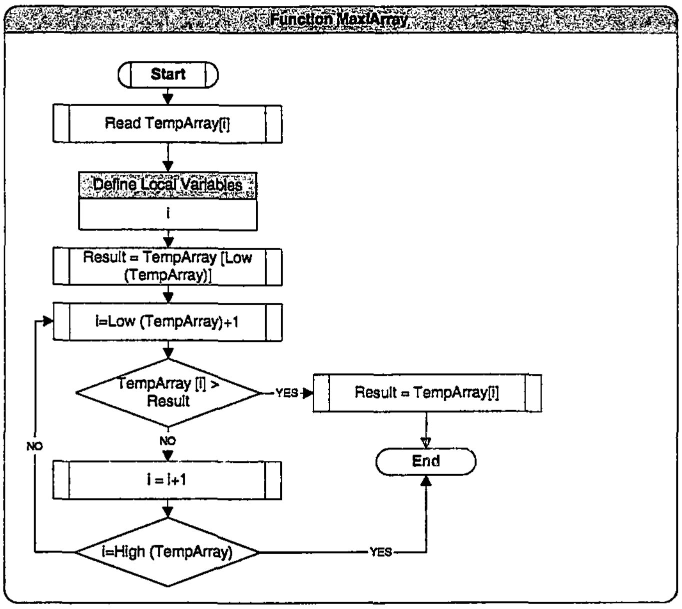


Figure A.1n Flow chart of cYo (Sub-functions)

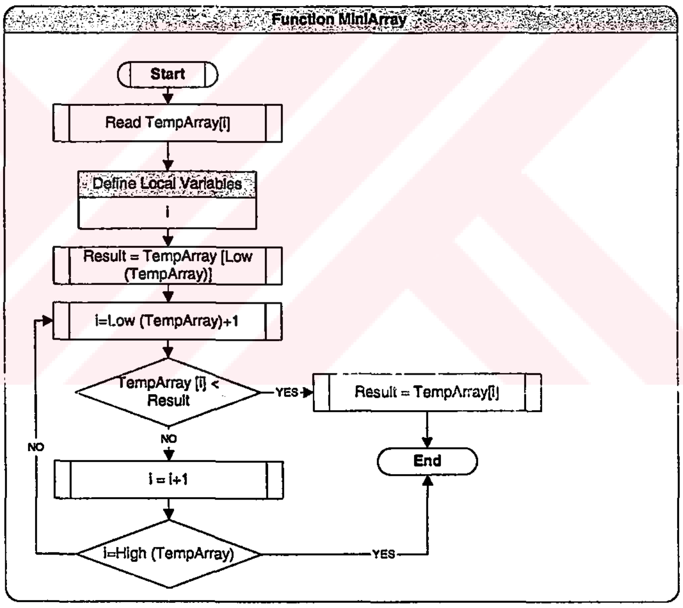


Figure A.1o Flow chart of cYo (Sub-functions)

Appendix B: CYO Manual

B.1 System Requirements

Program was developed on Windows XP operating system by a high level visual programming language. It reserves 3.3 mega byte Hard Disk and a memory between 13-93 mega bytes depending on the machine RAM capacity. It needs also some extra hard disk space for other files attached to the program and for saved output files.

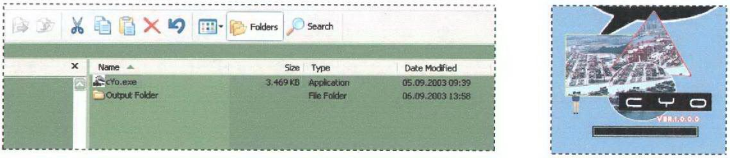
Program was not tested on the other Windows operating system platforms such as Windows 98 or Windows 2000 etc. Especially, it is possible to give some bugs if is run under these operating systems because of visual effects used in the program.

B.2 Steps to Use Program

1. Program consists of a folder and a standalone executable file "cYo.exe". Before run, copy this folder and file to any folder you want because it does not need installation (see Figure B.1a).
2. Just click the file "cYo.exe" to run the program (Figure B.1a).
3. Wait a few seconds for that flash screen disappears (Figure B.1b).
4. Select an action from main menu (Figure B.2b). You can start to simulate default data (Figure B.2c) or surf the pages to input a new data (Figure B.2d).
5. Visiting a page checks a checkbox on "visited" menu page (Figure B.2d).
6. Start first (an advice) with traffic pages giving *land-born* and *sea-born* traffic data (Figure B.5 through B.10).
7. Give annual container traffic to export on page *land-born traffic* tab as shown in Figure B.5. User can select any distribution function or can give data manually. This is the same for daily distribution.

