Development of a Computer Simulation Model to Optimize the Operations of a Multipurpose Seaport

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ABSTRACT

Seaports have traditionally promoted regional and international trade by generating commercial and industrial activities, which directly assist the economic progress of the country. Much research has been performed and many different mathematical and empirical models have been formulated to predict and evaluate containerized port operations. In this thesis, a simulation model is developed to analyze the operation of a multipurpose regional seaport in Wilmington, Delaware. The model then used to identify the possible bottlenecks and optimize the operation of the port.

The well known simulation software was chosen for the development of the model in the project because of its extensive graphic user interface, vast capacity of adapting different probability distribution, and the efficient transfer of model logic to the program. The simulation model generates different "what if" scenarios based on the change of different input variables (like number of cranes, number of ships and the number of cargoes in a trip, and change of intermodal shift from trucks to trains), which shows port performance under different conditions. The "what if" scenarios then tries to find the significant elements of the multipurpose terminal operation which, if changed, could most reduce the turnaround time of the vessels. The results of the simulation model are used to choose the optimal change in the significant elements (ship turnaround time, waiting time for bulk cargoes, containers, and trucks) of the terminal's operation.

Chapter 1

INTRODUCTION

A Seaport can play a major role in promoting regional and international trade by generating commercial and industrial activities, which directly assist the economic progress of the country. The history of many ports all over the world shows that a bold policy of modernizing and extending the current operation of a port could revitalize the economy of a region. In the current competitive port business era, failure to provide proper port capacity before increased traffic arrivals not only results in frequent congestion, (in both developed and developing countries) but also loss of business and reputation to other nearby ports. The last quarter of this millenium has experienced revolutionary changes in cargo movements. The biggest change in cargo handling in water transportation is the integrated land-water use of containerized cargo through intermodal transportation, which eventually creates and increases competition in nearby ports. Because of this change the criteria for port business depends on the optimization of port operation rather than the geographic location and the hinterland market that the port serves.

1.1 Background

Now-a-days companies wishing to move cargoes can choose from a much larger number of ports because their decision is less dependent on the inland transportation costs and port's physical location, but more on the quality and the cost of service inside the port. Slow service in a port means longer delays, hence a higher cost for shippers and ship owners. In trying to keep the port service competitive with other ports, the administrator and planner need to consider variables such as turnaround time for ships and trucks, warehouse capacity and facility, efficient intermodal transportation facilities inside the port, better cargo tracking, and less damage to cargo. These issues are much more acute for multipurpose ports, where different types of cargo operate at the same time by using same resources of the port and the same labor forces, making it difficult and complex for management to make proper decisions about the operation and management of a multipurpose seaport.

Raising throughput and lowering unit costs by efficient services, added investments, or both, needs good management decisions. But for multipurpose ports, efficiency would become a trade-off between containerized and non-containerized cargo. An increase in business in bulk cargo reduces the efficiency in containerized cargo handling. The size of the port and capacity of handling large ships is also a determining factor. As an example, for a vessel size of less than 700 Twenty Feet Equivalent Unit (TEU), hub ports handle twice as many outputs (28 TEU/ship/alongside hour) than multipurpose ports [1]. Though this calculation is for year 2006 on Asian seaports, with advanced operational planning and skilled labor, European and North

American seaports can currently achieve that throughput. The difference between throughputs among hub ports, major ports and multipurpose ports are quite considerable, but with the use of high-tech. information, proper management, decision-making, and optimization can improve container operation as well as bulk cargo handling. Improved decision making needs information for analysis, as well as good luck, healthy markets, political balance, and most importantly good relationships between the port authority and labor unions. System models can allow decision makers to simulate how efficiently or poorly containers and bulk cargoes flow from ships to berths; from berths to docksides; from docksides to either warehouses, container yards, or car terminals; from storage to checking and gate facilities into trucks and trains while accommodating same amount of movement in the opposite directions during the same time. As container and non-containerized cargo activity level might increase or decrease due to ships, trucks, or train arrival patterns, as well as using of port resources for the handling of different types of cargoes, a well developed simulation model can inform decision makers about how well each entity and the entire facility is performing in terms of time, cost, throughput, service, and labor. The trade-off in business of containerized and non-containerized cargoes, time spent by ships and trucks against cost of equipment, and labor and land costs can be estimated.

1.2 Problem Statement

The role of Wilmington's multi-purpose seaport is to provide efficient handling facilities for general cargo ships calling at the port carrying a variety of cargoes:

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containers, flats, pre-slung cargoes, large units of iron and steel, large units of package timber, and cars and heavy machinery, mixed with a basic load of mostly palletized break-bulk cargo. The Port of Wilmington also handles a significant number of containerized ships along with dry bulk cargo in the same line of quay, which makes her an ideal multi-purpose port. However, multipurpose seaport operation can actually cause a decrease in cargo-handling productivity and disrupt operations if the port is not equipped to handle them efficiently with a special layout of the terminal, and modern and efficient management [2].

Due to the potential growth of the port and peak business in winter, the port might face a queue of ships in some certain seasons, which eventually increases ship turnaround time. With current container ships and large bulk cargo ships, the cost of ship waiting is much more significant in the port operation than any other costs. The rapid growth of container operation also brings problems and issues of container handling and crane operations, efficiency, and capacity issues. Good and efficient management with proper optimization of port resources can solve these problems. Efficient and cost effective intermodal movements of different cargoes inside the port and the effect and potentiality of using double stack rail freight on the business of the port are also major issues for the port planning and long-term improvement of the port.

Another important aspect of concern is the operational organization of the terminal. Often, activities on the ship, on the dockside for bulk cargoes, containers, and ro-ro traffic, on the warehouses and yards, and the intermodal shifts of goods have been considered as separate activities. The inefficient operation of any or all activities would

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give the net result of considerable loss in operating capacity for equipment, cranes and all other resources. Identification of capacity, availability, and utilization of all the resources of the port as a part of single activity is also very important. At a specialized terminal, such separation is completely unacceptable, as a unified responsibility for the overall operation and unity of control of the specialized terminal becomes an increasingly important requirement for its efficiency.

1.3 Objective and Purpose

The objective of the study is to assist the port management in making good decisions by understanding the multipurpose port's operational system through computer simulation. The purpose of the thesis would be to run the simulation model for a multipurpose port and describe all the operations and incorporate them into the model. The output of the model would then be used to optimize the operation of the port and to identify the bottlenecks, if there is any, inside the port. The model will help to understand the entire complex logic of operation of a multipurpose seaport operation and the physical process of port management and cargo (Containerized and non-containerized) handling. Port operation is a complex process, and as discussed before, multipurpose port operation is more critical than a single purpose containerized port. The simulation model will identify various measures of effectiveness for different resources inside the Port and identify whether any chain of operation needs to be modified.

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Other important aspects of this research is to help port management gain better understanding of how the existing facility, with its size, labor force, maintenance programs, and equipment of different levels of performance, functions under different levels of activity. With the help of 'what if' scenarios by changing different parameters and service time in the model, the management would be able to take a decision from a set of alternative decisions to enhance performance. It would also help to reduce excess waiting and delays for cargo handling. Another important purpose of this project is to reduce ship turnaround time, which is the most critical factor for movement of cargoes by waterways. The objective also includes application of intermodal transportation for the handling of bulk, break-bulk, and containerized cargo from the port to its market area through the efficient and economic choice of transportation mode.

1.4 Scope of the Thesis

This thesis presents the development of a discrete simulation model that will try to satisfy the objectives and purposes of the thesis discussed earlier. Research on this project will use all known resources available on the subject of port optimization and simulation. As previously stated, most of the literature found was based on the single purpose ports, especially major containerized ports. The work includes a collection of all the operational and infrastructure data through the Port of Wilmington authority. Data related to the type of businesses in the past and present, and the trend of future business, was collected. Additionally, the model identifies the bottlenecks and different

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interactions between different types of cargo handling and operations, with suggested solutions for the optimization of port operations.

The analytical requirements of the program include the berth throughputs, ship turnaround time, crane utilization rate, warehouse capacity and utilization rate, and utilization rate of different port resources like forklifts, yard hustlers, economic impact of intermodal cargo transfer and handling, and economic aspects of overall port operations. The application is also able to analyze all the input of the port operation and use the model output to analyze the optimization of port operations.

The work includes the development of a program that achieves the analytical requirements mentioned above. The programming of the model is achieved through the use of a popular commercial simulation language called ProModel. In addition, the program would allow us to visualize the operation of the port during the simulation run. The program will also store the information and provide analytical output of the result.

There are some other issues in the Port of Wilmington that would not be covered by the simulation. Issues including the use of double stack freight (containerized) movement to and from the port to its hinterland, current and future market and demand, economic impact and the econometric analysis of the port, and the operational and economic comparison of the port with nearby large ports, would not be covered fully in this research. However, a brief description of all these issues will be discussed at the later part of this research.

1.5 Organization of Thesis

Chapter Two is a discussion of previous studies about port operation, simulation, and optimization. This chapter gives an overview of single purpose and multipurpose port operation and management. The chapter then presents and discusses previous simulation studies for the operation of seaports. Later in the chapter, previous research on the methods of optimization for different measures of effectiveness for the optimization of seaport operation is discussed.

Chapter Three consists of history and background of the Port of Wilmington, including past types of operation. The chapter then discusses the brief literature review of the previous study about the port. It then explains the current operational and infrastructure facilities of the port; ports policy and administrative structure.

Chapter Four discusses the simulation program. It discusses the ProModel simulation program, its components, and its application in the port simulation.

Chapter Five discusses the development of the simulation model for the Port of Wilmington with flowchart presentation of export and import. Later the chapter discusses the mechanism of simulation with different distribution functions.

Chapter Six discusses the output and application of the simulation model. The chapter also consists of the general cost performance and the data about "what if" scenarios for different runs of the model.

Chapter Seven consists of the evaluation, validation, and verification of the program. The program would be verified by using the special feature of the ProModel

software. The program will then be validated by using real life data of the actual port operation.

Chapter Eight concludes the thesis with a summary of the project, conclusions of the work with advantages and disadvantages, and recommendations and suggestions for future work. The chapter also discusses different miscellaneous issues that effect the port operation, but can't be solved by a simulation program alone. Some suggestions based on the model would also be discussed here.

Chapter 2

REVIEW OF PAST WORK ON PORT OPERATIION AND SIMULATION

2.1 Port Operation

The main idea of port operation is the handling of cargoes. This includes containerized cargo, break-bulk cargo, bulk (palletized) cargo, dry bulk cargo, and liquid bulk cargo. Among all, containerized cargo is the newest form of cargo operation and started mainly in the sixties [3]. Now-a-days many ports handle only one or two types of cargo and are considered a single purpose port. This term is more popular for containerized cargo-handling ports, as it becomes the trend to use containerized cargo for the shipment of goods. On the other hand, many regional ports still operate different types of cargoes from the same berth groups by using same dockside facilities. Cargo operation for these types of multipurpose ports are more difficult than single purpose ports and for high amount of cargo handling, optimization and improvement of efficiency is difficult to obtain.

The handling of different types of traffic (cargoes) at the same berth group causes lower throughput than if they are kept separate in separate berths. On the other hand, assigning special types of cargo for different berth groups or for specific types of port causes a loss of flexibility of port operations. Specialization of cargo handling loss the berthing capacity by dividing the port and the traffic before allocating berths, thus

the loss of berthing flexibility; and also loss of transit storage areas that may be achieved by mixing complementary traffic. On the contrary, a specialized port gives a gain in service capacity in the berth facility by segregation of the different classes of traffic, and also by separation of high and low average service times and large and small ships, i.e. there is a gain through greater consistency of demand [4].

The balance between these advantages and disadvantages of specialization needs separate judgement in each case and different studies based on mathematical models. Analytical studies and simulation will be discussed in the next section.

2.1.1 Single Purpose Port

A single purpose port is a specialized seaport terminal for handling unique cargoes. With the recent development of containerization in the last few decades, containerized ports are mainly known as single purpose ports. Ports operated with only dry bulk cargo, bulk cargo, or ro-ro cargo may also be considered as single purpose port. This type of port has unique economical appeal and uses special types of equipment for maximum throughput. Ports with specialized terminals can use the most economical port technology for each traffic type (e.g. the shallowest possible quays, the most efficient cranes and freight handling equipment, etc.). As 80 percent of all the seaborne cargo moves by containers now-a-days, the importance of single purpose ports are imperative [5]. With the increase of intermodalism, almost all large ports in the industrialized world handles substantially different traffic types (especially containers dry bulk) separately, and many ports are shifting their break-bulk and neo-bulk cargo handling into containerized operation.

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2.1.2 Multipurpose Port

A multipurpose port is the port where general cargo ships calling may carry a variety of cargoes transported in modern ways: containers, flats, pre-slung cargoes, large units of iron and steel, large units of packaged timber, as well as cars and heavy machinery, together with a basic load of palletized cargo, increasingly palletized [4]. In order to efficiently handle all these cargoes together, the terminal needs to have different types of equipment than the single purpose containerized terminal, and a greater variety of mechanical equipment than the conventional break-bulk terminal.

Multipurpose terminals ensure proper berth utilization for the seasonal fluctuation of specialized types of traffic by providing service to different types of traffic. For small traffic volumes, multipurpose traffic operation capabilities can also help reduce the underutilization due to traffic randomness and the inherent variability in the ship service times, even in instances when traffic is in a steady state [6].

2.2 Simulation Study

With the recent development of personal computer technology, the role of simulation for problem solving is inevitable. And with the development of new simulation software, the number of areas where this approach can be applied is continuously expanding. Military industry, manufacturing companies, distribution systems, service industries, and transportation systems are already using simulation models to improve operations. With this trend, many port authorities are now considering simulation as an optimization tool for their port business.

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A port simulation model is a tool used by port management for determining the effects of changes in throughput and various operational, technological, and investment options on port performance such as waiting time, turnaround time, queue length, revenue, demurrage, and other port-utilization factors [7]. This greatly assists the decision making process at the port. Kozan describes port simulation as the process of designing a model of a real system and, conducting experiments with the model for the purpose of understanding the behavior of seaport systems [8].

The study by Wadhwa determines the usefulness of port simulation models in port management and planning, where a model was developed for a high volume bulk-loading terminal in Australia [7]. The model objective is to demonstrate the application of port simulation models for decision making related to the improvement of port operations. The especial issue that the model considered was the effect of tidal variations in the channel and their effect on cargo and ship delays. The author suggested that, it was directly applicable to ports where larger ships may have to wait until high tide and availability of desired drafts before berthing, during loading and before leaving the port. The use of this model allowed a port to provide better services to its user. It decreased delays for the shippers and insured cargo volume by reducing the number of customers using other port facilities because of their dependence on tides for required draft.

Zador studied the simulation model for the analysis of different types of bulk cargo operation using different scenarios of berth operation [9]. A computer simulation model, which represents the operation of a multi-functional port, was developed to

identify the effect of various operating restrictions to analyze the operation of the system, and to evaluate alternative arrangements. The author suggests that simulation provide a fast and reliable analysis of potential operating problems in a port facility, especially in the design and construction stage.

Goodwin and Ramos studied the behavior of different components of a bulk loading and unloading terminal, and tested the effect of terminal's equipment and cargo stockpiles on operating conditions using a simulation model developed by Techni Multidiscipline Services (TMS) Ltd. [10]. To optimize the transport mode (road, railway, and waterway) and to obtain the best service, the selection of equipment and stockpile configuration required consideration and evaluation of numerous possible solutions. Similarly, loading and unloading, either directly from incoming traffic or from stockpile into vessels of varying size required similar considerations. The authors suggested possible application of their studies to determine the effects on the terminal; considering different usage, arrival patterns, or market forces. These applications were readily carried out by using the basic model to ascertain the likely increase in operating time if, for example, longer unit trains were to be used in later years or, alternatively, if the average parcel or vessel size increased or decreased. This result could be useful to further refine terminal concepts, to take into account the possible changes, or to provide the owner with advance notice to plan future additions or modifications.

Kozan compared the analytical and simulation model to discuss the major factors influencing the transfer efficiency of seaport container terminal [8]. The analysis was based on the container terminal in Brisbane, Australia. The model's

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objective was to utilize queuing techniques to draw inferences regarding strategies for the terminal's service improvement by using analytical expressions. The author considered all the container arrival as batch arrival and developed a multi server queuing system and designated as a stochastic model. The model was compared with another analytical model and a simulation approach. With the comparative analysis of different models the author suggests that analytical model can take the place of simulation model for a certain level of analysis.

Ramani designed and developed an interactive computer simulation model to support the logistics planning of container operations [5]. The author suggested that logistics planning of container operation 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 ships bay and the container storage yards and could improve the operation significantly. The model provides an estimate for port performance indicators such as berth occupancy, ship outputs, and ship turnaround time for various operation strategies in the logistics planning of container operation, and showed that improving logistics planning could reduce ship turnaround time.

Pallova studied the discrete simulation and econometric analysis method to improve the management and investment decision making at a containerized Port in Argentina for better and more cost effective service to its customer [11]. The study tried to understand the logic of terminal operation through a simulation model representing the physical process of container operation. The simulation program generates data including "what if" scenarios which show port performance under

various conditions. The author discussed the economic impact of the significant elements of terminal operation to reduce the turnaround time of vessels and identified the cost-effective change of port operation.

Most of the simulation studies and models that were developed were for single purpose ports (especially the containerized port). As the container operation is very favorable and its business is dominating the shipping world, study of simulation models and optimization for containerized port is a continuous phenomenon. Also there were studies about non-containerized cargo handling. As the need for a multipurpose port is still significant (especially as a regional port), it is important to develop a simulation analysis for multipurpose ports. This study is going to develop a simulation model to optimize and analyze the operation of a multipurpose port in Wilmington, Delaware, known as the Port of Wilmington.

2.3 Analytical Optimization

There are different methods and different levels of optimization developed for different types of port operations. A study by United Nations Conference on Trade and Development (UNCTAD) developed a set of equations to determine the berth operation for break-bulk and containerized cargo handling based on empirical data and mathematical calculation [4]. The operation of bulk cargo ships depends on the gang (a group of people working on a particular ship for loading and unloading) hour, tons per day per gang, percentage of time in the day the ship is in operation during staying at the port and is based on the equation 2.1 and 2.2.

Tons per day per gang = average number of tons per gang-hour $\times$ overall fraction of

time berthed ships worked $\times$ 24   **2.1**

Tons per ship per day = tons per day per gang $\times$ average number of gangs per ship per

shift   **2.2**

The approximate number of berths required for a port depends on the total annual forecast of tonnage and berth day requirement to handle that tonnage, based on equations 2.3 and 2.4.

Berth-day requirement = annual tonnage forecast/tons per ship day   **2.3**

Approximate number of berths required = berth-day requirement / (commission days

per year $\times$ typical berth utilization)   **2.4**

In equation 2.4, typical berth utilization is the maximum acceptable berth utilization that the port should operate with the minimum delays for the ship based on idle berth cost and ship waiting cost. Through these equations, approximate number of berths required could be determined and for different gang capacity and berth assignments, the annual tonnage can be forecasted. Figure 2.1 represents the chart based on the above equations.
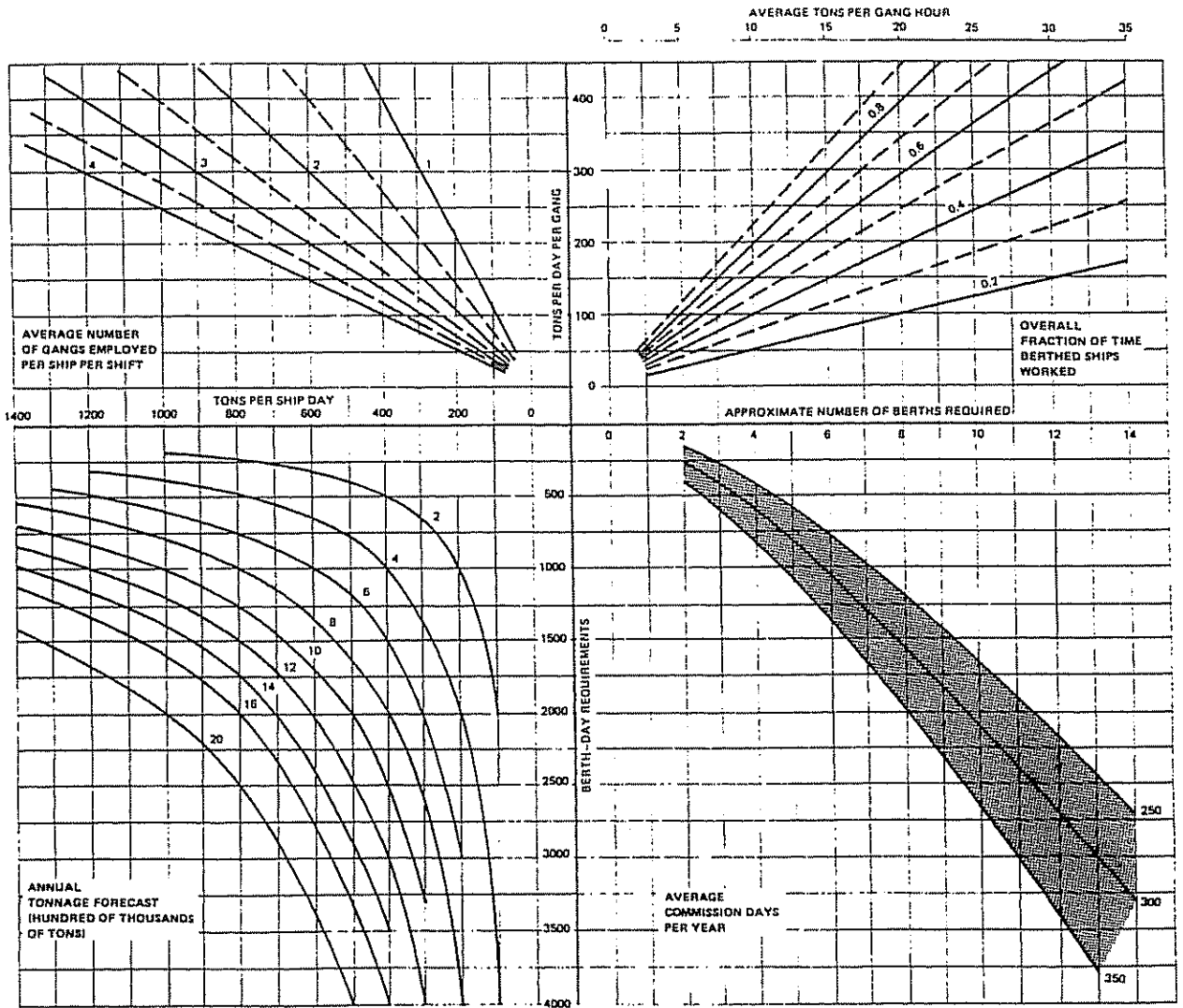
Figure 2.1: Break-bulk cargo terminal planning chart I

Source: [4]

UNCTAD also developed a set of equations to determine the annual ship cost for bulk cargo port based on the berth utilization and the average cost of operating a ship [4]. Equations 2.5, 2.6, 2.7 and 2.8 were developed to determine the berth day requirement per berth, berth utilization, total days at port and the annual ship cost. The equations are:

Berth-day requirement per berth = berth-day requirement / number of berths   **2.5**

Berth utilization = berth-day requirement per berth / commission days per year   **2.6**

Total time at port (days) = 365 × number of berths × berth utilization × waiting time factor   **2.7**

Annual ship cost = total time at port × average daily ship cost (in port)   **2.8**

In equation 2.7, waiting time factor is a function of number of berths and typical allowable berth utilization. Figure 2.2 represents the chart based on the above equation. As for the containerized ship, turnaround time, the total cost of ship, and container storage in hinterland area are the most dominating criteria. The study was done by UNCTAD based on those criteria.