8. Give railway percentage and empty percentage in total. Railway amount is included in traffic coming from hinterland.
9. Give sea born traffic on *sea-born traffic* pages in Figure B.8 through B.10. User can distribute the traffic by distribution function or manually. When user tabs on distribution function selection pages as in Figure B.8, daily and monthly traffic is automatically generated.
10. User can give the simulation parameters on "simulation parameters" pages as in Figure B.3 and B.4. On fee page, user gives the fees as US dollar for 1 container handling including warehousing service. Demurrage and 1 vacant capacity cost is given also on this page. User also gives working days of stuff as in Figure B.4.
11. Distribution of *container waiting days* can be given as in Figure B.11.
12. Give the initial number of containers waiting on the yard in Figure B.11 (tab 2). Daily accumulations are added or subtracted to or from this initial amount.
13. For cost-benefit analysis, user gives the upper and lower boundaries of yard capacity on Cost-Benefit Analysis page as in Figure B.13.
14. Give yard handling system sizes and equipment selection on *handling system and stack sizes* page as in Figure B.14. Considering optimum container number on the yard and container size, **cYo** calculates required yard area. User gives container stack size and projected handling system parameters including span lengths. For forklift or front loaders, total spans between container lanes must be distributed equally.
15. Click button in Figure B.2c to start the program.
16. After a few minutes depending on the machine speed, program generates outputs. During running, user can see the phases of the program run as in Figure B.19. There are two status bar of the program. First one shows the status of general run and second shows the cost-benefit analysis phase.
17. Results related to sea-born or land-born traffic can be seen on its pages (Figure B.6, B.10, B.15-18 and more not included here).
18. Program can give a report composed by input and output data and can print as in Figure B.23.

B.3 cYo Images



a) b)

Figure B.1 a) Program folder, b) its splash window

a) b) c) d)

Figure B.2 Menu Bar content a) Program Logo, b) menu for input and output pages, c) simulation starting, help, tools and exit buttons, d) history saver of visited pages.

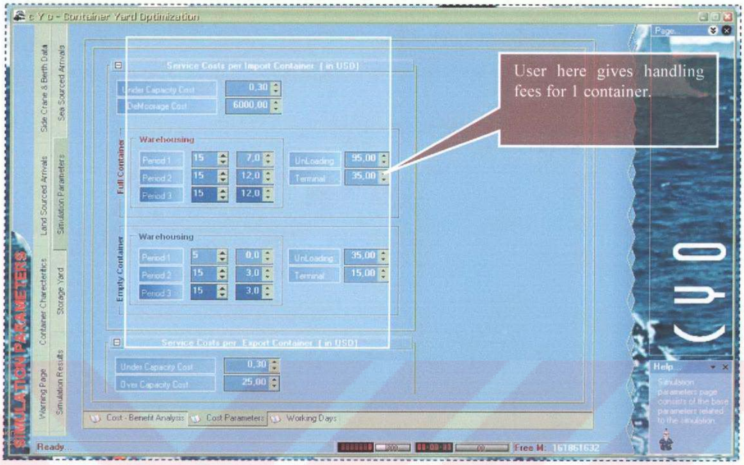


Figure B.3 Page where user can give container handling warehousing service fees.

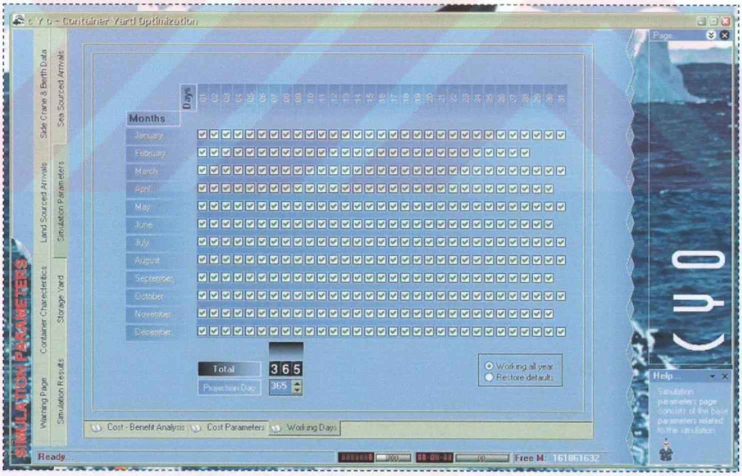


Figure B.4 Working day's page where user check which days stuff works.