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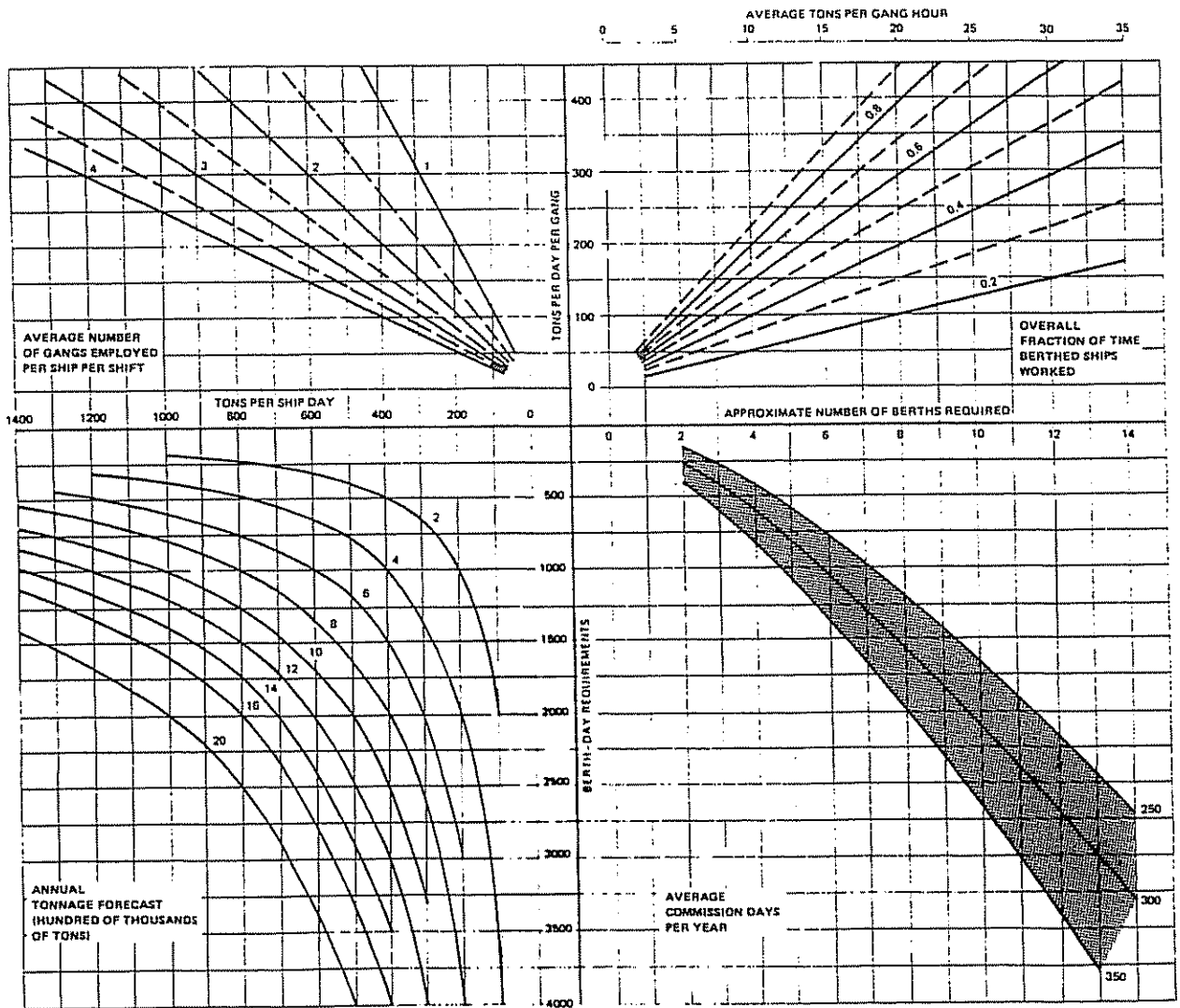
Figure 2.2: Break-bulk cargo terminal planning chart II

Source: [4]

Daganzo studied the peculiar queuing problem that arises on multipurpose port terminals serving liner ship traffic (containerized) which obeys a schedule time of arrival. These primary ships have absolute priority on the use of multipurpose port facilities, and secondary traffic (non-containerized) which arrives at random, can also be served anywhere in the port, and could be routed to the multipurpose berths if it does not delay any primary ship [6]. The author was trying to obtain simple analytical formulas for the multipurpose terminal's productivity, and the resulting change of berth utilization outside the terminal. The study developed an exact numerical solution for arbitrary traffic levels with constant service time and scheduled arrival of liner ships, and for the deterministic and perfectly linear operation of secondary traffic.

Noritake and Kimura studied a method to determine the optimum allocation and size of a seaport based on the regional/national economic point of view, because the amount of general cargo that is transported through the public wharves in a port is not always constant and changed depending on the relative location of the port to other ports in the region [12]. The study analyzed the transporting of general cargo consisting of two kinds of cost; the total inland transportation cost which is a linear function of the amount of cargo transported, and the total port operation cost which is a nonlinear function. The authors suggested the application of separable programming techniques for the optimum allocation and planning of berths based on the cost of cargo handling and transportation in a region.

Based on all the previous studies it can be concluded that for a sound analysis of a port's operation, a combination of simulation and analytical study would give the

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most accurate analysis. For multipurpose ports, this analysis is even more difficult as there is no detailed simulation model for the optimization of port operation due to its very complicated and uncertain nature of operation.

Chapter 3

GENERAL DESCRIPTION AND PREVIOUS STUDIES ABOUT THE PORT OF WILMINGTON

3.1 History of the Port

At the time of first Swedish colonists on the bank of Christina River, brought by Kalmar Nickel in 1638, Fort Christina was built, the first permanent settlement on the Delaware Valley [2]. Later on it was named Wilmington, after Spencer Compton, England's Earl of Wilmington [13]. In the early years of eighteenth century, when the community of Wilmington was very small and insignificant and Philadelphia was already an established commercial center, the town's location at the junction of Brandywine, Christina and Delaware River was recognized as a potential city with a port [2]. In the second half of the eighteenth century, approximately 300,000 bushels of flour per year was exported through Wilmington along the Brandywine River [13]. Due to rapid industrialization, the people in Wilmington voted in 1913 for the construction of a harbor facility, but the demand was justified and the dream was close to reality during the time of World War I. It was widely believed that the efficient movement of men and goods through the Atlantic seaport of the United States would be a deciding factor for the war and new ports were needed in the region, as the existing ports would not be able to handle all the businesses. At the end of war, the Board of Harbor

Commissioners was formed and the Wilmington port facility was initiated with $2.5 million investment by the end of 1920 [2].

The construction of the first unit of the marine terminal in Wilmington (Popularly known as The Port of Wilmington) began in 1921 and was completed in 1923 [2][13]. At the same time, the construction of a new roadway connecting the terminal to major highways throughout the state of Delaware was started by the State Highway Department. The marine terminal was also directly connected to all three railroads (the Pennsylvania, the Baltimore and Ohio, and the Philadelphia and Reading) passing through Wilmington at that time. A total of 105 acres of land was allocated for the port, and in the first year of operation 17000 tons of cargo were handled by the port; also the channel was set to a depth of 25-foot by removing two million cubic yards of river bottom [2] [13]. Early cargoes consisted of lumber, wood pulp, burlap, lead, ilmenite ore, fertilizer and petroleum products. Statistics on the port operation on 1923 are shown in Table 3.1.

From its inception in 1923, the port experienced steady growth in business. Some infrastructure development was done in 1927-28 and from then till World War II the port didn't experience any major development. The total cargo handling was reached around half a million and of that, about 70% were inbound cargo [13]. Though business during World War II was dull; after the end of the war and till late sixties, the port experienced steady increase in business. During that time there was infrastructure development work on the improvements and expansion of port facilities on warehouses, docks, reclamation of lands, equipment and roadways, but there was no long term plan

Table 3.1: Port of Wilmington – Statistics, 1923

Source: [13]

Berthing length	1,210 ft.
Land area	105 acres
Open storage	10 acres
Transit storage	48,000 sq. ft.
Warehouse storage	120,000 sq. ft.
Water depth at port	23 ft.
Channel depth	25 ft.
Annual tonnage	17,000 tons

or study for future business trends and economic impact of the port. From the late sixties through the seventies and into the mid-eighties, a number of studies and research projects were undertaken to evaluate the port operation with physical facility analysis, econometric analysis, and possibility of multimodal transportation with multipurpose operation of the port by implementing containerized cargo handling and operation. All these reports and studies of short- and long-term goals for port management will be discussed in the next section.

3.2 Literature review on the Port

Despite the Port of Wilmington's central location in the East Coast seaport systems, healthy labor-authority relationships, enormous potential to increase business, and good access to inter-state transportation systems, it experienced notable disadvantages in comparison to other regional ports. The port was not able to serve container ships and only since1982 have they started to serve containers with an initial idea of small-scale operation [2]. The idea of operating the Port of Wilmington as a non-containerized and containerized port simultaneously, and sharing the same equipment, resources, and facilities, increases the complexity of operation of the port. The warehouse space and dock capacity was not sufficient and well maintained for large containerized cargoes. In addition, the backup hinterland area was not sufficient for the growing business of the port and its long-term plan for expansion. In consequence, a number of studies were done to assess the potential growth of trades that

could effect the operations of the port and recommend measures that would enable the port to capitalize its resources.

3.2.1 Physical Facility Analysis

One of the major analyses was the impact of the location of the Port of Wilmington to the business in the East Coast, which compared the port with other nearby ports based on the attraction of business by the major ports in the eastern seaport systems [14]. In the analysis, 30 largest cities chosen based on population size and manufacturing activities east of the Mississippi river were used as destination points, where the Port of New York, the Port of Philadelphia, the Port of Wilmington, the Port of Baltimore, and the Port of Norfolk were used as ports of origin. The analysis was based on the population growth and industrial growth in the mid-seventies. Based on all these five ports as points of origin, the study tried to calculate the average mile per ton of cargo to move from any of the above mentioned ports to a destination when the good consumption is based on population. The same kind of analysis was done using the proportion of manufacturing activities and calculating the average miles a ton of cargo (raw materials) has to travel from each of the ports. The output is shown in Tables 3.2 and 3.3.

The table clearly shows that if only one port is used for shipment in all the major East Coast cities, Wilmington rates second, based on consumer-oriented goods. However, the differences between Philadelphia, Wilmington and Baltimore are very small. The same condition occurs for cargo movement based on industry-oriented consumption. Even for inland transportation of autos by trucks and trains, Wilmington

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Table 3.2: Average miles per ton using population and manufacturing activity proportions I.

Source: [14]

Point of Origin	Average miles for each ton based on population projection
Philadelphia	377.1 miles
Wilmington	377.3 miles
Baltimore	377.9 miles
New York	389.3 miles
Norfolk	500.5 miles

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Table 3.3: Average miles per ton using population and manufacturing activity proportions II.

Source: [14]

Point of Origin	Average miles for each ton based on manufacturing projection
Baltimore	412.0 miles
Wilmington	412.9 miles
Philadelphia	413.2 miles
New York	426.4 miles
Norfolk	534.3 miles

has greater prospects compared to other ports. From this analysis, it can be easily concluded that the Port of Wilmington is able to compete for those goods whose shippers wish to use only one port. The advantages of using one port, such as reduced management and inventory costs, are incentives for shippers. However, most of the shippers do business in different ports and, given the extensive use of containers, Wilmington is not able to attract those shippers who ship into many ports. Given more than one point of origin to choose, the inland transportation miles can be minimized without using the facilities of Wilmington. However, with the extensive use of intermodal transportation inside the port and better management and service, Wilmington could attract a good number of shippers to use it as the only port of call in the East [14].

3.2.2 Econometric Analysis and Prediction of Future Growth

General bulk cargo such as fruits, paper, beef, lumber, and containers accounts for one third of the port business and provides 80 percent of the port's revenue [2]. The other two third of the cargoes consists of dry bulk, liquid bulk and Ro-Ro cargoes. Chakravarthi studied the economic impact of the Port of Wilmington in the late eighties and identified the direct impact of sales revenue and local port users on cash flow, job market, and payroll [15]. He also analyzed the indirect effect of the port on the economy of the City of Wilmington. The author implied that the total cash flow impact of the port was $249 M with 1827 jobs and $61 M in payroll and suggested that the port would continue to serve the city as one of the major contributors to the local economy [15]. Other studies in the 70's and 80's predicted containerized and refrigerated cargo

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operation in the port as the two most prospective businesses [16]. Port of Wilmington is now the nation's largest port for refrigerated cargo handling and one of the leading ports of container cargo operation [17].

3.2.3 Multimodal Transportation and Regional Market Development

After the deregulation of railroad and trucking industries in 1978 and ocean shipping industry in 1984 cargo on which each U.S. port had come to rely on was no longer considered as captive cargo for its hinterland. Thus various cost competitive transportation schemes had become possible for delivering cargo to its destination point. This is the first time the ports were thrown into the position of having to work to attract and keep their carrier business by better service, reduced cost of cargo handling and operation, and efficient use of intermodal transportation for the movement of goods. As a result, port marketing has become important in the marine transportation industry.

A study in 1982 by Transportation Consulting Division emphasized better use of rail traffic, and suggested improvements of a port's own rail network, which eventually benefited the container transportation industry. The study also emphasized special uses for the port, such as fruit and the frozen food business, which eventually improved results, as the Port of Wilmington is the largest banana importer in the USA [2].

3.3 Current Port Operation and Structure

The Port of Wilmington has been successful in operations from its beginning early this century, and currently handles more than 4.8 million tons of exported and imported goods each year. The port of Wilmington has an edge over other Delaware

river ports in its strategic location because the ports of Philadelphia and Camden are about 40 miles further upstream, which increases river travelling time by four hours each day, hence making Wilmington more attractive than the ports upstream. With the new administration of Diamond State Port Corporation, and under the supervising authority of Delaware Department of Transportation (DelDOT) the state is much more involved in port operation then ever before. The operation of all the Ports in the mid-Atlantic region are interrelated, and considering the market demand is fixed, the gain in business of one Port is the loss of business for other Ports. With the fresh flow of money from the state, growth of container and refrigerated cargo business has increased in the last couple of years and gradually changes the current port operation and structure.

3.3.1 Port Infrastructure Facilities and Physical Characteristics

The Port of Wilmington is situated on the southern bank of the Christina River, close to the intersection with the Delaware River, and about 63 miles upstream from Cape Henlopen, Delaware and Cape May, New Jersey. It is one of the major ports and closest to the Atlantic Ocean along the Delaware River. There is now over 3500 feet of marginal berthing along the Christina river, including seven deepwater berths, a floating berth (for Roll-on / Roll-off carriers) of around 500 feet for vehicle loading and unloading, and a tanker berth of around 900 feet [2][18].

The port has excellent connections to highways through Interstate I-95, which connects with the major cities of the East Coast and is readily accessible through the I-495 spurt located only about one-half mile from the port's gate. Two and one half miles from the I-95 access is I-295, which connects with the New Jersey Turnpike via the

Delaware Memorial Bridge. Through these interstate routes, more than 25% of the U.S. population can be reached within one-day [19]. Major industrial centers in central and southern Delaware are linked to the interstate system by U.S. Highways 13 and 113 and provide direct connections with the Chesapeake Bay Bridge Tunnel to Norfolk and southern states. Richmond, Virginia is connected to Delaware Memorial Bridge through U.S. Route 301 via Chesapeake Bay Bridge at Annapolis, Maryland and later on joined with I-60 and I-95 at Richmond, thus bypassing Baltimore, Maryland and Washington DC areas with fast access to entire Delaware Valley. There are also good connections between the port and the Pennsylvania Turnpike that leads to markets in the west.

Delaware was served by two railroads, Conrail and CSX Transportation. CSX's main line serves New Castle county with connections to Conrail and the Port of Wilmington. The port connects with Conrail's New Castle cut-off line near the port's gate, which is about one mile from Conrail's main line [18]. Both Conrail and CSX serve north-south routes for Wilmington and have interconnections in Newark to the south and in Chester, Pennsylvania to the north as shown in Figure 3.1 [18]. Conrail is currently in the process of being acquired by CSX Transportation and Norfolk Southern Railway. The line that the port currently has access to will be given over to Norfolk Southern, with a second line, running further to the west, changing to CSX Transportation [20]. The port is hoping to negotiate with CSX in the future to establish a link between their rail line and the port [20]. This access is extremely important to the
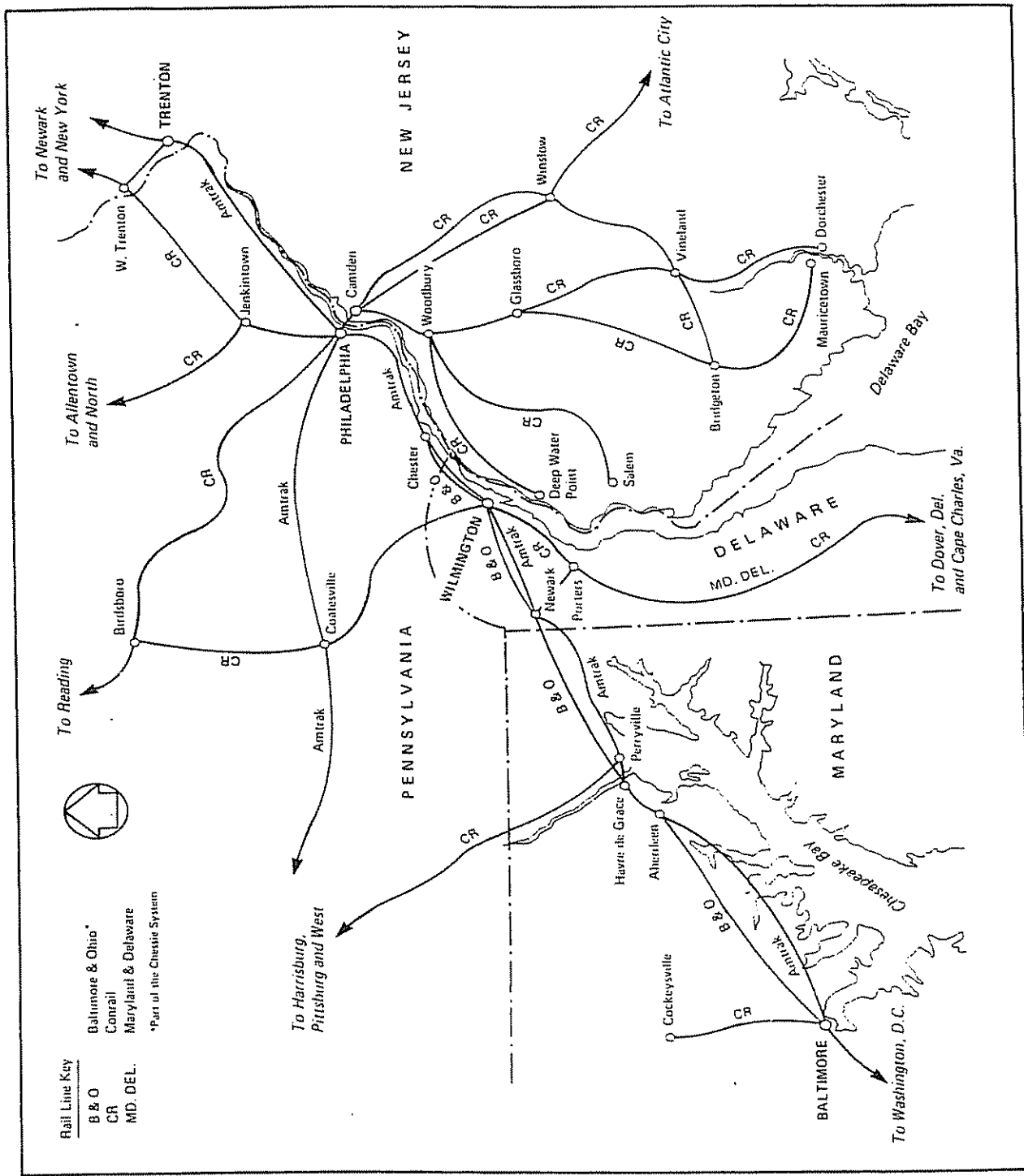
Figure 3.1: Regional rail system

Source: [18]

port's future in that it will promote competition between the two carriers and provide direct access for shippers to and from most major markets east of the Mississippi.

The imports to Wilmington are carried by trucks and rail to different hinterland in the United States. Imported automobiles go as far as Illinois and Wisconsin to the west, North Carolina to the south, and Pennsylvania and New Jersey in the mid-Atlantic region [21]. Imported fruits including bananas and Chilean fruits are used mainly in the mid-Atlantic states and New England. Dry bulk commodities, like iron, steel, petrol coke, limestone, salt, and gypsum generally are taken by customers within a 50 mile radius of the port territory.

A $ 1.7 million port rail rehabilitation and construction project, which involved the complete rehabilitation of the existing rail lines throughout the port, has completed recently [20]. The rehabilitation includes the installation of rubberized crossings at all the intersections, and the construction of 2,500 additional feet of new rail sidings, turnouts and storage track within the terminal for the improvement of rail access, including access to all the warehouses and automobile terminals to facilitate the movements of cargoes. The construction of the new sidings provided the auto terminal with three dedicated sidings for 26 bi-level or tri-level rail cars, and has enhanced the port's ability to transport autos through the Port of Wilmington [2].

3.3.2 Containerized Cargo Operation

A container is a large enclosed, reusable, watertight package box similar to a highway trailer and may contain a variety of commodities under a single billing. At the dock, it can be loaded onto freight trains or trucks for quick, easy, and cost effective

transportation to its final destination. Though all over the world, especially North America and Europe shippers started the revolutionary use of large containers for cargo handling in 60's and 70's, the Port of Wilmington couldn't start that before 1982 [2]. From the beginning of operation container handling was very prospectus, though it was planned as a subsidiary for bulk cargo operation [22]. As Dole and Chiquita, the port's two largest fruit shippers and container users, expanded their shipping services and increased imports of bananas and tropical fruit from Central America, the growth of containerized cargo continued to be increased. The total throughput of containers in 1998 was 199,000 TEU's (Twenty Foot Equivalent Units), with the containerized cargo tonnage of 1.364 M tons [17].

3.3.3 Bulk and Break-bulk Cargo Operation

Bulk cargoes mainly consist of break-bulk, dry bulk, RoRo, and liquid bulk cargoes. Major portions of break-bulk cargoes are refrigerated cargo, tropical fruits, steel, and forest products. RoRo cargoes mainly are the export and import autos shipped through floating berth, and the Port of Wilmington handled 113,366 units in 1998 [17]. The main dry bulk cargo in the port is gypsum, where the liquid bulk cargo is the petroleum product transferred through tanker berth. In the Port of Wilmington a significant amount of cargoes are dry bulk cargoes. In the fiscal year 1997 the shipment of dry bulk cargo was 1.06 million and was reduced 5% from FY 96 to FY 97 and around 31% from FY 97 to FY 98 [23]. The arrival of dry bulk cargo is not batch arrival, and requirements with respect to location, type of infrastructure, layout equipment, storage facilities, and auxiliary services are basically different than those in

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a typical general cargo port. This makes it very difficult to model the simulation program for the process of bulk cargo handling. Moreover, handling of dry bulk cargo is not always economically cost effective and environmentally hygienic for a multipurpose port where different types of cargo are operated through the same berth group. Generally dry bulk cargo handled by special types of port with special types of equipment.

3.4 Port Policy and Administration

There are 183 commercial deep draft ports located in along the Atlantic, Gulf, Pacific and Great Lakes coasts of U.S. Of these, 105 are public seaports, run by state, local, federal, or independent administration [18]. Unlike other North American countries, like Canada, U.S. has no national port authority. The system through which individuals serve on the governing bodies of the 105 U.S. port authorities varies widely. Some are govern by city, some by county, and some are directly under control and supervision of the state. From the beginning, the Port of Wilmington was owned and operated by the City of Wilmington under management of the city's department of commerce. The Main purpose of the port was to serve the business and market demand of the greater Wilmington city and to generate jobs for the city. At the time, financing was always a problem, and any capital investment has to be approved through political process in the city's capital budgeting system. As a result, port management was restricted to spending money for maintaining existing port facilities and responding to new opportunities because funding requests must compete against other city projects.

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Even revenue from the port was used for other city projects, instead of its own development. The port didn't have any independent voice about its long-term plan and highly competitive market of ship business; rather the director of commerce was a political post and was changing with every election. Due to the clarion call of the port users, and after long time study, the port was handed to the State of Delaware in 1995 and is run by Diamond State Port Corporation which is a subsidiary of the State of Delaware [2]. The port also was granted 25 million for infrastructure development to compete in the 21st Century. This fund is the largest fund granted in the last 75 years. This process of policy and administrative changes will enable the port to compete for bold and creative growth, which carries real risk but potentially large rewards as the Port of Wilmington evolves as a regional port with a potential market not only in Delaware, but in most part of U.S. East Coast region.

Chapter 4

SIMULATION

4.1 Introduction

Simulation modeling uses mathematical and logical techniques to describe the behavior of a system over time. The execution of present day simulation is based generally on the sampling idea of the Monte Carlo simulation method by using random sampling to estimate the output of an experiment [24]. Simulation is also considered as a decision making tool, as it allows the decision maker to change detailed representations of systems to determine how the system will respond to changes in its structure, environment, or underlying assumptions. Simulating a real system allows one to answer "what if" scenarios by testing the effects of proposed modifications before any changes in the actual system has been made.

A port simulation model provides a conceptual framework for integrating the general port structure and operations, information flows, and decision making function in the port. It subjects the port operations (loading, unloading, etc.) to the appropriate rules and constraints expected to apply in actual practice. A port simulation model should be able to include key operational statistics, as well as statistics on cargo flows, utilization of berths and equipment, and various productivity indices. The model should also ensure the validity of statistical output and provide confidence intervals [7].

Any simulation model tries to analyze systems as they operate over time. There are two basic ways to do so, depending on their nature. Discrete simulation models analyze systems only at given instance when changes in the system occur. A typical example of a discrete simulation model is the waiting line of a server, where average waiting time or length of the waiting line is of main interest. The simulation will only activate at discrete points when a customer enters or leaves the system. On the other hand, continuous simulation models monitor the system continuously. This type of simulation is employed to model systems where something is happening at every point in time, like the study of world population dynamics or flow of water through the pipeline. Continuous simulation models usually are represented in terms of difference-differential equations that describe the interactions among different elements of the system [24].

The final goal of a simulation model is to obtain a realistic picture of the entities, resources, attributes, and servers of the system. The information and the outputs can then be used to determine and analyze the performance and efficiency of the system. The accuracy of the model depends on the sufficient amount of input data and, the accuracy of the data is the prime condition to develop a representative simulation model for a real-life situation. Any types of changes on the model based on "what if" scenarios can then be executed and the decision-maker can take the decision on model optimization with a high level of confidence.

Simulation models can be developed in any general programming languages such as PASCAL, FORTRAN, C/C++ etc. But for the development of complex

simulation model the use of simulation language has distinct advantages over conventional programming languages. The greater development of computer technology leads to the widespread use of simulation as an analysis tool and has lead to the development of a number of specialized simulation languages. Here ProModel is used to develop the simulation model of the multipurpose port operation

4.2 ProModel Simulation Program

ProModel is a powerful, easy-to-use simulation tool, developed specifically for engineers and production managers to help improve the design and operation of manufacturing systems [25]. This animated simulation software is user friendly and the simulation model for the Port of Wilmington was created through this software. ProModel has the advantage of extensive graphic user interfaces with customized animation graphics, and provides easy transfer of data between the model and other window features like EXCEL to greatly speed up the modeling process. The coding of data into the model is relatively faster and easier in ProModel than conventional programming languages and helps the programmer to concentrate more on accurate system modeling. Once the model is done, any change in the model parameter is easy to operate and represents output in a very well organized manner. ProModel displays an animated representation of the system, which greatly helps understand the operation of the model and gathers statistics on performance measures that are later automatically tabulated and graphed.

4.2.1 System Components

The logical process of most simulation models can be represented in a block diagram. The requirements for each step vary from simulation to simulation but the basic procedure is essentially the same. Figure 4.1 shows the stepwise process for the development of simulation model for the Port of Wilmington. Each step need not be completed in its entirety before moving on to the next step. In this process, the simulation is studied in an iterative approach where activities are refined and sometimes redefined with each iteration. The primary value of adopting this systematic procedure is to ensure that the project is conducted in an organized, timely fashion with minimal waste of time and resources and maximum effectiveness in achieving the objective(s) [26]. A discrete simulation model was used in this project to model the multipurpose port because the port has very complicated interdependence queue and the server operation can be well reflected in discrete simulation modeling. Various physical facilities and resources at the port are considered as servers; while ships, trucks, trains, containers, bulk cargoes, and ro-ro cargoes are considered as the customer being served. This modeling approach would allow a dependable representation of the multipurpose port in operation and help the decision-maker make decisions based on the different parameters of model output. ProModel works based on the discrete simulation model by using different probability distributions as assigned by the user and every steps of the model processing is controlled by the user. The user has to define the distribution of time and the types of interaction in the different stages of processing based on the data available from the real life operation.

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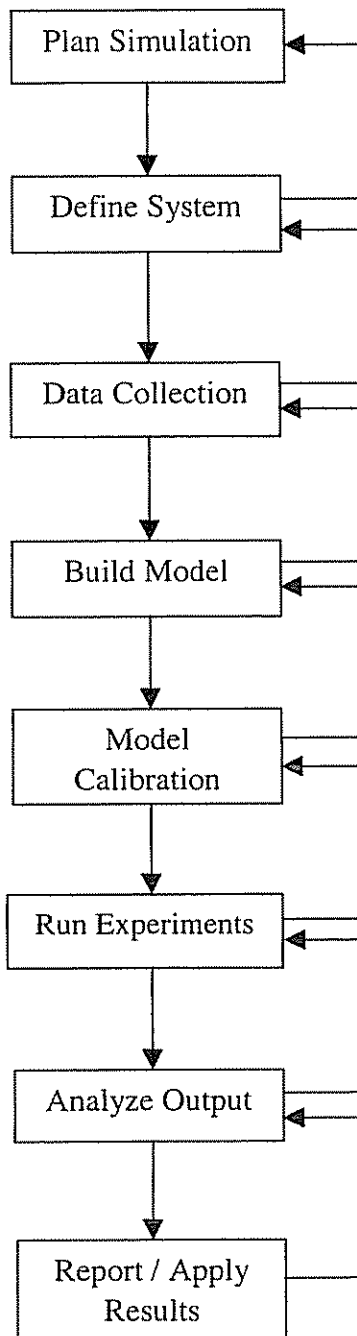
Figure 4.1: System Components of Simulation Study

4.2.2 Data Coding and Handling

In ProModel the production system is viewed as an arrangement of processing locations, such as machines or workstations through which entities such as parts are processed. A system may also include supporting resources such as operators and material handling equipment to aid in the processing and movement of entities. The first step of data coding is the location window where all the physical locations have to be identified and marked with the appropriate graphics. Figure 4.2 shows the location window for the simulation program developed in this thesis. The next step is the entity identification and the resource definition for the model. The heart of the model is the processing of all the entities through the locations based on the appropriate operational logic, which represents the real life operation of the modeled Port system. Coding of processing in the proper way will ensure the accuracy of the model. Figure 4.3 shows the processing window of the modeled program.

4.2.3 Output of the Program

The ProModel output program is an entirely stand-alone program that can be run from within ProModel from the output menu or directly from the Windows program manager. ProModel output program can handle periodic general reports, average periodic time series plots, extended entity statistics, and observation based variable statistics with multiple analysis. An output data manager simplifies the process of generating and analyzing the output data as well as increase performance on the generation and analysis of the output.

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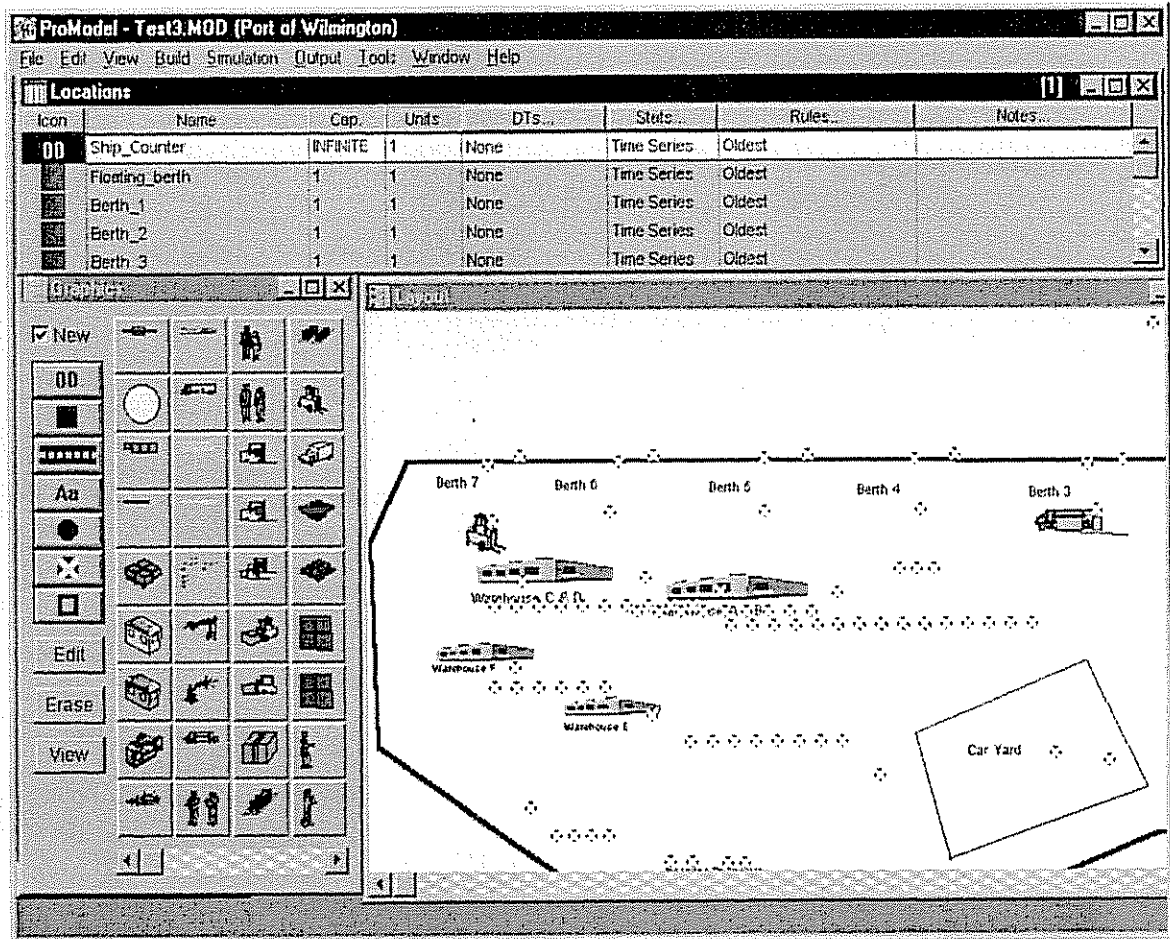
Figure 4.2: Location Window of the Simulation Model
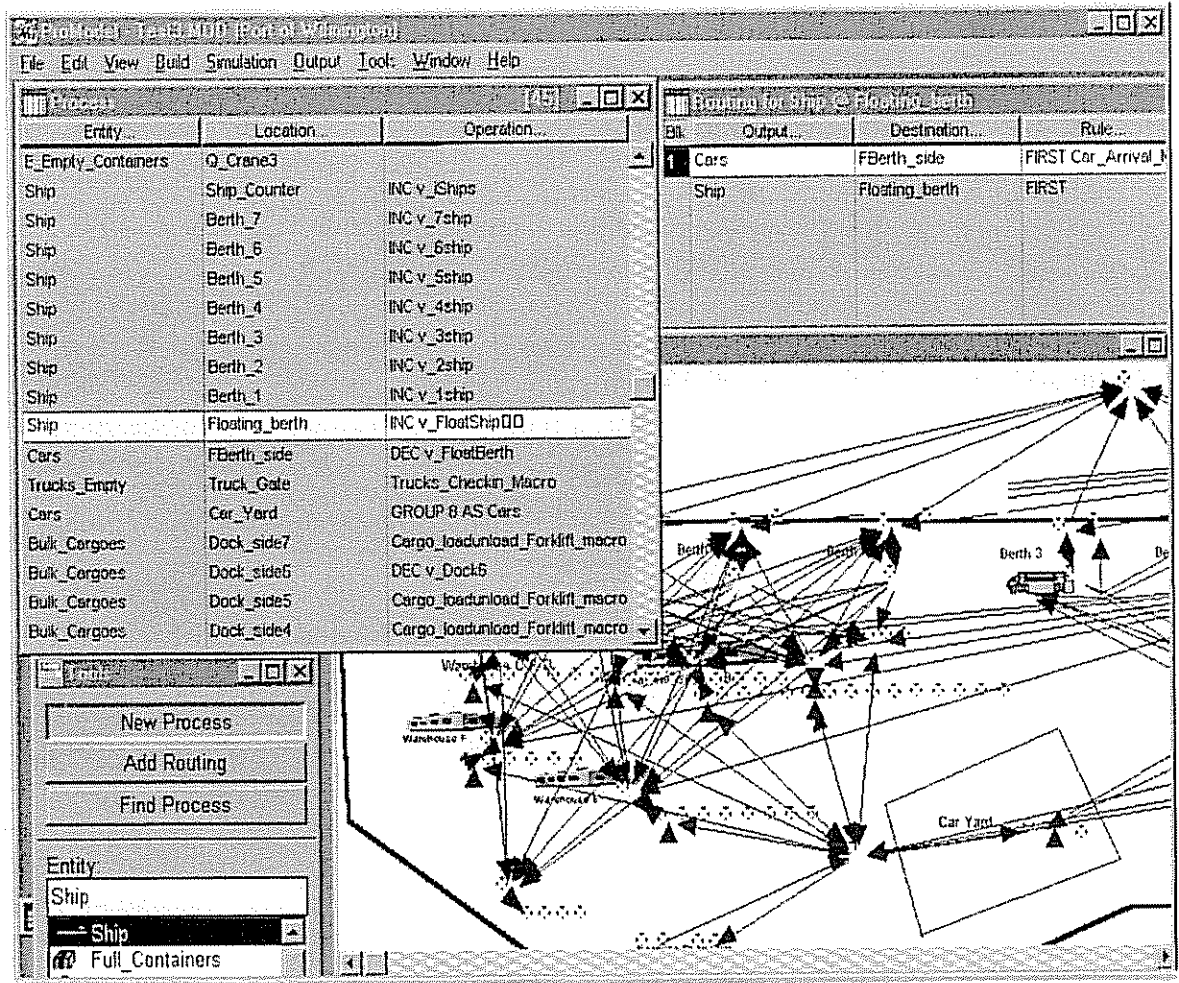
Figure 4.3: Processing Window of the Simulation Model

4.2.4 Software Component

The software component of ProModel includes the operating system, system utilities, and the simulation application software itself. The window based operating system provides linkage between various software applications and system utilities like graphic editor, shift editor, stat:fit, sim-runner, output window and the simulation software itself. Graphic editor creates different type of graphics that would be used in the simulation model. Sim-runner provides the runtime and warm up time for the simulation model, whereas stat:fit provides the statistical fit for the probability distribution, and shift editor provides the working shift assignment for different entities and resources inside the model. It is the simulation software itself that is the most important element of the software component. The simulation software allows for the creation, manipulation, animated display, and analysis of the program. The user defines how the particular service system operates, then ProModel displays a graphical representation of the system described by the user, and collects statistics on specified performance measures.