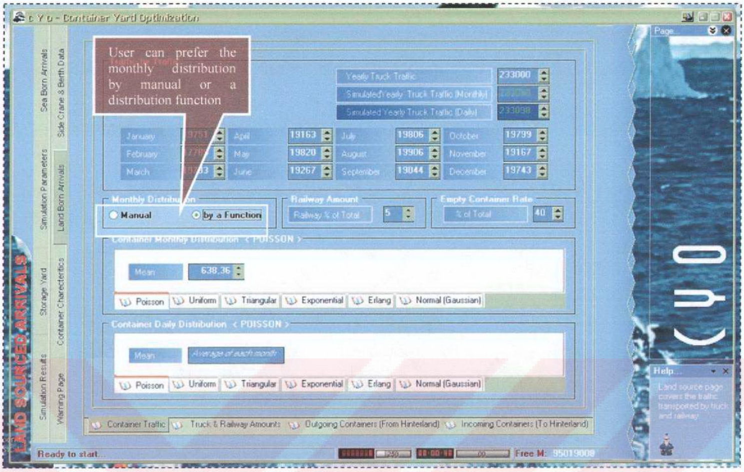


Figure B.5 Page of Land based traffic calculation, container traffic tab

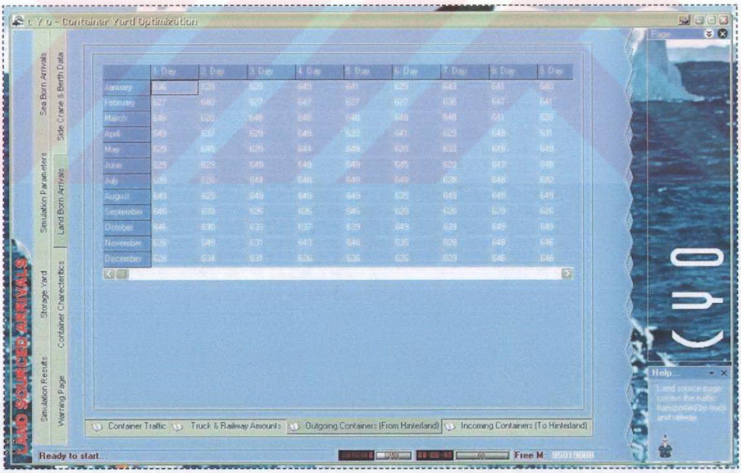


Figure B.6 Daily container arrivals form hinterland

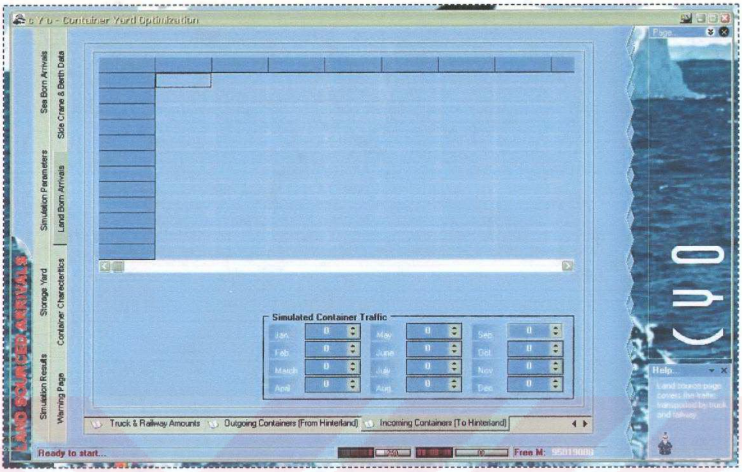


Figure B.7 Stock yard outs to hinterland after simulation and monthly totals

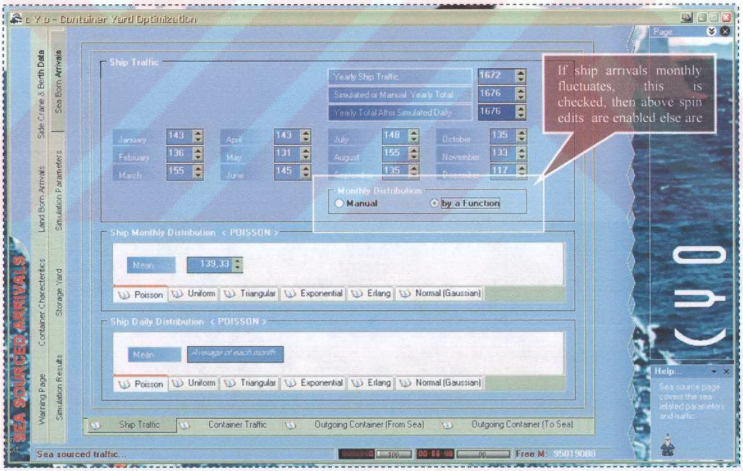


Figure B.8 Expected ship traffic page

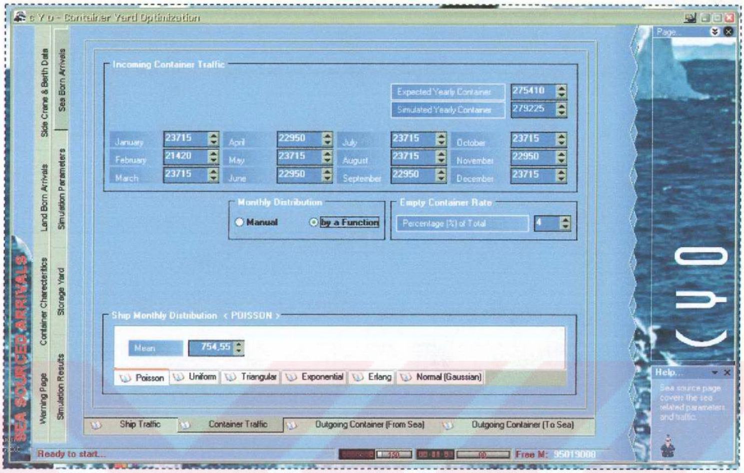


Figure B.9 Page of expected containers to be imported

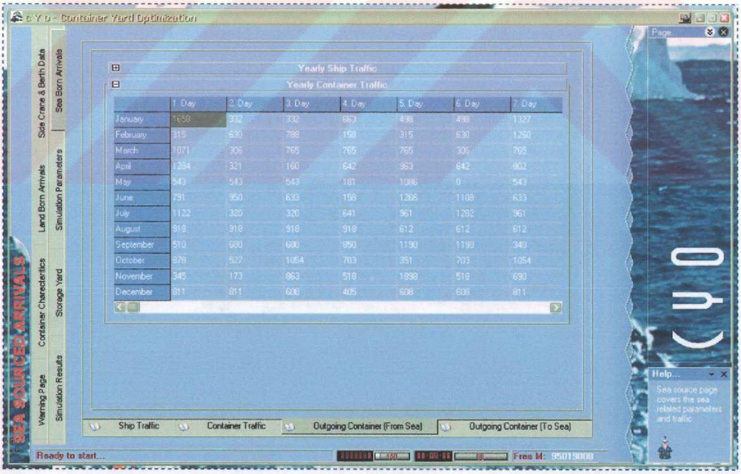


Figure B.10 Daily ship arrivals after simulation and monthly sub-totals

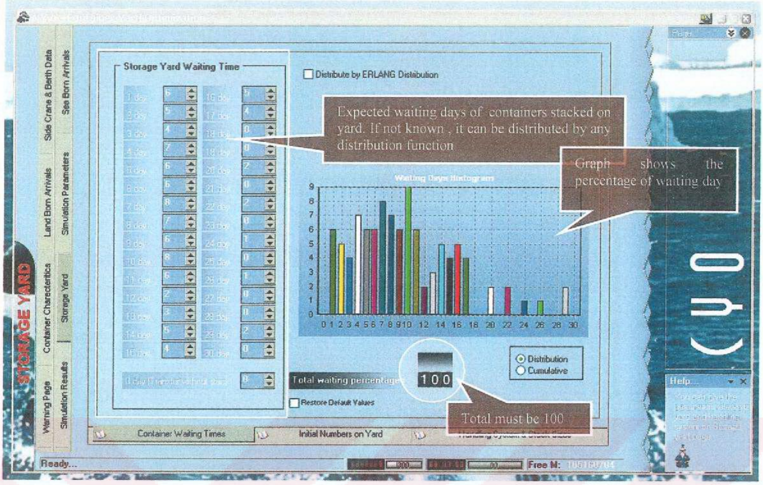


Figure B.11 Input page of expected waiting days of containers on storage yard

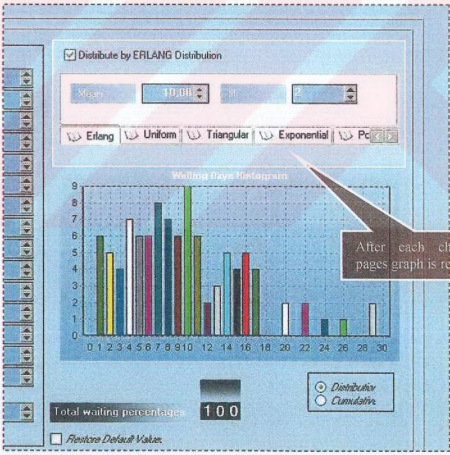


Figure B.12 Distribution by a function

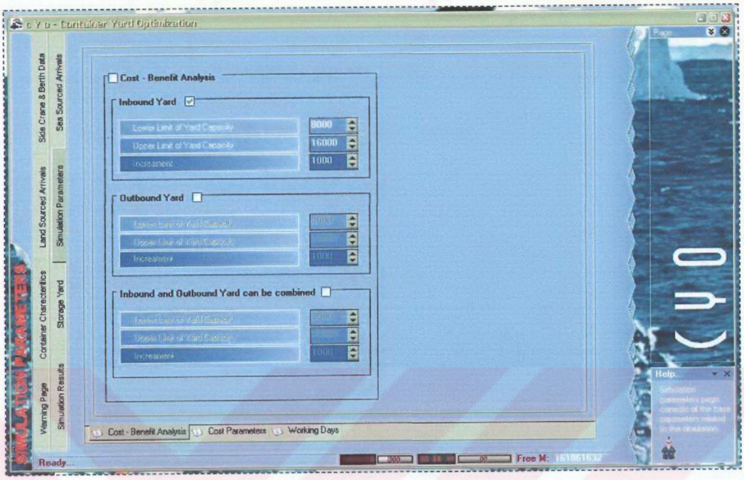


Figure B.13 Cost-Benefit Analysis result page

Figure B.14 Stock yard calculation depending on the container throughput

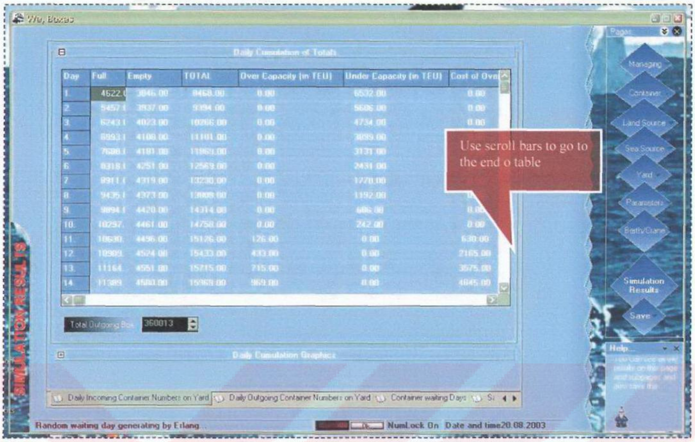


Figure B.15 Imported container accumulation on yard and cost of occupied and vacant containers