4.3 Hardware Component

The hardware component of the ProModel consists of the physical computer system that is used by the simulation software. The two choices for the hardware component type are workstation and microcomputer (Personal computer). Due to the rapid development of microcomputers, PC's are more popular for the use of the software program than the workstations. Even though the software can be loaded in as

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many computers as needed, only the computer which has the hardware key provide by the software developer can be used to develop the simulation program. Due to the complexity and graphic interface of the simulation model the program performs better with minimum of 32 MB Ram and higher Pentium computers in Windows 95, 98 and NT environment.

Chapter 5

DEVELOPMENT OF SIMULATION PROGRAM FOR THE PORT OF

WILMINGTON

5.1 Introduction

This chapter presents the building and evaluation of a simulation model for the

physical movement of bulk cargoes, containers, and autos in the Port of Wilmington,

Delaware. The simulation model presents the interrelated events and elements of the

port operation. The structure of the model used to develop the simulated port operation

starts with the arrival of ships in the port. A ship on arrival on Delaware River joins a

queue. The first-come first served discipline is normally employed to grant permission

to a berth in Christina River through the use of tugboat. The assignment of berths

depends on the type of cargo, availability of berths and dockside equipment, and the

availability of pilot, tugs, etc. Once all conditions are fulfilled, the ship makes its way

to the terminal with a pilot on board. There is a finite and relatively constant time in

this endeavor.

On arrival at a berth, the ship anchors and waits for permission to unload and for

the commencement for unloading. The unloading is continued until completed and the

ship is ready to leave unless the same ship carries some exporting cargoes. The loading

and unloading time of cargoes is a function of loading equipment, backup facilities in

the warehouses, container yards, and the operation of cargoes from the warehouse to the dockside and vice versa. After the completion of unloading and loading (if there is any) maneuvers, a ship may have to wait before sailing out for documentation, any supply for ship crew, waiting for tugs and pilot. The flowchart of the model and the assumptions used to develop the model will be discussed in the next section.

5.2 Model Formulation

The model is simplified to achieve the study objectives, and reasonable assumptions were made whenever necessary with the most important factors that contribute to terminal services considered in the process. For the multipurpose port the five main types of cargoes are containers, general bulk cargoes, Ro-Ro cargoes, liquid bulk cargoes, and dry bulk cargoes, and the Port of Wilmington handles all these types. Liquid bulk cargo is transferred directly through pipeline to the oil reservoir and generally doesn't effect the overall port operation. The operation of different types of cargo by using the same port facility is complex and the three main types of cargoes; containers, bulk-cargoes and RoRo cargoes are considered in this research for modeling the port operation. For the modeling of container operations in the port, the arrival of containers was considered as batch arrivals and the ship was considered as a batch of containers. Batch arrival is the arrival of a group of homogenous entities using the same resources at the same time. On the contrary, the arrival of ships is independent and they arrive as a single entity. Kozan (1997) did a detailed study about the arrival of containers at a seaport and suggests that batch arrival process represent the arrival of

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cargo for uniform cargo operations [8]. As the size of the containers are uniform (mostly 40 ft and 20 ft containers) this assumption would fit the model quite accurately. On the other hand, the size and shape of bulk cargoes are not uniform. In the Port of Wilmington major portions of bulk cargoes are frozen meats, bananas and other tropical fruits, packaged forest, iron and steel products. The majority of cargoes (like fruits and frozen meats) are transferred as palletized cargoes. For the simulation model all the bulk cargoes are considered as palletized cargoes and considered as batch arrivals where the ship would be considered as a batch of pallets. As most of the RoRo cargoes are vehicles, the arrival or departure of RoRo ships are considered as a batch of vehicles. The arrival rate of batches of containers, pallets, and vehicles is the same as the arrival rate of the ships. The service time is considered as the time per pallets, containers, or vehicles.

The simulation model of the port represents all characteristics of port operation including ships, full and empty trucks, berths, dockside areas, container yard, warehouses, transit sheds, rail yard, auto yard, RoRo berths, crane, forklifts, top loaders, and yard hustlers in statistical-mathematical terms. Probability distribution and random distribution with deterministic process were used to keep the simulation model as close as to the real operations based on the data collected from port visit, and discussed later in this chapter. In the simulation model two fundamental concepts of probability application were used. The first concept is that two events are mutually exclusive, which means that if one event occurs the other cannot occur, and the second concept is that the occurrence of one event does not have influence on the occurrence of other

event [11][27]. These mean that any two events are independent in operation and don't have to wait for the completion of the other event.

The process logic for each entity and each element of import and export are shown in the port flow diagram in figures 5.1 and 5.2. Figure 5.1 shows the flowchart of import and figure 5.2 is for the flowchart of export in the Port of Wilmington. As discussed before the flowchart doesn't include the operation of liquid bulk and dry bulk cargoes. In the model, all containerized cargoes were considered to be kept in container yard and no special routing were made for frozen containers as they are always kept in the container yard inside the Port of Wilmington.

5.3 Simulation Inputs

The data for the simulation study was collected from a variety of sources. The Port of Wilmington was visited several times to get the general idea of the port operation, and interviews with the port operating personnel also gave good ideas about the operation of the port. Since the volume and complexity of data for multipurpose port operations is huge and sometimes impossible to get exact data, reasonable assumptions were made whenever necessary. The data input system for the model is very user friendly, and whenever necessary, any input variables could be changed by the user of the program. Literature sources provided insight into the dynamics of the shipping industry, especially the operation of containerized cargoes.

All the service and operation times, including arrival rates, were represented by the appropriate probability distributions as discussed in the following sections. The

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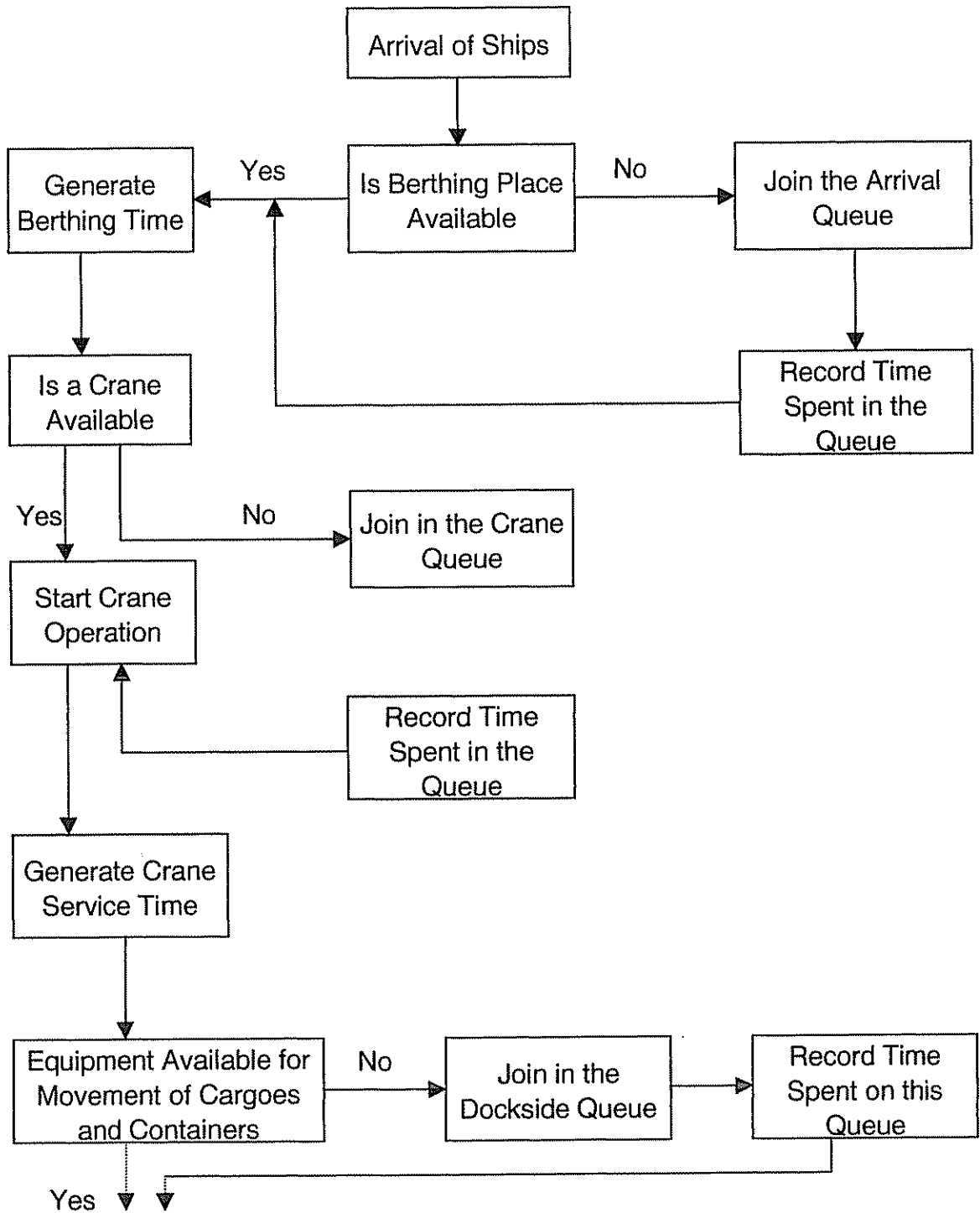
Figure 5.1: Flowchart of Import in the Port of Wilmington

Figure 5.1: Continued

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                                              ┌─────────────────┐
                                              │ Join in the Waiting │
                                              │      Queue       │
                                              └─────────────────┘
                                                       │
                                                       ▼
┌─────────────────────┐              ┌─────────────────┐
│  Start Equipment     │◄─────────────│   Record Time    │
│ Operation and Generate│              │  Spent in the    │
│   Service Time       │              │      Queue       │
└─────────────────────┘              └─────────────────┘
           │
           ▼
┌─────────────────────┐
│   Service Time for   │
│ Trucks and Trains in │
│   the Outer Gate     │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│ Departure of Trucks  │
│     and Trains       │
└─────────────────────┘
```

Figure 5.1: Continued

```
┌────────────────────────────┐
│ Arrival of Trucks and Trains│
└────────────────────────────┘
              │
              ▼
┌────────────────────────────┐
│   Service Time for Trucks   │
│ and Trains in the Outgate   │
└────────────────────────────┘
              │
              ▼
┌────────────────────────────┐         No        ┌──────────────────────────┐
│  Equipment available for the├──────────────────▶│  Join the Waiting Queue  │
│    Movement of Cargoes      │                   └──────────────────────────┘
└────────────────────────────┘
            Yes │
              ▼
┌────────────────────────────┐
│    Bulk Cargoes move to     │◀──────────────────┘
│  Warehouse, Containers      │
│    and Cars to Yards        │
└────────────────────────────┘
              │
              ▼
┌────────────────────────────┐        No         ┌──────────────────────────┐
│    Is there any ship in the │──────────────────▶│ Wait for the availability│
│  Dockside waiting to load   │                   │       of Equipment       │
│          Cargo              │                   └──────────────────────────┘
└────────────────────────────┘
            Yes │
              ▼
┌────────────────────────────┐
│   Equipment Available for   │◀──────────────────┘
│          Loading            │
└────────────────────────────┘
              │
              ▼
┌────────────────────────────┐
│  Load the cargoes onto the  │
│           Ship              │
└────────────────────────────┘
```

Figure 5.2: Flowchart of Export in the Port of Wilmington

probability distribution would help to express behavior of the system for long-term basis and expresses the behavior of the server for whom data couldn't be gathered. All the data are divided in the following sections: activities, resources, locations, entities and variables.

5.3.1 Locations and Activities

The terminal of Port of Wilmington has one marginal wharf having berthing capacity of 4530 feet. Out of that, 3060 feet are employed for seven fixed berths, 510 for floating berth and 960 feet for tanker berth. Physical layout of the terminal is shown in Figure 5.3. Ships arrive at the marginal wharf in the Christina River from the Delaware River through the use of tugboats. Berth one, two, and three are closer to the Delaware River where berth four, five, six, and seven are the furthest. On average, the docking time is normally distributed from half an hour to one hour.

There are six warehouses for bulk cargoes, and out of them warehouses A, B, C, D, and E are temperature controlled with the total storage capacity of 700,000 square feet. Warehouses A, B, and C, are beside the marginal wharf and close to berths 5, 6 and 7. Newly built warehouses E, D and F are inside the port. Cargoes are stacked in the warehouse as pallets and the capacity of the warehouses are measured as the number of pallets storage facility. The storing capacity of all the warehouses are from four to six thousand units of palletized cargo, and the capacity of warehouse A is 3704 pallets, warehouse C is 6791 pallets, warehouse D is 4457 pallets, and warehouse F is 3922 pallets, and all is in single tire.
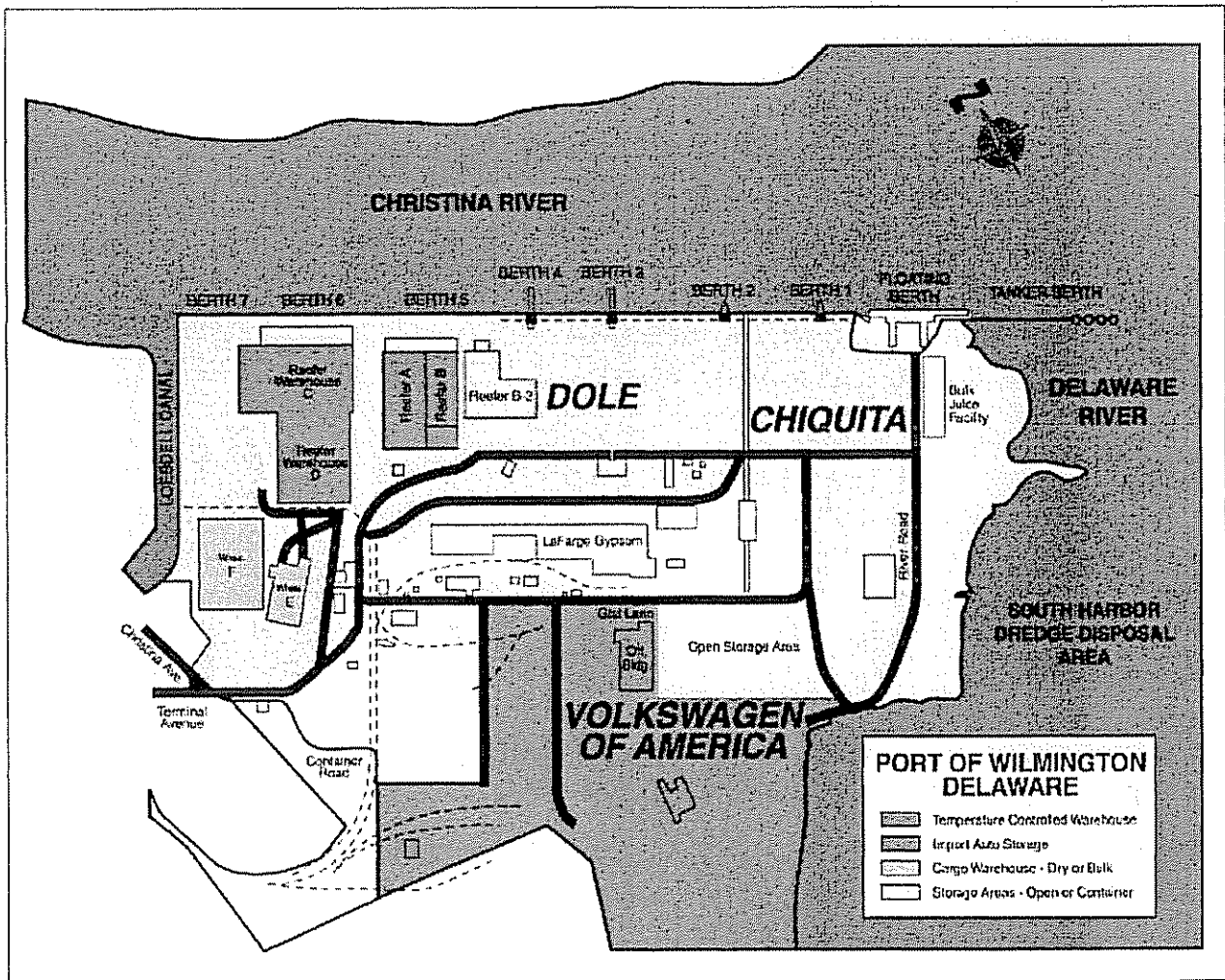
Figure 5.3: Layout of the Port of Wilmington

Source: [17]

The shape and the size of the container yard influences the efficiency of container operation. Dole and Chiquita Company mainly operate the containerized cargo in the Port of Wilmington and the container operation is not as systematic as the solely containerized ports. Temperature controlled containers for fruits and meats, and empty containers are handled inside the container yard. Separate data for the percentage of refrigerated containers are not available and the operation of the containers in the port are distinguished as full and empty containers, and the usual size is 40 FEU (Forty-Feet Equivalent Unit). The port doesn't own any containers and all the containers (full or empty) handled in the port are without chassis. The stack of the containers is usually one but may be more for the high demand and scarcity of spaces. Private users handle the operation of the container yard in the port and the exact number of available ground slots for the container yard was not available. The port is in the process of acquiring more space for container operation.

The auto business in the port is operated by Volkswagen and Audi for import autos and by Ford and GM for export autos. The loading and unloading of vehicles are by roll-off and roll-on and no mechanical equipment is needed to move them. Usually trucks are used for the carrying of vehicles outside the port, and rail cars are also used for the transport of autos. No exact information was available for the percentage of autos handled by rail car of by trucks.

Customs are also an important part of any types of port operation that handles export and import of cargoes. As a significant portion of port's business is imported fruits and frozen meats, US Department of Agriculture (USDA) checks imported

cargoes stored in the warehouses. The simulation model includes this service time in the model. Due to the long trusted relationship between the port authority and the clients, only a very few containers are checked for customs.

The outside gates are an important part of the flow of operations inside the port as they control the flow of empty and full trucks. Four gates are used in the port, and for the simplicity of the model, two were used for in-gate and the other two for out-gate. The incoming trucks have to show their papers to enter the port and the outgoing trucks have to show their shipping documents. The time required for these checks depends on the problems encountered. Most of the clients of the ports are long time users, and this checking time is very insignificant. Even though any long-term data was not available, the service time could be expressed as exponentially distributed with mean of around one minute.

Berthing facilities provide adequate space for loading and unloading, and using mechanical equipment for maneuvering cargoes. Actually berthing facilities are the most important part of port operations, and an indirect measure of port productivity because the handling of cargo increases with the increase of the number of berths. Berths two and three are for the operation of containerized cargo, as they can only be served by the containerized crane. Berth one is mainly used for dry bulk cargo operation. Also berths one, two, and three are deep draft berths, whereas the draft decreases gradually from berth four to seven. The specialized tanker berth and the RoRo berth are the closest to the Delaware River.

5.3.2 Resources

Resources are the mechanical equipment that help move cargo quickly and efficiently inside the port. The moving equipment for bulk cargoes and containers are not the same and their operational logic is also different. Resources load and unload the palletized cargoes and containers, then transport the freight through the yard to warehouses, dockyards, container yards, rail-sliding, and ultimately to the ships. The resources used in the Port of Wilmington are cranes, forklifts, top loaders, and yard hustlers. Conveyer belts are also used for the transportation of dry cargoes (Gypsum plant) in the port, but dry bulk cargo operation is not considered in the simulation model. For each type of resources, the number of units it operates and their service time are determined through operation of the system and changed to fit the various resource combinations inside the port.

Among all resources, cranes are the most vital and expensive resources used for the loading and unloading of cargoes from the ship. Cranes are usually used for quick and efficient handling of containers. The port has two cranes in effective operating condition and out of them only one (C - 4) is used for container operation and may also be used for the bulk cargo operation. C-1 crane can only be operated in berth one, two, and three for dry bulk and break bulk cargo operation. The containerized crane can approximately move 22 – 25 containers per hour. As the port is operating with only one containerized crane, any breakdown would have a drastic effect on container operation. The port is in the process of buying another containerized crane this year. On average, 200 – 400 ton bulk cargoes can be moved through the cranes per hour.

Forklifts are mainly used in the terminal for the movement of bulk cargoes. The port has 57 forklifts, but in the winter season when the fruit business is running their peak, the port rented more forklifts from the local stevedoring companies [23]. Forklifts are quick and efficient mechanical equipment for the movement of cargoes. They also move cargoes from the warehouse to the trucks and rail sliding. Heavy-duty forklifts are used for the movements of containers in the yard, and can stack containers inside the yard. The service time for forklifts to collect cargoes is modeled as being normally distributed with a mean of one minute and a standard deviation of half minute for bulk cargo operation. The running speed of forklifts is also varies from 10 to 15 miles per hour, depending on the area and road type. The maintenance cost of forklifts is cheaper than other mechanical equipment, and has more flexibility to operate cargoes.

On the other hand top loaders are used for the stacking of containers in the yard and load/unload of containers on the truck. Top loaders are used for the high stacking of containers but are relatively slower than the forklifts. Currently, four top loaders are used in the port for maneuvering containers. The service time for top loaders is higher than the forklifts.

The equipment that moves containers between the dockside and the container yards are called yard hustlers. Because the container handling in the port is operated by the private user, exact information was not available for the number of yard hustlers. On average, twenty yard hustlers are used by Dole and Chiquita fruit company for the movement of their containers. However, it was understood that the port user has enough yard hustlers to smoothly operate the container movement.

5.3.3 Entities

One of the main entities in the model is the truck. Basic truck parameters include empty and full trucks, arrival schedule of trucks, and time spent in the terminal processing. Mainly two types of trucks enter the terminal - full trucks and empty trucks. Full trucks contain full containers, empty containers, and export vehicles or bulk cargoes. On the other hand, empty trucks load bulk cargoes, empty or full containers, and import vehicles. One hundred fifty to four hundred trucks visit the port daily, empty or full.

The Port usually handles around 400 ships per year. The peak time for ship operation is the winter fruit season, thus the average number of ships is higher at that time. Figure 5.4 shows the monthly call of ships in the Port of Wilmington for FY 96 – 97 [23]. The number of ship arrives in the terminal was considered as 7 ships per week with the Poisson distribution of arrival rate. The number of full containers arriving at the port through one ship was considered normally distributed with mean from 600 to 750 and standard deviation of 50. Considering 5% - 7% empty containers is normally distributed with mean 50 and standard deviation of 10. The number of full containers leaving the port is also normally distributed with mean 20 and standard deviation 5. The amount of cargo that is transferred by train is not significant in the Port of Wilmington. Besides, no information was obtained for operation by train to carry cargo to and from the port and the percentage of cargo handled by train daily. The model considered one train serving the port daily for carrying cargo.

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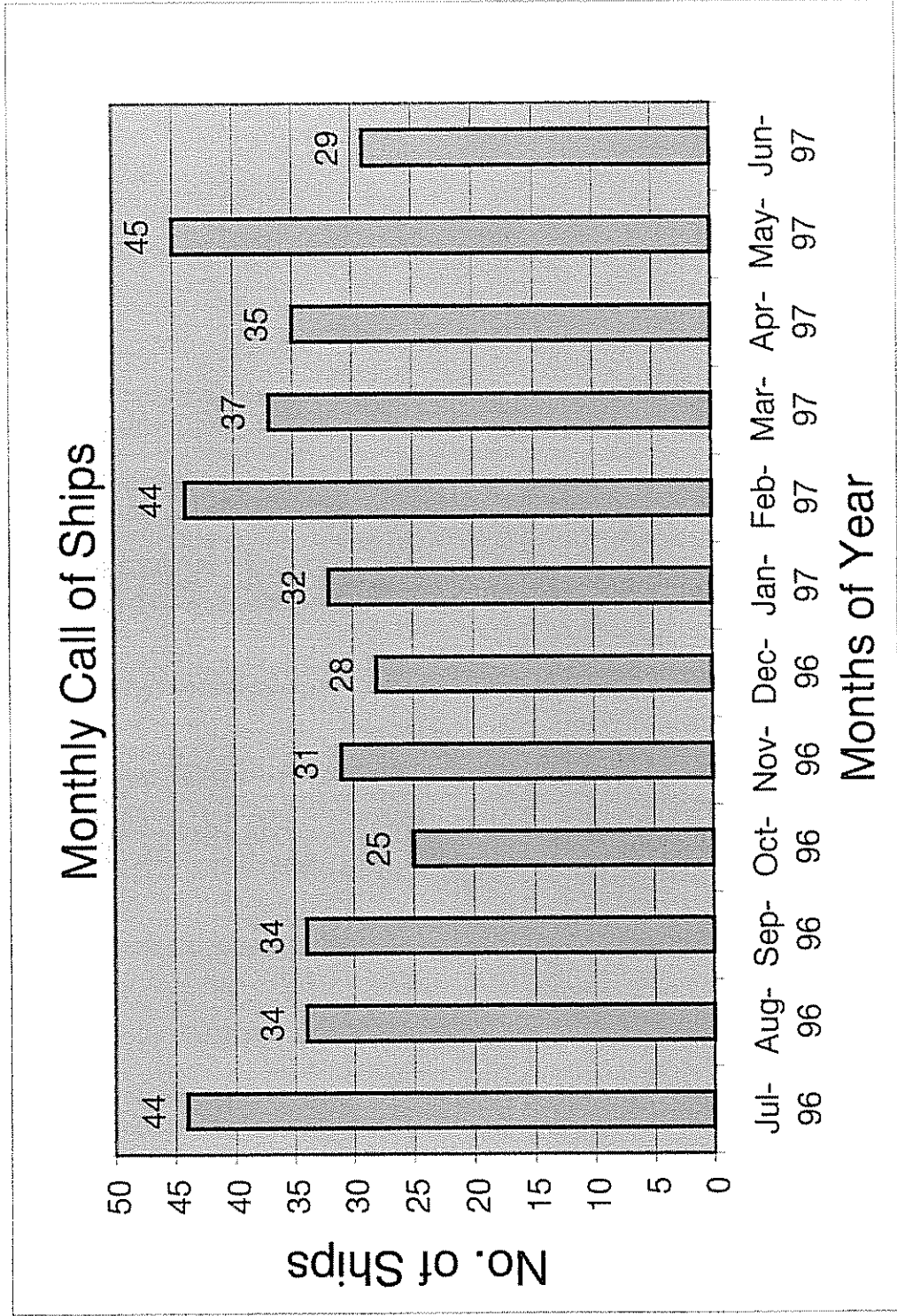
Figure 5.4: Ship and Barge Calls for the Port of Wilmington

Source: [23]

5.4 Mechanism of Simulation

The total time associated with the operation of a ship through the system of the port can be expressed in the following steps. The arrival of ships in the port system, the unloading of cargoes from the ships, transferring of cargoes from the dockside to the storage area, dispatching of cargoes through trucks and trains from the storage area to the markets, arrival of cargoes through trucks and trains to storage area, loading of ships, and leaving of ships from the port system. The simulation process may be described for the ship as it goes through the system.

5.4.1 Arrivals

The basic units of arrival to the system are ships in the berths, trains in the rail yard, and empty and full-trucks in the truck gate. Arrivals of containers and cargoes obey batch arrivals, and a batch arrival queuing model is used to analyze the classification of delays. The situation is referred to as a batch-arrival multi server queuing system and designed as a stochastic model [8]. The queuing system modeled for the berth group is based on assumptions of random arrivals with Erlang 2 service distribution [4]. The notation is $M/E_2/n$ where M is for Markovian or random arrivals, E2 for Erlang 2 service time and n for number of servers. The distribution of intervals between arrivals is best described by Erlang 2 and the ship arrivals are random and independent, and the distribution dwell time of each ship is Erlangian.

When an arrival occurs, the time interval for the next arrival is generated. This inter-arrival time for ships, trucks, and trains are assumed to follow exponential distribution. Kozan analyzed the distribution of inter arrival time and proved it by using

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the Chi- Square goodness of fit test that the inter arrival time are consistent and follows the exponential distribution [8]. Since the number of containers and bulk cargoes in every shipment is not constant, it is very important to find the proper distribution for them. If the dock is available for ship berthing, and a pilot and tugboat are available, and the channel is free, the arriving ship is given an immediate clearance and proceeds without delay. If the channel is occupied by some other incoming or outgoing ship, the ship experiences delay outside the channel in the Delaware River. The diurnal profile of ship arrival is shown in Figure 5.4. As the operation of port cycle describes the number of ships served per week, the inter-arrival time was determined as the number of ship arrivals per week.

5.4.2 Ship Unloading service Time

The arriving ship occupies the channel for two time intervals, when arriving and leaving from the port. The channel can be occupied by only one ship at a time and priority is given to incoming ships over outgoing ships. The service time interval for the ships from the time of docking clearance to dock on the marginal wharf is 25 minutes to 50 minutes. The time interval is similar for ships leaving from the dockside to ship outer harbor through the channel. The Cumulative Density Function (CDF) is shown in Figure 5.5.

After arriving at the dockside, the ship starts unloading the freight depending on the availability of the equipment. For containerized cargo ships, the commencement of cargo unloading depends on the availability of the crane. If the crane is available, it starts unloading cargo at a rate of 22 to 25 containers per hour. The service time for the
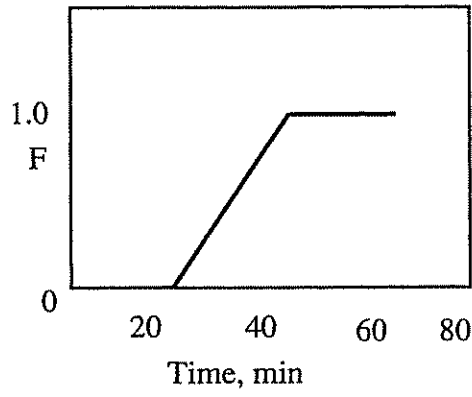
a) Ship Docking Service
Time
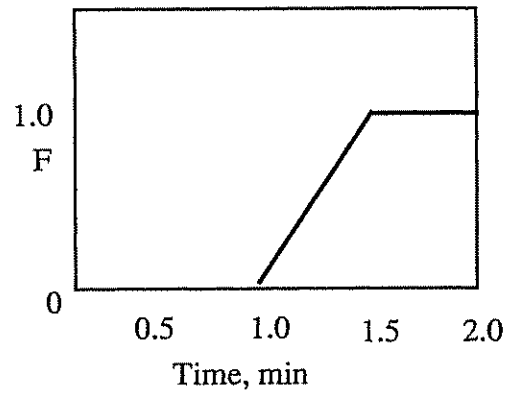
b) Pickup Service Time For
Yard Hustler
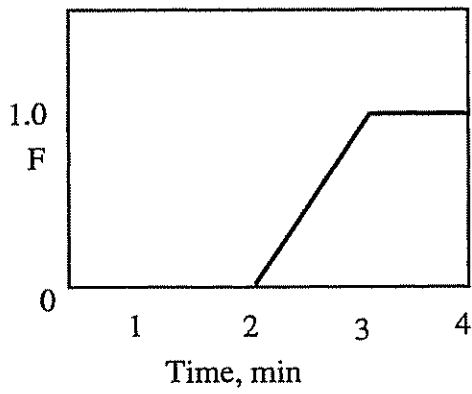
c) Forklifts Service Time
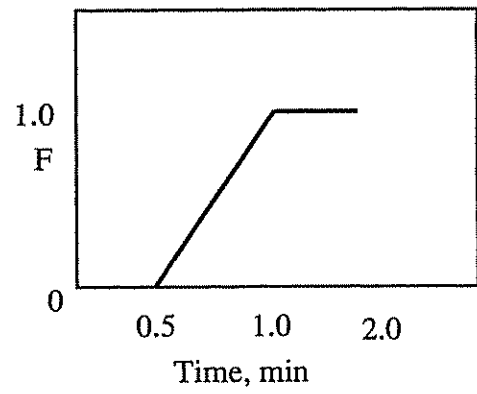
d) Service Time For Cargo
Checker

Figure 5.5: Cumulative Density Function of service time for different activities I

ship staying at the dock starts with the ship docked in the harbor, and finishes with the ship leaving the dockside. The crane takes the container from the ship and places it onto the yard hustler to carry the container to the container yard. The CDF of the time to place the container is shown on Figure 5.5. The speed of a yard hustler to move from dockside to container yard is 1250 feet/min. Kozan analyzed the distribution of the number of containers in an Australian port for two years [8]. The experiment proves that the distribution of container batch sizes resembles the shape of an Erlang function and he conducted chi-square goodness of fit test to determine the accuracy of the assumption of Erlang distribution of container operation. With the determined mean and standard deviation of the observed batch of containers, the random observation formed an Erlang distribution with $k = 3$.

Bulk cargo is unloaded with the small cranes on board in the ship. Cargoes are unloaded on the dockside and carried by the forklifts to the warehouses or transit shed. Three to four gangs of workers work on the ship and on the ground to operate the unloading operation. The unloading time depends on the total amount of palletized cargoes, number of cranes on the ship, dockside area, number of forklifts available to serve the ship, and the availability of spaces in the warehouses and transit sheds. The CDF of service time for the forklift to pick one pallet is shown in Figure 5.5. The time it takes for the Forklift to place the cargo from the dockside to the storage area depends on the distance it travels and the speed of a forklift. The speed of a forklift is considered 150 to 300 feet/minute. The number of batches of bulk cargo is highly variable, but also formed an Erlang distribution with $k = 3$.

The RoRo cargo ships start downloading roll-on / roll-off cargoes (mainly autos) to the auto yard inside the port. Around 700 to 1000 autos are carried by a ship and also follow Erlang distribution with k = 3.

5.4.3 Storage Area Operation

Placement of bulk cargo in the warehouse is verifies by the checker and CDF of the service time generated by checker is shown in figure 5.5. After storing the palletized cargo (mainly fruit and meat) in the warehouse, the cargo is inspected and the service time is distributed from one to five minutes. The bulk cargoes are then placed in truck loading bays and loaded in the trucks by the forklifts. The CDF of time for forklifts are the same as Figure 5.5. Some cargoes are also transferred by forklifts to rail yard for transport through trains. For temporary storage, cargoes are placed in the transit shed and later on moved to the warehouse or rail yards.

Containers are stacked in the container yard from the yard hustlers by top loaders or forklifts, or loaded onto the trucks for the hinterland market. The service time of top loaders is uniformly distributed as shown in Figure 5.6. Priority is given to full containers over empty containers for any operation in the container yard. The cars from the car yard are loaded in the auto carrying truck and the CDF of the service time is distributed in the Figure 5.6. Loaded trucks of containers, autos, and bulk cargoes leave the port area through the out gate and the service time is uniformly distributed as shown in Figure 5.6.
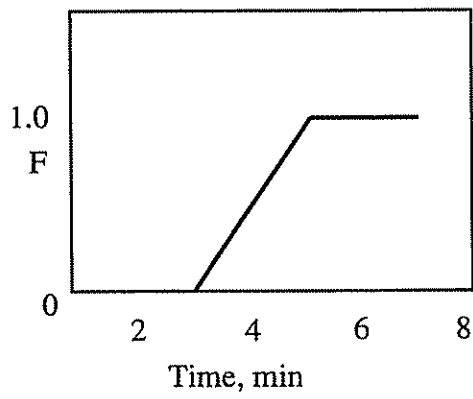
a) Top Loader Service Time
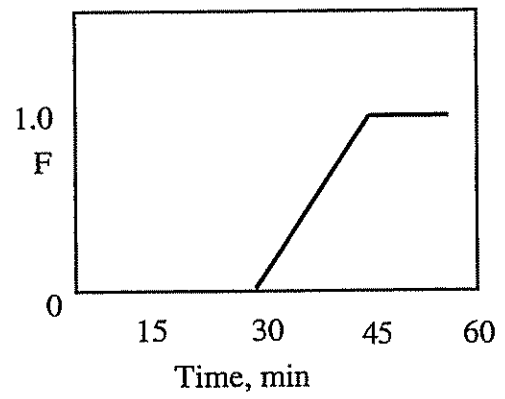
b) Auto Loading Truck
Service Time
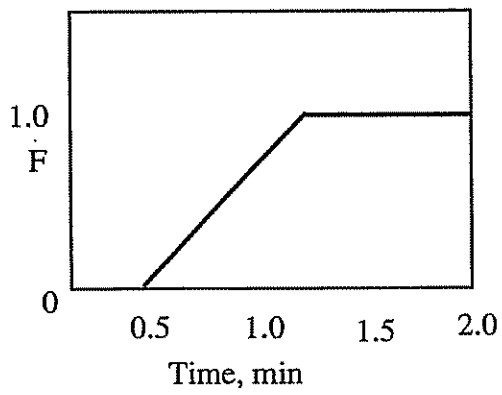
c) Out-gate Service Time
Interval
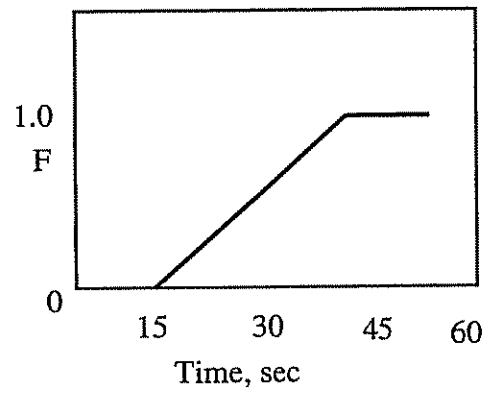
d) In-gate Service Time
Interval

Figure 5.6: Cumulative Density Function of service time for different activities II

5.4.4 Arrival Cargo Operation

Loaded and empty trucks enter the port system through the in gate and are moved to the container yard, truck loading bay, or auto yard. Top loaders are used to unload the containers from the truck to container yard, and forklifts are used to unload the pallets from the truck to warehouse. The service time for top loaders and forklifts to get to the import and export cargoes are same. The variation of the average time in the in gate is shown in Figure 5.6.

5.4.5 Departure Operation

After unloading the cargoes from the ship, it will prepare for leaving unless any cargo is waiting to export, or wait to receive supply from the ship chandler. Upon completion of all its work, the ship is bound to leave dependent on the availability of the tugboat and channel clearance. If there is no ship waiting in the outer harbor, and if there is no ship inside the channel, then the outbound ship gets clearance to move and simulates the service time for leaving the harbor, distributed from 20 minutes to 40 minutes. At this point, the departure is counted as completed and the departing ship is no longer within the control of the port system. The channel, now vacated, is available for the subsequent departure or arrival of ships.

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Chapter 6

APPLICATION OF SIMULATION MODEL

6.1 Introduction

The previous chapter presented the algorithm of the simulation model and the building of the model studied in this research work. This chapter will discuss the results of the model and its applications, with the possible bottlenecks of current and future expansion of port operation to facilitate the decision making of port operation. This chapter will also discuss the utilization and productivity, with performance measurements of the port operation. Later, this chapter will discuss the different scenarios that were used to evaluate proposed change in the port operation.

6.2 Simulation Outputs

This section shows the results of the simulation model and its application to aid the port authority's decision making. The model was run for a pre-determined length of time with all possible events occurring in the run length. Here, the model was run for one year to obtain the steady state of the simulation model. A steady state implies that average output of the simulation model is independent of its initial condition. Also, one month of simulation run was considered as the warm-up time to facilitate the activities of the simulation model to be in steady state.

The simulation model on this study is based on the original data of the multipurpose Port of Wilmington. Analysis of the data were conducted and conclusions reached after the steady-state condition was carried out, based on the output values that were produced at the stopping point by summarizing all the events from the inception of the actual run.

Each run of the simulated model also generated an output report which includes statistical information about all fixed facilities in the terminal (warehouses, container yards, car yards, rail and auto yards, dockside facilities, transit sheds and so on), cargo moving equipment (forklifts, different types of cranes, top loaders), arrival entities (ships, trucks, trains) and the variables to count different activities inside the port operation. The simulation model identifies fixed facilities as locations, the equipment as resources, and the arrivals as entities.

6.2.1 Utilization

The output data provides information of all the activities that occurred in the simulation model. Information is generated about the schedule hours of operation, capacity of the resources, average hours per entry, maximum contents, average contents, current contents, and the utilization rate. All statistical data are important for making investment decisions to improve terminal productivity. Utilization rate is especially important as it indicates whether the current location is working on its full capacity or if there is still a possibility to increase business within the existing facility. But, it should be keep in mind that even with a low utilization rate, some certain facilities will not give better results with the increase in business, because the

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interaction between facilities is very intense, interrelated, and complex. The change on one variables greatly effect the others, which will be discussed in the "what if" scenarios. In general, utilization rate is the primary indicator of bottlenecks in the model. As an example, the utilization rate of a refrigerated warehouse is always very high, which indicates that increased refrigerated cargo business depends on the availability of more space, especially during the peak ship traffic season. The most sensitive parameter of the model, is the ship waiting time, because it is the most expensive parameter, and the port operator always tries to reduce this waiting time even at the expense of low utilization rate for other activities.

The summary of statistics for resources are reported on either a collective or individual level. These include the number of times the resources were used, the average time per use, and the average time traveled to get the bulk cargoes or containers to fill up the requirement of ships, trucks, trains, or yards. Utilization rate is expressed as the percent time the equipment spent at each activity, and is shown for the time in use, travel to use, parking, and idle time. The report also shows the percentage of time that resources were needed, but delayed due to the blocked travel path, an indication of a bottleneck. From the output data it is evident that the terminal is not fully utilized in its recourse capacity. The only exception is the containerized crane and will be discussed in the crane productivity section.

The entity statistics summary shows the detailed statistics for the number of containerized ships, bulk cargo ships, RoRo ships, bulk cargoes, containers and autos, and empty and full trucks and trains that enter and leave the system. Also given are the

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total of each of these entities left in the system at the end of the simulation run, and the total average hours each entity spent in system. The total average time is composed of the time each entity spent traveling between fixed facilities, in processing, and waiting for fixed terminal facilities to become available. The average time each entity spent in the system is important to calculate terminal productivity, to identify steady-state conditions, and to verify and validate the model.

The utilization of a warehouse is also an important measurement of effectiveness for the bulk cargo (palletized) operation in the port. A significant amount of cargo business in the Port of Wilmington is bulk cargoes. The measure of warehouse productivity is the utilization of warehouses. The model shows that the utilization rate of a warehouse is more than 50 percent, and in certain times of the year, the warehouses are mostly full. This high utilization rate and the lack of spaces indicate that the port would not be able to handle more temperature controlled bulk cargoes in the peak winter season unless more warehouses facilities are introduced. Another option could be reducing the storage of bulk cargoes in the warehouse, which would help to increase spaces for more bulk cargoes. Uniform distribution of cargo operation over the year could all help to reduce this peak season problem.

Another important measurement of effectiveness is the berth productivity. The measure of berth productivity used in this study was berth utilization. This measure is the percentage of average berth capacity occupied during a simulation run. For the multipurpose port, berth utilization was separated for containerized, bulk, and RoRo berth operation. It was difficult to get the exact berth utilization fort the Port of

Wilmington, as some ships are served during day or night shifts and some ships are served only in daytime. Berth utilization is also an indicator whether there might be a queue of ships in the outer harbor, which may increase the ship turnaround time. Berth utilization for containerized berth is 15 percent. Whereas, for bulk cargo, berths are 19 percent, and RoRo berth is around 10 percent. This overall low utilization rate is due to the uneven distribution of ship arrivals over the span of the year. The port is over crowded during the winter peak season, when the utilization rate is much higher than the year average. Berth utilization is a concern to the managers of the terminal and the ship lines in different ways. The port manager always wants to see high utilization rates that reflect the high activity of the port. On the other hand, shippers are interested about the low utilization of the port, which would ensure that berth would be available when the ship is in the port. The goal of the terminal manager is to maintain a high berth utilization rate, while at the same time, ensure little or no ship waiting time and queue.