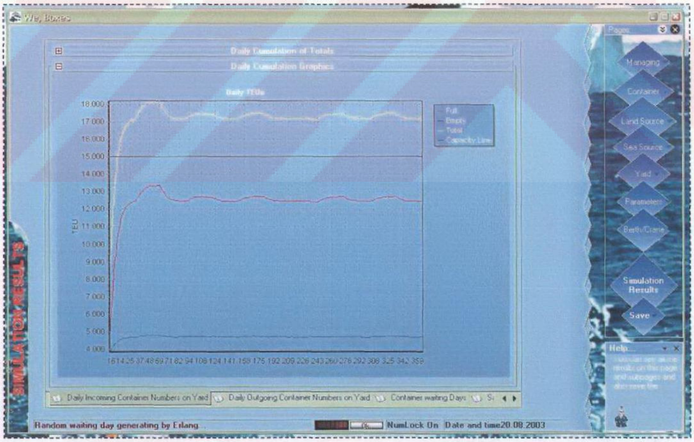


Figure B.16 The graph of imported container circulation on yard

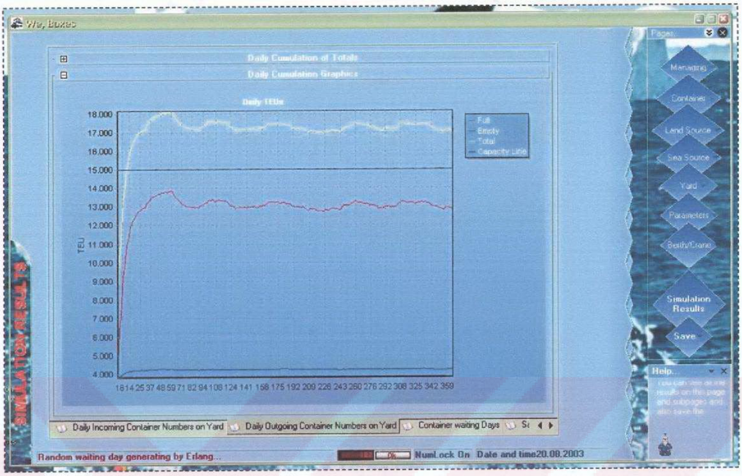
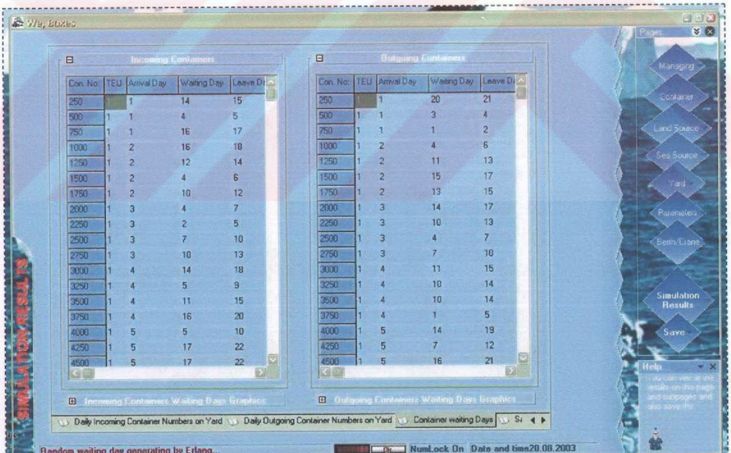


Figure B.17 The graph of exported container circulation on yard



Incoming Containers

Con. No:	TEU	Arrival Day	Waiting Day	Leave D
250	1	1	14	15
500	1	1	4	5
750	1	1	16	17
1000	1	2	16	18
1250	1	2	12	14
1500	1	2	4	6
1750	1	2	10	12
2000	1	3	4	7
2250	1	3	2	5
2500	1	3	7	10
2750	1	3	10	13
3000	1	4	14	18
3250	1	4	5	9
3500	1	4	11	15
3750	1	4	16	20
4000	1	5	5	10
4250	1	5	17	22
4500	1	5	17	22

Outgoing Containers

Con. No:	TEU	Arrival Day	Waiting Day	Leave D
250	1	1	20	21
500	1	1	3	4
750	1	1	1	2
1000	1	2	4	6
1250	1	2	11	13
1500	1	2	15	17
1750	1	2	13	15
2000	1	3	14	17
2250	1	3	10	13
2500	1	3	4	7
2750	1	3	7	10
3000	1	4	11	15
3250	1	4	10	14
3500	1	4	10	14
3750	1	4	1	5
4000	1	5	14	19
4250	1	5	7	12
4500	1	5	16	21