6.2.2 Productivity

The terminal is a complex system and involves a variety of major interacting components such as berths, cranes, forklifts, other moving equipment, warehouses, car yard, container yard, transit shed, and gates. Various parties are affected by the operation of these components such as; the port administrator and the community, the shipping line, the terminal operator, the terminal workforce and the truckers. This complexity makes it unlikely that one single measure of productivity can capture all the interactions between operating components and interested parties. The complexity of operation also increases due to the handling of different types of cargo, which makes it

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difficult to assign priorities. The following section will determine a variety of productivity measures generated from the original simulation model output.

A crane's productivity is measured by the number of containers it moves within a given time period. The time required to move a full or empty container is defined as the exchange of a container between the terminal and the ship. Though most of the containers handled in the Port of Wilmington are 40-foot, the time required to move a 20-foot container is considered the same as a 40-foot container. The number of containers moved per crane per hour measures crane productivity. For the existing port operation, only one crane is considered for the handling of containerized cargo. Because the port is in the process of acquiring another containerized crane, two cranes were considered for the analysis of "what if" scenarios. Average crane productivity per hour was 23 container moves. This value is low compared to other purely containerized ports as the crane productivity also depends on the yard support, movement of containers from the dockside to yards, and the availability of required equipment for loading and unloading of containers. Most of these factors are not directly modeled in the simulation but, are reflected in the service rate data deceived from the terminal and literature review. Crane productivity is vital to all interested parties in the terminal because high crane productivity is an indication of lower ship turnaround time for containerized ships.

6.2.3 Throughputs

The throughput of the port reflects the ability of container, bulk, and RoRo cargoes to transfer from the ship to trucks and trains, and vice versa. For the port of

Wilmington this would be mainly one way Import throughput. The measure of productivity chosen for the container yard includes the number of TEU's per year. For the bulk cargoes it is the number of pallets per year and for the RoRo cargoes is the number of autos per year. The factors that affect the yard productivity are the type of cargo, equipment, operational layout, physical size of the container and car yard, mode of transportation selected to transfer cargo from the port to its hinterland, management (including coordination among different terminal users and the quality of information), penalty of using storage more than scheduled time limit, labor skills, and motivation. Improving yard throughput is not only the interest of terminal management, but also of the shippers and trucking companies. This measure of throughputs can be used by the terminal operator for expansion planning, production guarantees, and assessing the growth area.

6.2.4 Cost Performance

The cost analysis in this model is not a full-scale econometric analysis but rather the analysis is based on the simulation study and different 'what if' scenarios. Because the port operates different types of cargo (containers, bulk, Ro-Ro, dry and liquid bulk), it is very difficult to determine which method of cost performance optimization should be used. One general interest is to reduce ship turnaround time. Other areas of interest might be reducing the business of some types of cargo and increasing the business of more profitable types of cargoes. The statistically relevant variables which influence ship turnaround time are the number of cranes, number of moves per crane, number of support equipment inside the port (yard hustlers, forklifts, top loaders, etc.), and

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availability and location of warehouses. Changing any of these variables alters the productivity of the terminal, and economic cost performance is needed to determine which variable(s) improves the efficiency of the terminal in a cost effective manner. The goal is to optimize terminal operation with minimizing cost, subject to maintaining an acceptable level of service to the customers.

The cost of ship turnaround time is much higher for containerized ships than others. Besides, most clients of containerized cargo businesses are located permanently in the Port of Wilmington. Reducing the ship turnaround time (especially for the containerized ship and Ro-Ro cargo ships) are a primary goal for the different 'what if' scenarios and cost performance analysis. In addition, the port has to compete with other nearby large ports like Baltimore and Philadelphia. A detailed econometric analysis would be advisable to identify whether the Port should continue as a multipurpose port or be converted to a pure containerized port.

6.3 'What if' Scenarios

Once the simulation model was verified, validated, and compared closely with the actual port output, several "what if" scenarios were run to see their effect on the terminal operating system and to measure the sensitivity of the model. Running the different scenarios would evaluate how each change effected the terminal operation. Different changes include changing resources and reallocation of facilities, changing fixed and mobile equipment parameters, improving information flows, and improving

service rates. The scenarios were chosen to accomplish higher productivity, faster service, and reduce delay for customers, and accomplish these objectives at least cost.

Physical changes were made to investigate the relationship between available equipment and the quality of service. Changes focused on the amounts of terminal operating equipment such as cranes, forklifts, yard hustlers, top loaders, number of trucks, and change of transporting modes from trucks to trains and vice versa. The port is currently running with only one containerized crane and adding one more crane would decrease ship turnaround time by 4 to 5 hours. As larger containerized ship is going to start business with the Port of Wilmington very soon for Dole and Chiquita, this changes would be even more. Also, change of service rate of crane, yard hustlers, and forklifts would have positive impact on ship turnaround time. The change in cargo transport from trucks to train would improve the flow of cargo and reduce the cost of transportation for bulk and longer haul cargo operation.

One of the major scenarios is the effect of adding new crane on the port operation especially the containerized cargo operation and its effect on other resources. Scenario I is the addition of one more crane in the resources considering other parameters ship arrival rate is same. Scenario II considers two container cranes with 20% increase of yard hustlers, and 10% increase in cargo movement by train. Scenario III considers the increase of ship business by eight ship per week, whereas scenario IV considers the 20% increase in warehouse capacity. Table 6.1 shows the comparison on different "what if" scenarios.

Table 6.1: Comparison of Different "what if" Scenarios

		Scenario I	Scenario II	Scenario III	Scenario IV
BULK CARGO	YARD THROUGHPUT (Tons)	642,000	687,000	668,000	665,000
	SHIP TURNAROUND TIME (Hours)	29	26.5	33.5	27.2
CONTAINER CARGO	YARD THROUGHPUT (TEU's)	162,000	182,000	168,000	151,000
	SHIP TURNAROUND TIME (Hours)	20.8	16.2	25.5	21.1
RO-RO CARGO	YARD THROUGHPUT (Units)	72,000	68,000	85,000	70,000
	SHIP TURNAROUND TIME (Hours)	13.6	12	15	13.2

The analysis of these scenarios reveals some interesting facts of the multipurpose port operation, especially the strong interaction and influence between different types of cargo operation. As expected, the addition of one crane reduces the ship turnaround time for containerized cargo ship but doesn't effect much as all other parameters remain same. Also if the number of cranes increases with the increase of yard hustlers and more cargo moved by trains, this reduces the ship turnaround time for all types of ship, and also increases the cargo handling capacity for bulk and containerized cargo. Again the increase number of ships doesn't necessarily increase the freight operation in the same way as the ship turnaround time increases in all cases. Similarly, increase in warehouse capacity increases the bulk cargo operation and reduce the ship turnaround time but has a negative effect on other types of cargo. From the scenario comparison table it is evident that the optimization (reducing ship turnaround time) of port heavily depends on the change of modal shift, i.e. movement of more cargoes by train than trucks.

The information flow inside the terminal also has significant impact on cargo handling. Benefits include improved gate flow, quicker freight turnover and response time, effective and efficient berth and land use, quicker document generation, more accurate inventory control, and improved customer service. Better information systems could track containers and pallets efficiently and could provide beforehand information about the pickup of cargoes. This information would allow for stacking of bulk cargoes and containers in a way that avoids repeated moving.

Chapter 7

VERIFICATION AND VALIDATION OF THE PROGRAM

7.1 Introduction

Once the model is defined, it needs to be debugged to ensure that it works correctly, then tested for its accuracy and applicability. The purpose of demonstrating that a model works as intended is referred to in simulation literature as model *Verification* [26]. It also determines that a simulation computer program correctly translated the conceptual simulation model (flowcharts, assumptions) into a working program. On the other hand, *Validation* is determining whether the conceptual simulation model is an accurate representation of the system [28].

There are a number of principles helping with the verification process. The simulation model should be run under a variety of settings of input parameters and checked whether the model gives reasonable output [29]. One of the most powerful systems is "graphic animation" and "trace". "Graphic animation" shows the pictured representation of the flowchart and helps to understand whether the model works as intended. "Trace" shows the logical operation of the flowchart and assumptions and helps to debug the program.

It is also important to determine the degree to which the model corresponds to the real system, or at least accurately represents the model specification documentation.

Real life port operational data is important to evaluate with the model data. Real-life data, in this case real life Port operational data for the Port of Wilmington, is used to determine if the program is in fact useful to represent the operation of the port. This is accomplished in the validation process. This process always occurs after the program is verified to be accurately working (in other words, after the verification process) [29]. This chapter will describe and examine the verification and validation process of the simulation software built for the multipurpose operation of the Port of Wilmington.

7.2 Verification of the model

The simulation model of the port operation was closely monitored during the running of the computer model to accomplish verification (debugging) of the model. The processing logic of the model was verified by using some established debugging methods like, trace option, graphic animations, and screen messages. ProModel simulation program has all these valuable tools to debug a model written in the program. The trace option allows one to formally track the events in the model by continuous or step-by-step trace. It keeps the step-by-step path of all the activities and actions of bulk cargo, container, RoRo cargo, trucks, customers, equipment through the system, and allows check for any types of logical errors that might occur during the building process of the model. During the initial run of the model it verified that the model is working as intended in the flowcharts and the model is using all the assumptions used in the model building process. Figure 7.1 shows the trace operation taken from the model run. Graphic animation allows the modeler to observe every

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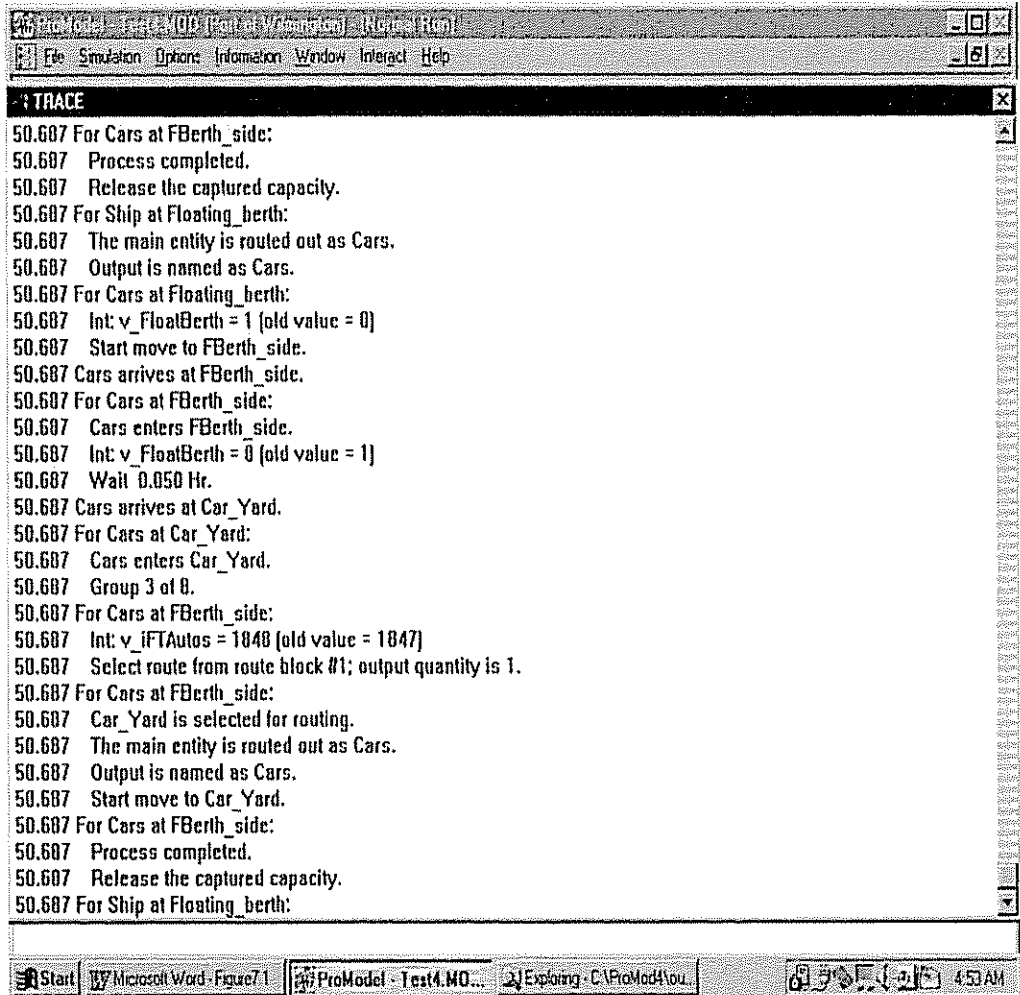
Figure 7.1: Trace Diagram of the model run

process through visual graphics and verify the model's physical representation of the real life operation. It was also very helpful to understand the movement of all the resources and particularly helped to debug the movement of bulk cargo into different warehouses, and the movement of trucks inside the port model. Screen message also helped to remove the logical inconsistency from the model and assist to follow the desired program path.

During the development phase of the model flowcharts of the model were presented to professors and students of transportation engineering at the University of Delaware. Also the initial development of the model was closely observed by the port managers which helped a lot to during the development process of the model. The modules of the program were tested separately by printing out the port processing operation into text files ("trace" technique). It was checked whether these values are reasonable. The entity and arrival function for bulk-cargo, containers, ships, trucks, and Ro-Ro cargoes are checked in this way. The activity of resources, and locations were also tested in this way. The resulting outputs of several runs were also inspected to determine whether they are reasonable.

7.3 Validation of the model

Validation is an inductive process used to draw the conclusion about the accuracy of the model based on evidence available [26]. Validation check whether the simulation model reasonably approximates the real system, whether there is an adequate agreement between the model and the system being modeled. The model's ability to

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generate the type of output similar to real-life observation is the most important indicator of its validity. An absolutely valid simulation model does not exist. The idealistic goal of validation is a simulation model good enough to be used to make decisions about the system similar to those that would be made by experimenting with the system itself [28]. Various indicators of the model's logic and data were checked periodically to determine the validity of the model and to insure it was approaching a close reality of the terminal operation. As an example, on average, the amount of time a ship stayed in the terminal (ship turnaround time) is twenty-two hours (in the model), which is close to the ship turnaround time for the observed data (twenty-four hours). A vigorous approach to validate the model is to compare the simulation model with the real life scenario based on some measures effectiveness that are going to use for decision making. This will be explained in next section.

7.3.1 Comparison of existing data with the models output

The most commonly used approach for validation by simulation practitioners is the "inspection approach". This approach involves the computation of one or more statistics from the real-world observations and corresponding statistics from the model outputs, and to compare them without the use of any formal statistical procedure. The inspection approach can provide valuable insight into the adequacy of the simulation models, but extreme care must be used in interpreting the results of this approach.

Both quantitative and qualitative comparison was done to validate the simulation model. The most important optimization criteria, ship turnaround time, was used to identify whether the simulation model could successfully represent the actual scenario.

Ship turnaround time for bulk cargoes, containers, and Ro-Ro cargoes were compared to identify the validity of the model. Besides the annual tonnage of different types of cargo were also compared. The average waiting time for bulk cargoes, containers, and Ro-Ro cargoes was not available for real life situation to compare with the simulation output. The utilization rate of warehouses was obtained from the port officials as a qualitative information. Based on their experience, the port officials consider the utilization rate as "High", "Medium" or "Low". Port usually consider any utilization rate more than 50 percent as high, less than 15 percent as low and between them as Medium. Warehouse utilization is high in both cases, container yard utilization is medium in both cases, but the utilization rate is different in the cases of berth utilization. This might be due to the absence of any fine line to define these qualitative information. All the comparison of this measure of effectiveness is shown in table 7.1.

Though the simulation output and the real life data does not exactly match, but the analysis is fairly representative for a complex simulation model and it is reasonable to say that the model can analyze the port operation. The differences of outputs in real life and simulation are shown in table 7.1 and describe as comments. Besides, the simulation model was presented to the port authority and different port operation managers in the Port of Wilmington. They also recognize that the model could represent the port operation properly.

After the verification and validation process the model was run several times with the change of some parameter to reduce the differences of outputs that are shown on the comments in table 7.1. This is known as the process of *Calibration*. During the

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Table 7.1: Comparison of Real Life and Simulation output

	Real Life	Simulation	Comments	After Calibration
Container Ship Turnaround Time	24 Hrs	22 Hrs	8% difference	22.4 Hrs
Cargo Ship Turnaround Time	32 Hrs	28 Hrs	12.5% difference	29.2 Hrs
Ro-Ro Ship Turnaround Time	8 – 12 Hrs	14 Hrs	25% difference with weighted mean	14.4 Hrs
Annual Tonnage of Bulk-Cargo	751,000 Units	650,000 Units	13.5% difference	665,000 Units
Annual Tonnage of Containers	199,240 TEU	155,000 TEU	22.2% difference	162,050 TEU
Annual Shipment of Ro-Ro Cars	113,366 Units	75,000 Units	33.8% difference	91,300 Units
Warehouse Utilization	High	High	Same	High
Berth Utilization	Medium	Low	Different, simulation output is very close to the medium range	Low
Container Yard Utilization	Medium	Medium	Same	Medium

normal run of the simulation model it was observed that a significant number of cargoes stay in the system after the end of one year simulation run. This was happened due to the non-availability of empty trucks to carry imported bulk cargo, containers, and Ro-Ro cars from the port to its market place. Also the number of Ro-Ro ships was not actually represented in the original simulation model. All these values were modified in the calibration process and the output of the calibrated run model is also shown in table 7.1 to get the comparison of real-life, simulation and the calibration model. Overall, it is encouraging that verification, validation, and calibration proved that the simulation model could successfully determine the operation of a multipurpose seaport.

Chapter 8

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 Summary

The main objective of this work is to develop a simulation model to analyze and optimize the multipurpose port operation of the Port of Wilmington. The first section is a summary of the work and results of the study. The second section discusses the advantages and limitations of the program. The final section discusses the recommendations for future research.

In the current competitive market, port managers need accurate information about the port operation to ensure an optimal level of service to their customers, and planning in the future. The simulation model is developed for this study to represent the current physical operation of the Port of Wilmington. Various "what if" scenarios were analyzed in the model to see how the behavior of the port changes with different situations. As an example, it was demonstrated how ship turnaround time would be effected with the increase of business in the port and what measurement should be taken to reduce the ship turnaround time.

The study will lead to develop a model that can successfully represent the operation of a multipurpose port. Although there are many parameters in a multipurpose port, the idea was set to reduce ship turnaround time in this "what if"

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study. The significant variables in this simulation model which were found to reduce ship turnaround time are different for different types of cargoes. The most significant variables for containerized ships were; number of cranes, yard hustlers, and size of container yard. On the other hand, for bulk cargo ships, the turnaround time depends on the number of forklifts, warehouse storage area, and the shipment of cargo from the port to its hinterland. The mode of shipment of cargo from the port to its market has a decisive effect for the increase of port business and reducing of overall ship turnaround time and directly related to the increase use of train as a mode of cargo transfer from the port to its hinterland.

8.2 Conclusions

In the course of developing the simulation model for the purpose this thesis, optimization and the use of computer model for port operation was thoroughly studied, especially in the case of multipurpose port. This section will summarize the findings and recommendations about the use and application of the model in the operation of the Port of Wilmington. The study gave a good idea about the use of simulation model for the modification and decision making of port operation, and the capabilities of computer model to predict future port operation. After the lengthy literature search and knowledge acquisition process through the completion of this thesis, it is obvious that sound planning and prudent management decision is crucial for competitive port business which could be obtained through the aid or a simulation model. The accuracy of the model highly depends on the availability of wide range of data and the

complexity of the model increases with the increase of different types of cargo operation. Due to the sheer complexity it is very difficult to represent total port operation in any simulation model accurately, however; with extensive information of port operation, reliable forecast of traffic flow in the port could help to produce a reliable simulation model for a port.

8.2.1 Advantage of the Program

This simulation study will help the Diamond State Port Corporation to understand the operation of the Port of Wilmington more systematically and will help to make any type of investment decision. One of the major aspects is to get an overall idea of the cargo operation and identify any possible bottlenecks, which are very difficult to find without any simulation model. The model also shows the effect of changing resources and physical facilities, and helps determine decisions for the administrators about any possible change. In the highly competitive market of the East Coast, all the ports must maintain a minimum level of service to keep business and be competitive. The simulation established in this model will help the port authority to understand the overall port operation of the Port of Wilmington and will help to make decisions on improvements to the port facilities and operations in the new millenium.

The program is very user friendly, and different situation, can be observed by changing parameters in the program. Running the model and changing parameters are very simple, with easy to follow instructions, and performs with little error. The program runs in the Windows environment and utilizes the advantages of the environment with easy-to-use input screens. The outputs are presented in a file which is

very easy to follow. Output also presents a set of graphs that help the user understand the model in a simple and easy way.

8.2.2 Limitations of the Program

The operation of a seaport involves different types of parameters and uncertainties which are not possible to incorporate in the simulation model. This is especially true for a multipurpose port where different types of cargoes use the same port facilities with different types of operation and the objective of operation is not well defined. The program does not represent the effect of liquid and dry bulk cargo operation, and the effect of their infrastructure facilities on the operation of other types of cargoes. It also does not include the effect of some uncertain parameters like weather condition and labor union on the model. Ability to represent the model as a real life scenario depends on extensive data collection. A model of this complexity needs extensive and long time data of the current port operation to represent the real life scenario more successfully.

Another limitation of the model is to determine the overall effect of intermodal transportation on the Port of Wilmington. Though it is understood from the model that increase of port business depends on the increase use of rail cargo operation, but the long term economical and physical effect of cargo handling by rails on the port was not stated. The use of double-stack freight movement for the port to its hinterland and its effect on the Delaware's current freight routes was not considered in the model. The model deals with the operation inside the port, but the immediate effect of the outside situation on the inside operation was not possible within the scope of this research.

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The research also didn't incorporate the econometric analysis of the current port operation and the effect of expanding port business on the basis of economical optimization. The comparison of cargo handling efficiency of the Port of Wilmington with nearby large ports like Baltimore and Philadelphia was not discussed in this model. Last but not least, this simulation model is an aid to make decisions or understand the activities inside the port but it would not be wise to take decision solely on the basis of computer based simulation model, as lots of criteria is involved in a seaport operation which might not be represented in a simulated model.

8.3 Recommendations for Future Research

Because the development of a simulation model to represent the port operation is a relatively new area of research, almost all literature suggests that very little work has been done to develop simulation models for multipurpose port operation. Even though most of the large ports in United States and all over the world converted to single purpose port (especially containerized), research should continue for the development of more accurate and realistic simulation models for regional multipurpose sea ports. This model is the first step in developing a simulation model for the port. Lots of improvement could be done in the future to incorporate all kinds of activities from the port in the simulation model. Research should be done to get more detailed operational and economical data about the Port of Wilmington and how to incorporate them in the simulation model.

Research should also be done in future on the impact of the Port of Wilmington to the State of Delaware and the greater Delaware Valley region. Another area of research could be the effect of intermodalism on multipurpose sea port operation and the economic impact of converting a multipurpose sea port to single purpose port.

APPENDIX

Complete Code of the Multipurpose Port Simulation Program Developed by

ProModel Software