Figure B.18 Arrival, waiting and departure days of each container

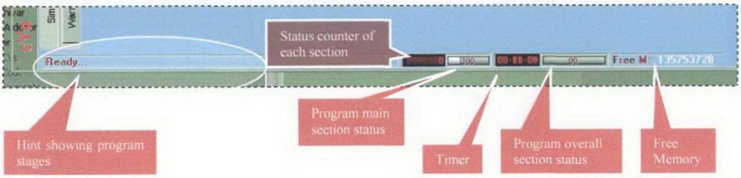


Figure B.19 Status bar

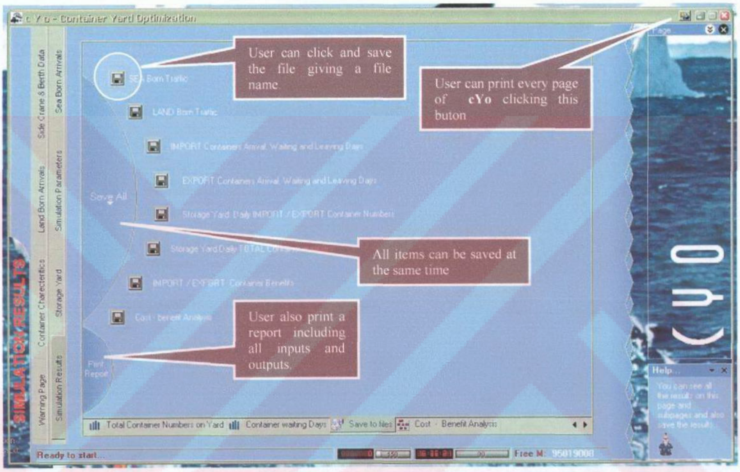


Figure B.20 Saving results to files

Appendix C: Container Handling Equipments

C.1 Yard Equipments

C.1.1 Rail-Mounted Transtainers

These equipments are used for high level stacking of containers. They can stack up to the high of 6 six level and up to the wide of 15 lines. They have some advantages in comparing with others. They are well adapted to highly-organized operations, have low level maintenance costs but rarely seen on multipurpose terminals. They require high level sub-structure costs.

C.1.2 Rubber-Tired Transtainers

These equipments are also used for high level stacking of containers. They can stack up to the high of 4 six level and up to the wide of 6-7 lines. They have some advantages in comparing with others. They are well adapted to highly organized operations, have low level maintenance costs if compared with other equipments except for rail-mounted transtainers but rarely seen on multipurpose terminals. They require high level sub-structure costs.

C.1.3 Straddle Carriers

These equipments offer high flexibility but the purchase price and maintenance costs are high. Also the load imposed on the pavement is heavy. Early hydraulic models were notoriously unreliable, and the oil leaks on the pavement made the surface very slippery.

C.1.4 Chassis

This equipment is a chassis of a trailer and container stay on the trailer during their stay on land. Chassis are expensive because they must be equipped for traveling on the public road.

C.1.5 Forklifts

Forklifts can be used for horizontal and vertical transport. Stacking height is usually two or three-high. They require more space for traffic lanes; it is slower and also dangerous. Wheel loads are higher. The system is practically only used on low-throughput terminals with enough space and for the (block) stacking of empty containers. Front loaders can empty containers up to eight level stacking so they are used efficiently for yard activities.

C.1.6 Tractors

This equipment is used to carry chassis convoys. It is efficiently for inland transport on yards, form stacking area to the berths.

C.1.7 Mobile cranes

These types are mobile and can move one to other. They are used on port having low capacities

Figure C.1 A rail-mounted transtainer

Figure C.2 A rubber-tired Transtainer

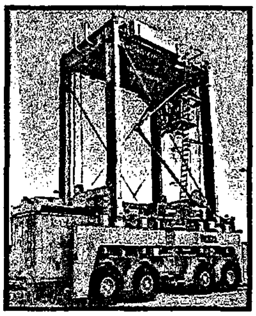


Figure C.3 A straddle carrier

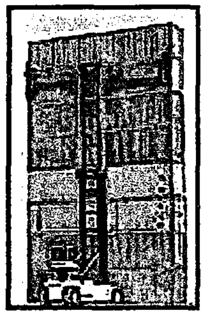


Figure C.4 Reach stacker forklift type

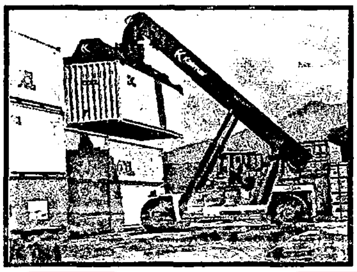


Figure C.5 Top loader forklift type

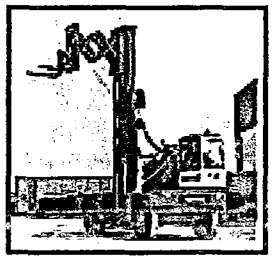


Figure C.6 Side loader forklift type

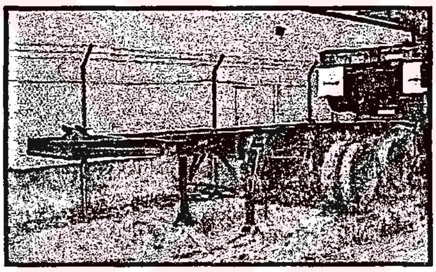


Figure C.7 Chassis

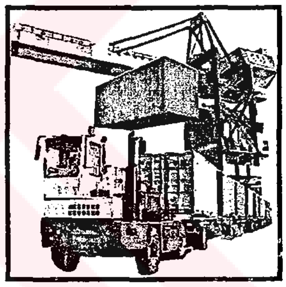


Figure C.8 Tractor

Figure C.9 A mobile crane

C.2 Side Cranes

This equipment is used for handling of the ship and loading or unloading yard equipments. They can be classified in mobile, bridge or gantries and are preferred by their hourly capacities.

C.2.1 Bridge cranes

These types are used for narrow berth moles as in Figure C.10.

C.2.2 Gantry cranes

These are most used types. High capacity ports use widely all over the world. Their capacities are higher in comparison with the others (see Figure C.11).

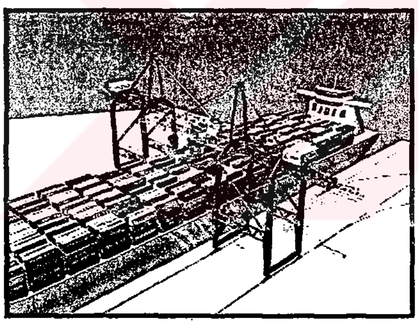


Figure C.10 A bridge crane

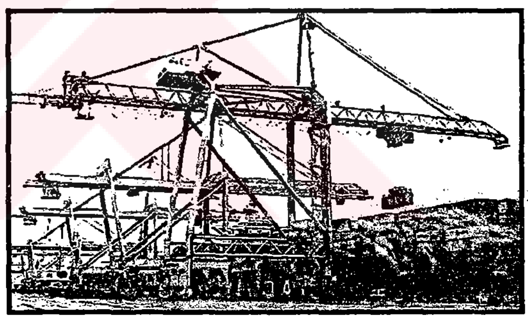


Figure C.11 A gantry crane

Appendix D: Yard Layout Schemes to Handling System

The size and layout of the stacking areas depend greatly upon the operational system on the terminal.

The systems are often called after the main piece of equipment that is used for the moving and/or stacking of the containers. In Figure D.1, an example handling activity is shown.

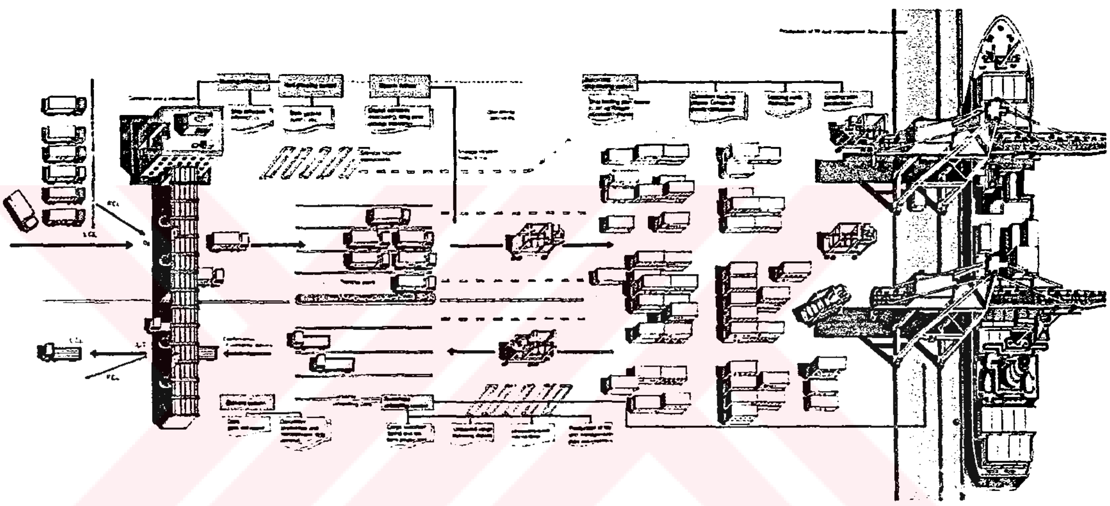


Figure D.1 A typical handling activity

The following main systems may be distinguished:

D.1 Transtainer systems

These systems are called according to the main piece of equipment which is the transtainer, or stacking crane, sometimes also called yard crane in distinction of the quay crane. With the use of stacking cranes the highest stacking density can be reached. Spacing between containers under the crane is minimum and traffic lanes between stacks may also be narrower as no turns have to be made.

The rail-mounted type can be made with larger span than the rubber-mounted crane and is therefore slightly more space efficient. An important advantage of this type is that it can be automated relatively easily. Naturally, being rail-mounted, it is inflexible. Particularly in locations where the rails have to be supported by piles, to change the crane-tracks is practically impossible.

The rubber-tired crane is more flexible. It can be shifted from one stack to another. In a lot of cases, the positioning of the stacks on the terminals is also rather inflexible as the soil-conditions make it necessary to construct special 'runways' for the wheels of the cranes. Automation is practically impossible as yet.

In these systems the containers must be transported to the stack from the apron and vice-versa. For this horizontal transport straddle carriers or truck and trailers (terminal chassis) can be used.

The systems are favorable for high-throughput terminals. Stacking cranes are quick working and high densities can be achieved. The investments are high, leading to the necessity to handle large numbers of containers to keep the cost per unit under a reasonable level. Span between container blocks is 5 meters.

D.2 Straddle carrier system

In this system the transportation and stacking of containers on the terminal is done by straddle carriers. The stacking density is much higher than that for the chassis systems. Lanes can be somewhat narrower and the space required per ground-slot is smaller. Stacking can go up to 4-high. This requires straddle carriers that can lift the container 5-high (so-called 1 over 4). These machines are expensive in price and in maintenance. They are also rather dangerous. They move fast and the driver has not always a good field of vision. They require 8 m. traffic paths and a 1.5 m span between container lines.