```
****************************************************************
*
*
*
*                    Formatted Listing of Model:
*
*                    C:\ProMod4\models\Test4.MOD
*
*
*
****************************************************************

  Time Units:                        Hours
  Distance Units:                    Feet


****************************************************************
*
*                              Locations
*
****************************************************************

  Name                Cap        Units Stats         Rules
Cost
  ----------------    --------   ----- ------------   ----------------
  Ship_Counter        INFINITE   1     Time Series Oldest,  ,
  Floating_berth      1          1     Time Series Oldest,  ,
  Berth_1             1          1     Time Series Oldest,  ,
  Berth_2             1          1     Time Series Oldest,  ,
  Berth_3             1          1     Time Series Oldest,  ,
  Berth_4             1          1     Time Series Oldest,  ,
  Berth_5             1          1     Time Series Oldest,  ,
  Berth_6             1          1     Time Series Oldest,  ,
  Berth_7             1          1     Time Series Oldest,  ,
  Dock_side7          20         1     Time Series Oldest,  ,
  Dock_side6          20         1     Time Series Oldest,  ,
  Dock_side5          20         1     Time Series Oldest,  ,
  Dock_side4          20         1     Time Series Oldest,  ,
  Dock_side3          7          1     Time Series Oldest,  ,
  Dock_side2          7          1     Time Series Oldest,  ,
  Dock_side1          25         1     Time Series Oldest,  ,
  Q_Crane3            5          1     Time Series Oldest, FIFO,
  Q_Crane2            5          1     Time Series Oldest, FIFO,
  Q_Crane1            5          1     Time Series Oldest, FIFO,
  Warehouse_A         4500       1     Time Series Oldest,  ,
  Warehouse_B         5000       1     Time Series Oldest,  ,
  Warehouse_C         3215       1     Time Series Oldest,  ,
  Warehouse_D         4000       1     Time Series Oldest,  ,
  Warehouse_E         4500       1     Time Series Oldest,  ,
```

```
Warehouse_F          4000    1     Time Series Oldest, ,
Transit_shed         175     3     Time Series Oldest, ,  First
Transit_shed.1       175     1     Time Series Oldest, ,
Transit_shed.2       175     1     Time Series Oldest, ,
Transit_shed.3       175     1     Time Series Oldest, ,
Container_Dole       850     1     Time Series Oldest, ,
Container_Chiquita   850     1     Time Series Oldest, ,
Container_Others     500     1     Time Series Oldest, ,
Car_Yard             1450    1     Time Series Oldest, ,
Truck_Gate           10      2     Time Series Oldest, ,  First
Truck_Gate.1         10      1     Time Series Oldest, ,
Truck_Gate.2         10      1     Time Series Oldest, ,
Truckspot_WH_C       16      10    Time Series Oldest, ,  First
Truckspot_WH_C.1     16      1     Time Series Oldest, ,
Truckspot_WH_C.2     16      1     Time Series Oldest, ,
Truckspot_WH_C.3     16      1     Time Series Oldest, ,
Truckspot_WH_C.4     16      1     Time Series Oldest, ,
Truckspot_WH_C.5     16      1     Time Series Oldest, ,
Truckspot_WH_C.6     16      1     Time Series Oldest, ,
Truckspot_WH_C.7     16      1     Time Series Oldest, ,
Truckspot_WH_C.8     16      1     Time Series Oldest, ,
Truckspot_WH_C.9     16      1     Time Series Oldest, ,
Truckspot_WH_C.10    16      1     Time Series Oldest, ,
Truckspot_WH_D       16      9     Time Series Oldest, ,  First
Truckspot_WH_D.1     16      1     Time Series Oldest, ,
Truckspot_WH_D.2     16      1     Time Series Oldest, ,
Truckspot_WH_D.3     16      1     Time Series Oldest, ,
Truckspot_WH_D.4     16      1     Time Series Oldest, ,
Truckspot_WH_D.5     16      1     Time Series Oldest, ,
Truckspot_WH_D.6     16      1     Time Series Oldest, ,
Truckspot_WH_D.7     16      1     Time Series Oldest, ,
Truckspot_WH_D.8     16      1     Time Series Oldest, ,
Truckspot_WH_D.9     16      1     Time Series Oldest, ,
Truckspot_WH_F       16      6     Time Series Oldest, ,  First
Truckspot_WH_F.1     16      1     Time Series Oldest, ,
Truckspot_WH_F.2     16      1     Time Series Oldest, ,
Truckspot_WH_F.3     16      1     Time Series Oldest, ,
Truckspot_WH_F.4     16      1     Time Series Oldest, ,
Truckspot_WH_F.5     16      1     Time Series Oldest, ,
Truckspot_WH_F.6     16      1     Time Series Oldest, ,
Truckspot_WH_E       16      8     Time Series Oldest, ,  First
Truckspot_WH_E.1     16      1     Time Series Oldest, ,
Truckspot_WH_E.2     16      1     Time Series Oldest, ,
Truckspot_WH_E.3     16      1     Time Series Oldest, ,
Truckspot_WH_E.4     16      1     Time Series Oldest, ,
Truckspot_WH_E.5     16      1     Time Series Oldest, ,
Truckspot_WH_E.6     16      1     Time Series Oldest, ,
Truckspot_WH_E.7     16      1     Time Series Oldest, ,
Truckspot_WH_E.8     16      1     Time Series Oldest, ,
```

```
Truckspot_WH_A        16      10      Time Series Oldest, , First
Truckspot_WH_A.1      16      1       Time Series Oldest, ,
Truckspot_WH_A.2      16      1       Time Series Oldest, ,
Truckspot_WH_A.3      16      1       Time Series Oldest, ,
Truckspot_WH_A.4      16      1       Time Series Oldest, ,
Truckspot_WH_A.5      16      1       Time Series Oldest, ,
Truckspot_WH_A.6      16      1       Time Series Oldest, ,
Truckspot_WH_A.7      16      1       Time Series Oldest, ,
Truckspot_WH_A.8      16      1       Time Series Oldest, ,
Truckspot_WH_A.9      16      1       Time Series Oldest, ,
Truckspot_WH_A.10     16      1       Time Series Oldest, ,
Truckspot_WH_B        16      10      Time Series Oldest, , First
Truckspot_WH_B.1      16      1       Time Series Oldest, ,
Truckspot_WH_B.2      16      1       Time Series Oldest, ,
Truckspot_WH_B.3      16      1       Time Series Oldest, ,
Truckspot_WH_B.4      16      1       Time Series Oldest, ,
Truckspot_WH_B.5      ·16     1       Time Series Oldest, ,
Truckspot_WH_B.6      16      1       Time Series Oldest, ,
Truckspot_WH_B.7      16      1       Time Series Oldest, ,
Truckspot_WH_B.8      16      1       Time Series Oldest, ,
Truckspot_WH_B.9      16      1       Time Series Oldest, ,
Truckspot_WH_B.10     16      1       Time Series Oldest, ,
Railyard_1_bulk       370     1       Time Series Oldest, ,
Railyard               1      4       Time Series Oldest, , First
Railyard.1             1      1       Time Series Oldest, ,
Railyard.2             1      1       Time Series Oldest, ,
Railyard.3             1      1       Time Series Oldest, ,
Railyard.4             1      1       Time Series Oldest, ,
Truck_restplace       inf     1       Time Series Oldest, FIFO,
FBerth_side           5       1       Time Series Oldest, ,
transit_point         inf     1       Time Series Oldest, ,
Ship_outer_harbour    5       1       Time Series Oldest, ,
Truck_OutGate         5       2       Time Series Oldest, , First
Truck_OutGate.1       5       1       Time Series Oldest, ,
Truck_OutGate.2       5       1       Time Series Oldest, ,
FloatingS_Berth       1       1       Time Series Oldest, ,
BerthS_1              1       1       Time Series Oldest, ,
BerthS_2              1       1       Time Series Oldest, ,
BerthS_3              1       1       Time Series Oldest, ,
BerthS_4              inf      1       Time Series Oldest, ,
BerthS_5              1       1       Time Series Oldest, ,
BerthS_6              1       1       Time Series Oldest, ,
BerthS_7              1       1       Time Series Oldest, ,


***********************************************************************
*
*                              Entities
*
```

```
*************************************************************

    Name                Speed (fpm)   Stats          Cost
    ------------------  ------------  ------------   -------------
    Ship                150           Time Series
    Full_Containers     150           Time Series
    Bulk_Cargoes        450           Time Series
    Trucks_Empty        750           Time Series
    Cars                450           Time Series
    Trucks_Full         750           Time Series
    Empty_Con           150           Time Series
    FT_AfterRelease     150           Time Series
    ET_AfterLoaded      750           Time Series
    E_Bulk_Cargoes      150           Time Series
    I_Bulk_Cargoes      150           Time Series
    E_Car               150           Time Series
    E_Full_Containers   150           Time Series
    E_Empty_Containers  150           Time Series
    FT_AfterCrelease    750           Time Series
    Ship_Go             150           Time Series
    Trains              150           Time Series
    T_Bulk_Cargoes      150           Time Series


*************************************************************
*
*                         Path Networks
*
*************************************************************

    Name          Type       T/S                  From      To        BI
Dist/Time  Speed Factor
    ----------  ------------  -------------------  --------  --------  ----
----------  ------------
    Cranenet_1 Passing       Speed & Distance N1            N2        Bi
60          1
                                              N1            N3        Bi
970         1
                                              N3            N4        Bi
60          1
    Cranenet_2 Passing       Speed & Distance N1            N2        Bi
60          1
                                              N2            N3        Bi
1450        1
                                              N3            N4        Bi
60          1
    Cranenet_3 Passing       Speed & Distance N1            N2        Bi
70          1
```

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					N2	N3	Bi
1450	1						
					N3	N4	Bi
70	1						
		PortNet	Passing	Speed & Distance	N1	N2	Bi
400	1						
					N2	N3	Bi
600	1						
					N3	N4	Bi
500	1						
					N4	N5	Bi
500	1						
					N5	N6	Bi
500	1						
					N6	N7	Bi
550	1						
					N5	N8	Bi
900	1						
					N6	N8	Bi
500	1						
					N7	N8	Bi
300	1						
					N8	N9	Bi
250	1						
					N8	N10	Bi
500	1						
					N8	N11	Bi
650	1						
					N10	N13	Bi
800	1						
					N11	N13	Bi
1000	1						
					N14	N8	Bi
800	1						
					N8	N15	Bi
1500	1						
					N15	N16	Bi
1700	1						
					N9	N13	Bi
700	1						
					N13	N12	Bi
1000	1						
					N12	N17	Bi
700	1						
					N15	N19	Bi
1000	1						
					N1	N20	Bi
150	1						

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200	1
200	1
200	1
300	1
800	1
50	1
100	1
150	1
500	1
50	1
300	1
100	1
700	1
800	1
500	1
700	1
600	1
400	1
1000	1
500	1
300	1
800	1
2000	1
1000	1

N2	N21	Bi
N3	N21	Bi
N21	N22	Bi
N4	N23	Bi
N23	N22	Bi
N21	N24	Bi
N23	N25	Bi
N22	N26	Bi
N22	N27	Bi
N22	N28	Bi
N1	N29	Bi
N29	N30	Bi
N29	N31	Bi
N22	N31	Bi
N32	N33	Bi
N32	N34	Bi
N32	N23	Bi
N23	N35	Bi
N32	N22	Bi
N22	N36	Bi
N22	N37	Bi
N22	N38	Bi
N12	N19	Bi
N15	N4	Bi

			N5	N15	Bi
900	1		N15	N23	Bi
800	1		N14	N9	Bi
1000	1		N9	N15	Bi
2000	1		N15	N18	Bi
800	1		N14	N18	Bi
2200	1		N8	N23	Bi
1500	1		N29	N21	Bi
700	1		N22	N3	Bi
600	1		N32	N29	Bi
1500	1		N32	N21	Bi
1200	1		N32	N12	Bi
500	1		N17	N32	Bi
300	1		N16	N32	Bi
300	1				

```
**********************************************************************
*
*                              Interfaces
*
**********************************************************************
```

Net	Node	Location
Cranenet_1	N2	Berth_3
	N1	Dock_side3
	N3	Dock_side2
	N4	Berth_2
Cranenet_2	N1	Berth_3
	N1	Berth_2
	N2	Dock_side3
	N2	Dock_side2
	N3	Dock_side1
	N4	Berth_1
Cranenet_3	N1	Berth_3

	N2	Dock_side3
	N3	Dock_side2
	N3	Dock_side1
	N4	Berth_2
	N4	Berth_1
	N2	Q_Crane3
PortNet	N1	Dock_side7
	N2	Dock_side6
	N3	Dock_side5
	N4	Dock_side4
	N5	Dock_side3
	N6	Dock_side2
	N7	Dock_side1
	N14	FBerth_side
	N9	Container_Dole
	N10	Container_Chiquita
	N11	Container_Others
	N15	Car_Yard
	N6	Q_Crane2
	N5	Q_Crane3
	N7	Q_Crane1
	N16	Truck_Gate
	N19	Railyard
	N20	Warehouse_C
	N21	Warehouse_D
	N22	Warehouse_A
	N23	Warehouse_B
	N28	Warehouse_E
	N30	Warehouse_F
	N36	Truckspot_WH_A
	N35	Truckspot_WH_B
	N38	Truckspot_WH_C
	N37	Truckspot_WH_D
	N34	Truckspot_WH_E
	N27	Truckspot_WH_F
	N31	Railyard_1_bulk
	N4	Transit_shed
	N32	Truck_restplace
	N17	Truck_OutGate
	N14	Floating_berth
	N1	BerthS_7
	N2	BerthS_6
	N3	BerthS_5
	N4	BerthS_4
	N5	BerthS_3
	N6	BerthS_2
	N7	BerthS_1
	N14	FloatingS_Berth

```
*************************************************************************
*
*                                 Resources
*
*************************************************************************


                                       Res       Ent
   Name             Units             Stats   Search   Search   Path
Motion              Cost
   -------------    -----------------  -------- -------- --------  ------
----  ---------------  -------------
   Crane_1          1                 By Unit  Closest  Closest
Cranenet_1 Empty: 350 fpm
                                                                  Home:

N1    Full: 250 fpm


(Return)

   Crane_2          1                 By Unit  Closest  Oldest
Cranenet_2 Empty: 300 fpm
                                                                  Home:

N3    Full: 200 fpm

   Crane_3          1                 By Unit  Closest  Oldest
Cranenet_3 Empty: 350 fpm
                                                                  Home:

N3    Full: 250 fpm

   Forklifts     Num_of_forklifts   Summary  Closest  Oldest
PortNet      Empty: 150 fpm
                                                                  Home:

N1    Full: 150 fpm

   Toploaders    Num_of_toploaders Summary  Closest  Oldest
PortNet      Empty: 150 fpm
                                                                  Home:

N13   Full: 150 fpm

   YardHustlers  Num_of_yardhass     Summary  Closest  Oldest
PortNet      Empty: 150 fpm
                                                                  Home:

N11   Full: 150 fpm


*************************************************************************
*
*                                 Processing
*
```

```
**********************************************************

                                      Process
Routing

  Entity              Location           Operation              Blk
Output              Destination        Rule
Move Logic
  ----------------   -----------------  -----------------    ----
----------------   -----------------  ------------------------
-  ----------
  Trucks_Full         Truck_Gate         Trucks_Checkin_Macro
                                         INC v_iInFTrucks
                                                                1
Trucks_Full         Truck_restplace    FIRST 1
MOVE ON PortNet


  Trucks_Full         Truck_restplace    WAIT 5 MIN
                                                                1
Trucks_Full         Truckspot_WH_C     0.100000 1
MOVE ON PortNet



Trucks_Full         Car_Yard           0.100000
MOVE ON PortNet




Trucks_Full         Container_Chiquita 0.100000
MOVE ON PortNet



Trucks_Full         Container_Others   0.000000
MOVE ON PortNet



Trucks_Full         Container_Dole     0.200000
MOVE ON PortNet



Trucks_Full         Truckspot_WH_A     0.100000
MOVE ON PortNet


                          107
```

```
Trucks_Full          Truckspot_WH_D       0.100000
MOVE ON PortNet


USE Toploaders FOR 5 min


Trucks_Full          Truckspot_WH_B       0.100000
MOVE ON PortNet


USE Toploaders FOR 5 min


Trucks_Full          Truckspot_WH_E       0.200000
DISPLAY 12


MOVE ON PortNet


USE Toploaders FOR 5 min
  Trucks_Full            Truckspot_WH_A       WAIT 3 MIN



                                                                1

E_Bulk_Cargoes       Warehouse_A          FIRST 5
MOVE WITH Forklifts FOR 2 MIN THEN FREE



                                                                2*

FT_AfterRelease      Truckspot_WH_A       FIRST 1
  FT_AfterRelease       Truckspot_WH_A       WAIT 10 MIN
                                                                1

FT_AfterRelease      Truck_restplace      FIRST 1
MOVE ON PortNet


  Trucks_Full          Truckspot_WH_B       WAIT 3 MIN
                                            //RENAME AS

FT_AfterRelease

                                            //RENAME AS

E_Bulk_Cargoes

                                            GRAPHIC 1
                                                                1
E_Bulk_Cargoes       Warehouse_B          FIRST
Cargo_on_Trucks_Macro  MOVE WITH Forklifts FOR 2 MIN THEN FREE