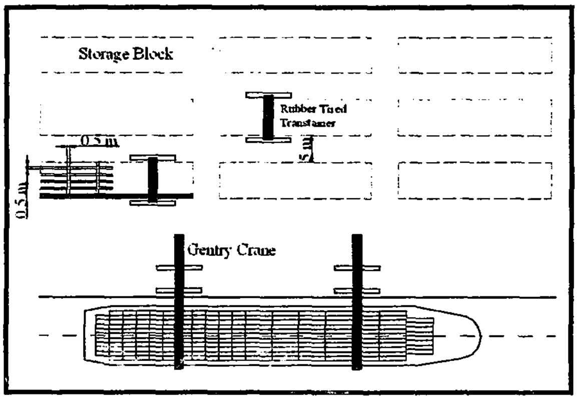


Figure D.1 A yard layout for the rubber-tired transtainer system

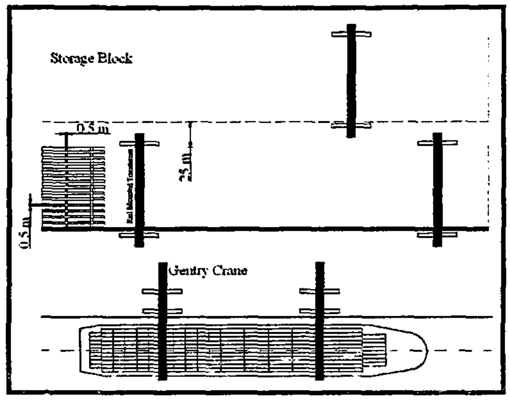


Figure D.2 A rail-mounted trans-tainer system layout

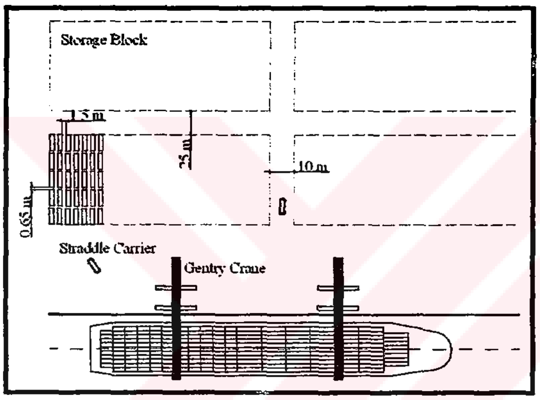


Figure D.3 A straddle carrier handling system layout

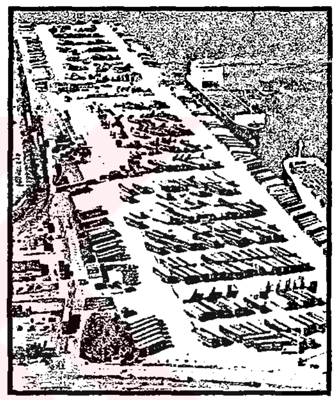


Figure D.4 A chassis system layout

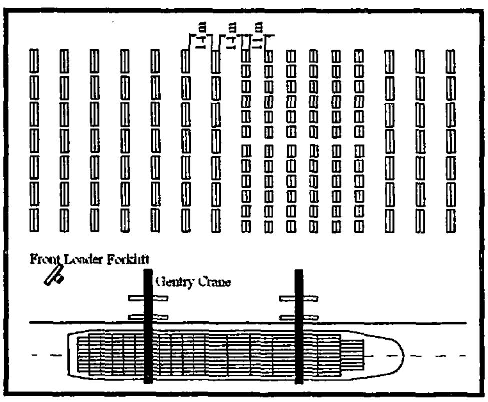


Figure D.5 A forklift handling system layout

D.3 Chassis system

Containers are placed upon trailers (chassis) and they stay on the trailer during their stay on land. Stacking is not possible but container flow is efficient. They require wide storage areas.

D.4 Forklift system

This system can be used for horizontal and vertical transport. Stacking height is usually two or three high for import, four high for export container blocks. Compared with others, it needs more space for traffic lanes; it is slower and also dangerous. It requires 11-13 meters span between container lines and 8 meters traffic path. Wheel loads are higher. The system is practically only used on low-throughput terminals with enough space and for the (block) stacking of empty containers.

Table D.1 shows a comparison of the systems considering some constraints.

Table D.1 Comparison of the handling systems

System Features	Tractor/Chassis System	Straddle Carrier System	Yard Gantry Crane System	Forklift System
Land utilization	Very poor 185 TEU/hectare	Good 385 TEU/hectares	Very Good 750 TEU/hectare	Poor 275 TEU/hectare
Capacity	-	25 m²/TEU	25 m²/TEU	60 m²/TEU
Terminal development costs	Very low: high quality surfacing not necessary	Medium: hard wearing surface needed	High: high load bearing surface needed for crane wheels	High: heavy wear on terminal surface
Equipment cost	High: large number of chassis required	Moderate: six straddle carriers per ship/shore crane	High	Moderate: cost effective for low throughputs
Equipment maintenance cost	Low	High	Low	Medium
Manning levels 2 crane operation	High: 28 men. Low skill required	Low: 22 men. High skill required	High: 29 men. Medium skill required	Medium: 26 men. Medium skill required
Operating factors	Good accessibility. Simple terminal organization	High flexibility. Good stacking	Good land use. Scope for automation	Versatile equipment

Source: UNCTAD, Improving port performance – container terminal development.