                                                                2*

FT_AfterRelease      Truckspot_WH_B       FIRST 1
```

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```
    FT_AfterRelease       Truckspot_WH_B        WAIT 10 MIN
                                                                        1
FT_AfterRelease         Truck_restplace       FIRST 1
MOVE ON PortNet

 Trucks_Full            Truckspot_WH_C        //RENAME AS
FT_AfterRelease
                                              GRAPHIC 1
                                              WAIT 3 MIN
                                                                        1
E_Bulk_Cargoes          Warehouse_C           FIRST
Cargo_on_Trucks_Macro  MOVE WITH Forklifts FOR 2 MIN THEN FREE
                                                                       2*
FT_AfterRelease         Truckspot_WH_C        FIRST 1
  FT_AfterRelease         Truckspot_WH_C        WAIT 10 MIN
                                                                        1
FT_AfterRelease         Truck_restplace       FIRST 1
MOVE ON PortNet

 Trucks_Full            Truckspot_WH_D        //RENAME AS
FT_AfterRelease
                                              GRAPHIC 1
                                              WAIT 1 MIN
                                                                        1
E_Bulk_Cargoes          Warehouse_D           FIRST
Cargo_on_Trucks_Macro  MOVE WITH Forklifts FOR 1 MIN THEN FREE
                                                                       2*
FT_AfterRelease         Truckspot_WH_D        FIRST 1
  FT_AfterRelease         Truckspot_WH_D        WAIT 10 MIN
                                                                        1
FT_AfterRelease         Truck_restplace       FIRST 1
MOVE ON PortNet

 Trucks_Full            Truckspot_WH_E        //RENAME AS
FT_AfterRelease
                                              WAIT 1 MIN
                                              GRAPHIC 1
                                                                        1
E_Bulk_Cargoes          Warehouse_E           FIRST
Cargo_on_Trucks_Macro  MOVE WITH Forklifts FOR 1 MIN THEN FREE
                                                                       2*
FT_AfterRelease         Truckspot_WH_E        FIRST 1
  FT_AfterRelease         Truckspot_WH_E        WAIT 10 MIN
                                                                        1
FT_AfterRelease         Truck_restplace       FIRST 1
MOVE ON PortNet
```

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```
  Trucks_Full          Truckspot_WH_F        //RENAME AS
FT_AfterRelease

                                             GRAPHIC 1
                                             WAIT 1 MIN
                                                                        1
E_Bulk_Cargoes        Warehouse_F           FIRST
Cargo_on_Trucks_Macro  MOVE WITH Forklifts FOR 1 MIN THEN FREE

                                                                        2*
FT_AfterRelease       Truckspot_WH_F        FIRST 1
DISPLAY 443

  FT_AfterRelease      Truckspot_WH_F        WAIT 10 MIN
                                                                        1
FT_AfterRelease       Truck_restplace       FIRST 1
MOVE ON PortNet

  Trucks_Full          Car_Yard              //RENAME AS
FT_AfterRelease

                                             GRAPHIC 1
                                             WAIT 2 MIN
                                                                        1
E_Car                 Car_Yard              FIRST 8
Car_load_unload_on_trucks

MOVE ON PortNet

INC v_iFTAutos

                                                                        2*
FT_AfterRelease       Truck_restplace       FIRST 1
WAIT 10 MIN

  E_Car                Car_Yard              //WAIT UNTIL v_FloatShip
> 0
                                                                        1
E_Car                 Floating_berth        JOIN 1
MOVE ON PortNet

INC v_EAuto

  FT_AfterRelease      Truck_restplace                                  1
FT_AfterRelease       Truck_OutGate         FIRST 1
MOVE ON PortNet

  FT_AfterRelease      Truck_OutGate         WAIT 1 MIN
                                                                        1
FT_AfterRelease       EXIT                  FIRST 1
```

```
    E_Bulk_Cargoes        Warehouse_A
//Warehouse_to_Dockside_Macro
                                              Wait 200 min
                                                //Cargo_Loading_on_Ships
                                                                    1
E_Bulk_Cargoes        Berth_7              JOIN 1
//WAIT UNTIL Dock_side7 = 0

MOVE WITH Forklifts THEN FREE

Cargo_Loading_on_Ships


E_Bulk_Cargoes        Berth_6              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_5              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_4              JOIN
MOVE WITH Forklifts THEN FREE
 E_Bulk_Cargoes        Warehouse_B
//Warehouse_to_Dockside_Macro
                                           WAIT 200 MIN
                                                                    1
E_Bulk_Cargoes        Berth_7              JOIN 1
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_6              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_5              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_4              JOIN
MOVE WITH Forklifts THEN FREE
 E_Bulk_Cargoes        Warehouse_C
//Warehouse_to_Dockside_Macro
                                           WAIT 200 MIN
                                                                    1
E_Bulk_Cargoes        Berth_7              JOIN 1
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_6              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes        Berth_5              JOIN
MOVE WITH Forklifts THEN FREE
```

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```
E_Bulk_Cargoes      Berth_4              JOIN
MOVE WITH Forklifts THEN FREE
 E_Bulk_Cargoes      Warehouse_D
//Warehouse_to_Dockside_Macro

                                         WAIT 200 MIN
                                                                    1
E_Bulk_Cargoes      Berth_7              JOIN 1
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_6              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_5              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_4              JOIN
MOVE WITH Forklifts THEN FREE
 E_Bulk_Cargoes      Warehouse_E
//Warehouse_to_Dockside_Macro

                                         WAIT 200 MIN
                                                                    1
E_Bulk_Cargoes      Berth_7              JOIN 1
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_6              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_5              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_4              JOIN
MOVE WITH Forklifts THEN FREE
 E_Bulk_Cargoes      Warehouse_F
//Warehouse_to_Dockside_Macro

                                         WAIT 200 MIN
                                         DISPLAY 235
                                                                    1
E_Bulk_Cargoes      Berth_7              JOIN 1
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_6              JOIN
MOVE WITH Forklifts THEN FREE

E_Bulk_Cargoes      Berth_5              JOIN
MOVE WITH Forklifts THEN FREE
```

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```
E_Bulk_Cargoes        Berth_4                 JOIN
MOVE WITH Forklifts THEN FREE
 E_Bulk_Cargoes      Q_Crane1                                          1
E_Bulk_Cargoes        Berth_1                 JOIN 1
MOVE WITH Crane_1 FOR 2 MIN THEN FREE


 Trucks_Full          Container_Dole                                   1
E_Full_Containers  Container_Dole     TURN 1
MOVE WITH Toploaders FOR 3 MIN THEN FREE


E_Empty_Containers Container_Dole      TURN
MOVE WITH Toploaders FOR 3 MIN THEN FREE
                                                                2*
FT_AfterCrelease    Truck_restplace    FIRST 1
MOVE ON PortNet

 E_Empty_Containers Container_Dole          // IF v_2ship > 0 THEN
                                            //MOVE FOR 2 MIN
                                            //ELSE
                                            //IF v_3ship > 0 THEN
                                            //MOVE.FOR 2 MIN
                                            //ELSE
                                            //WAIT 30 MIN/*

                                                                1
E_Empty_Containers Q_Crane3,89          FIRST 1
MOVE WITH YardHustlers FOR 2 MIN THEN FREE
 E_Full_Containers   Container_Dole     //WAIT UNTIL v_3ship > 0
                                                                1
E_Full_Containers  Q_Crane3,99          FIRST 1
MOVE WITH YardHustlers THEN FREE

 Trucks_Full           Container_Chiquita //RENAME FT_AfterCrelease
                                                                1
E_Full_Containers  Container_Chiquita TURN 1
MOVE WITH Toploaders FOR 3 MIN THEN FREE

//GRAPHIC 2


E_Empty_Containers Container_Chiquita TURN
MOVE WITH Toploaders FOR 3 MIN THEN FREE

//GRAPHIC 3
```

```
                                                                            2
FT_AfterCrelease    Truck_restplace      FIRST 1
//MOVE ON PortNet

MOVE FOR 2 MIN


 E_Full_Containers   Container_Chiquita                                     1
E_Full_Containers   Q_Crane3,89          FIRST 1
MOVE WITH YardHustlers FOR 2 MIN THEN FREE

 E_Empty_Containers Container_Chiquita //WAIT UNTIL v_3ship > 0
                                                                            1
E_Empty_Containers Q_Crane3,99          FIRST 1
MOVE WITH YardHustlers THEN FREE
 Trucks_Full            Container_Others                                    1
E_Full_Containers   Container_Others     TURN 1
MOVE WITH Toploaders FOR 3 MIN THEN FREE

E_Empty_Containers Container_Others     TURN
MOVE WITH Toploaders FOR 3 MIN THEN FREE
                                                                            2*
FT_AfterCrelease    Truck_restplace      FIRST 1
MOVE ON PortNet

 E_Full_Containers   Container_Others                                       1
E_Full_Containers   Q_Crane3,49          FIRST 1
MOVE WITH YardHustlers FOR 2 MIN THEN FREE
 E_Empty_Containers Container_Others     //WAIT UNTIL v_3ship > 0
                                                                            1
E_Empty_Containers Q_Crane3,19          FIRST 1
MOVE WITH YardHustlers THEN FREE
 E_Full_Containers   Q_Crane3                                               1
E_Full_Containers   BerthS_3,99          JOIN 1
MOVE WITH Crane_3 FOR 2 MIN THEN FREE
                                                                            2
E_Full_Containers   BerthS_2,89          JOIN 1
MOVE WITH Crane_3 FOR 2 MIN THEN FREE
 E_Empty_Containers Q_Crane3                                                1
E_Empty_Containers BerthS_2             JOIN 1
MOVE WITH Crane_3 FOR 2 MIN THEN FREE

                                                                            2
E_Empty_Containers Berth_2              JOIN 1
MOVE WITH Crane_3 FOR 2 MIN THEN FREE


 Ship                 Ship_Counter        INC v_iShips
```

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```
Ship                    Floating_berth      0.100000 1
Ship_DockingTime_Macros

//WAIT UNTIL Attr = 1

Ship                    Berth_1             0.080000
Ship_DockingTime_Macros

Ship                    Berth_2             0.150000
Ship_DockingTime_Macros



Ship                    Berth_3             0.150000
Ship_DockingTime_Macros

Ship                    Berth_4             0.100000
Ship_DockingTime_Macros

Ship                    Berth_5             0.140000
Ship_DockingTime_Macros

Ship                    Berth_6             0.140000
Ship_DockingTime_Macros

Ship                    Berth_7             0.140000
Ship_DockingTime_Macros

 Ship                   Berth_7              INC v_7ship
                                                              1
Bulk_Cargoes        Dock_side7          FIRST Cargo_import_Macro
INC v_Dock7

Cargo_Unloading_Time_From_Ship

Ship                 Berth_7            FIRST
 Ship                Berth_6             INC v_6ship
                                                              1
Bulk_Cargoes        Dock_side6          FIRST Cargo_import_Macro
Cargo_Unloading_Time_From_Ship
```

```
INC v_Dock6

Ship                    Berth_6                FIRST
  Ship                    Berth_5                INC v_5ship
                                                                        1
Bulk_Cargoes            Dock_side5             FIRST Cargo_import_Macro
Cargo_Unloading_Time_From_Ship

INC v_Dock5

Ship                    Berth_5                FIRST
  Ship                    Berth_4                INC v_4ship
                                                 //WAIT UNTIL Attr = 1
                                                                        1
Bulk_Cargoes            Dock_side4             FIRST Cargo_import_Macro
Cargo_Unloading_Time_From_Ship

INC v_Dock4

Ship                    Berth_4                FIRST
  Ship                    Berth_3                INC v_3ship
                                                                        1
Full_Containers       Dock_side3             FIRST Num_of_InFContainers
MOVE WITH Crane_1 FOR 2 min THEN FREE

INC v_Dock3


Empty_Con             Dock_side3             FIRST
MOVE WITH Crane_1 FOR 2 min THEN FREE

INC v_Dock3


Ship                    Berth_3                FIRST
  Ship                    Berth_2                INC v_2ship
                                                                        1
Full_Containers       Dock_side2             FIRST Num_of_InFContainers
MOVE WITH Crane_1 FOR 2 min THEN FREE

INC v_Doc2


Empty_Con             Dock_side2             FIRST
MOVE WITH Crane_1 FOR 2 min THEN FREE

INC v_Doc2
```

```
Ship                 Berth_2              FIRST
 Ship                 Berth_1              INC v_1ship
                                                                    1
Bulk_Cargoes        Dock_side1           FIRST Cargo_import_Macro2
MOVE WITH Crane_3 FOR .5 MIN THEN FREE

INC v_Dock1


Ship                 Berth_1              FIRST
 Ship                 Floating_berth       INC v_FloatShip
                                                                    1
Cars                 FBerth_side          FIRST Car_Arrival_Macro
INC v_FloatBerth


Ship                 Floating_berth       FIRST
 Cars                 FBerth_side          DEC v_FloatBerth
                                          WAIT 3 MIN
                                          INC v_iFTAutos
                                                                    1
Cars                 Car_Yard             FIRST 1
MOVE FOR 3 MIN



 Trucks_Empty        Truck_Gate           Trucks_Checkin_Macro
                                          INC v_iInETrucks
                                                                    1
Trucks_Empty        Truck_restplace      FIRST 1
MOVE ON PortNet


 Cars                Car_Yard             GROUP 8 AS Cars
                                          JOIN 1 Trucks_Empty

                                          //JOIN 8 Cars
                                          Car_load_unload_on_trucks
                                          //RENAME AS
ET_AfterLoaded


                                                                    1
ET_AfterLoaded      Truck_restplace      FIRST 1
MOVE ON PortNet
```

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```
 Bulk_Cargoes          Dock_side7
Cargo_loadunload_Forklift_macro
                                        DEC v_Dock7
                                        INC v_iFTCargoes
                                                                1

Bulk_Cargoes          Warehouse_A       RANDOM 1
MOVE WITH Forklifts FOR 3 MIN THEN FREE


Bulk_Cargoes          Warehouse_B       RANDOM
MOVE WITH Forklifts FOR 3 MIN THEN FREE


Bulk_Cargoes          Warehouse_C       RANDOM
MOVE WITH Forklifts FOR 3 MIN THEN FREE


Bulk_Cargoes          Warehouse_D       RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes          Warehouse_E       RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes          Warehouse_F       RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes          Transit_shed      RANDOM
MOVE WITH Forklifts FOR 3 MIN THEN FREE
 Bulk_Cargoes          Dock_side6            DEC v_Dock6
                                             INC v_iFTCargoes

Cargo_loadunload_Forklift_macro
                                                                1
Bulk_Cargoes          Warehouse_A       MOST 1
MOVE WITH Forklifts FOR 3 MIN THEN FREE


Bulk_Cargoes          Warehouse_B       MOST
MOVE WITH Forklifts FOR 3 MIN THEN FREE


Bulk_Cargoes          Warehouse_C       MOST
MOVE WITH Forklifts FOR 4 MIN THEN FREE
```

```
Bulk_Cargoes         Warehouse_D         MOST
MOVE WITH Forklifts FOR 4 MIN THEN FREE


Bulk_Cargoes         Warehouse_E         MOST
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes         Warehouse_F         MOST
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes         Transit_shed        MOST
MOVE WITH Forklifts FOR 3 MIN THEN FREE
 Bulk_Cargoes        Dock_side5
Cargo_loadunload_Forklift_macro
                                    INC v_iFTCargoes
                                    DEC v_Dock5              1
Bulk_Cargoes         Warehouse_A         RANDOM 1
MOVE WITH Forklifts THEN FREE


Bulk_Cargoes         Warehouse_B         RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes         Warehouse_C         RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes         Warehouse_D         RANDOM
MOVE WITH Forklifts FOR 8 MIN THEN FREE


Bulk_Cargoes         Warehouse_E         RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE


Bulk_Cargoes         Warehouse_F         RANDOM
MOVE WITH Forklifts FOR 8 MIN THEN FREE


Bulk_Cargoes         Transit_shed        RANDOM
MOVE WITH Forklifts FOR 5 MIN THEN FREE
 Bulk_Cargoes        Dock_side4
Cargo_loadunload_Forklift_macro
                                    INC v_iFTCargoes
```

```
                                              DEC v_Dock4            1
Bulk_Cargoes       Warehouse_A        FIRST 1
MOVE WITH Forklifts FOR 4 MIN THEN FREE



Bulk_Cargoes       Warehouse_B        FIRST
MOVE WITH Forklifts FOR 4 MIN THEN FREE



Bulk_Cargoes       Warehouse_C        FIRST
MOVE WITH Forklifts FOR 6 MIN THEN FREE



Bulk_Cargoes       Warehouse_D        FIRST
MOVE WITH Forklifts FOR 8 MIN THEN FREE



Bulk_Cargoes       Warehouse_E        FIRST
MOVE WITH Forklifts FOR 5 MIN THEN FREE



Bulk_Cargoes       Warehouse_F        FIRST
MOVE WITH Forklifts FOR 4 MIN THEN FREE



Bulk_Cargoes       Transit_shed       FIRST
MOVE WITH Forklifts FOR 3 MIN THEN FREE
  Full_Containers    Dock_side3           DEC v_Dock3
                                          INC v_iFTContainers

                                                                    1
Full_Containers    Container_Dole     FIRST 1
MOVE WITH YardHustlers FOR 7 MIN THEN FREE



Full_Containers    Container_Others   FIRST
MOVE WITH YardHustlers FOR 6 MIN THEN FREE

  Empty_Con            Dock_side3           DEC v_Dock3
                                          INC v_iFTContainers
                                                                    1
Empty_Con          Container_Dole     FIRST 1
MOVE WITH YardHustlers FOR 5 MIN THEN FREE

Empty_Con          Container_Others   FIRST
MOVE WITH YardHustlers FOR 5 MIN THEN FREE
```

```
Full_Containers      Dock_side2              DEC v_Doc2
                                             INC v_iFTContainers
                                                                    1
Full_Containers   Container_Chiquita FIRST 1
MOVE WITH YardHustlers, 99 FOR 6 MIN THEN FREE

Full_Containers   Container_Others   FIRST
MOVE WITH YardHustlers, 89 FOR 6 MIN THEN FREE
  Empty_Con              Dock_side2           INC v_iFTContainers
                                              DEC v_Doc2
                                                                    1
Empty_Con           Container_Chiquita FIRST 1
MOVE WITH YardHustlers, 99 FOR 5 MIN THEN FREE


Empty_Con           Container_Others   FIRST
MOVE WITH YardHustlers, 89 FOR 5 MIN THEN FREE

 Trucks_Empty         Truck_restplace                              1
Trucks_Empty         Container_Dole     JOIN 1
MOVE ON PortNet




Trucks_Empty        Container_Chiquita JOIN
MOVE ON PortNet


Trucks_Empty        Container_Others   JOIN
MOVE ON PortNet


Trucks_Empty        Truckspot_WH_A     JOIN
MOVE ON PortNet


Trucks_Empty        Truckspot_WH_B     JOIN
MOVE ON PortNet

Trucks_Empty        Truckspot_WH_C     JOIN
MOVE ON PortNet

Trucks_Empty        Truckspot_WH_D     JOIN
MOVE ON PortNet

Trucks_Empty        Truckspot_WH_E     JOIN
MOVE ON PortNet
```

```
Trucks_Empty          Truckspot_WH_F      JOIN
MOVE ON PortNet

Trucks_Empty          Car_Yard            JOIN
MOVE ON PortNet

Trucks_Empty          Transit_shed        JOIN
MOVE ON PortNet
   Full_Containers      Container_Dole       JOIN 1 Trucks_Empty
                                             //JOIN 1 Full_Containers
                                             //RENAME AS
ET_AfterLoaded
                                             USE Toploaders FOR 3 min
                                                                    1
ET_AfterLoaded        Truck_restplace     FIRST 1
MOVE ON PortNet

   Empty_Con            Container_Dole       JOIN 1 Trucks_Empty
                                             //JOIN 1 Empty_Con
                                             //RENAME AS
ET_AfterLoaded
                                             //USE 1 Forklifts FOR
1min
                                             USE Toploaders FOR 4 min
                                                                    1
ET_AfterLoaded        Truck_restplace     FIRST 1
MOVE ON PortNet

   Full_Containers      Container_Chiquita JOIN 1 Trucks_Empty
                                             //JOIN 1 Full_Containers,
99
                                             //JOIN 1 Empty_Con, 89
                                             //RENAME AS
ET_AfterLoaded
                                             USE Toploaders FOR 2 min
                                                                    1
ET_AfterLoaded        Truck_restplace     FIRST 1
MOVE ON PortNet

   Empty_Con            Container_Chiquita JOIN 1 Trucks_Empty
                                             //RENAME ET_AfterLoaded
                                             USE Toploaders FOR 2 min
                                                                    1
ET_AfterLoaded        Truck_restplace     FIRST 1
MOVE ON PortNet

   Full_Containers      Container_Others    JOIN 1 Trucks_Empty
```

```
                                    USE 1 Toploaders FOR 2
min

                                    //JOIN 1 Full_Containers,
99
                                    //JOIN 1 Empty_Con, 79
                                    //RENAME AS
ET_AfterLoaded
                                    //USE 1 Forklifts FOR 2
min
                                                         1
ET_AfterLoaded      Truck_restplace      FIRST 1
MOVE ON PortNet

 Empty_Con            Container_Others    JOIN 1 Trucks_Empty
                                         //RENAME AS
ET_AfterLoaded
                                    USE Toploaders FOR 2 min
                                                         1
ET_AfterLoaded      Truck_restplace      FIRST 1
MOVE ON PortNet

 Bulk_Cargoes        Dock_side1
Cargo_loadunload_Forklift_macro
                                    DEC v_Dock1
                                    INC v_iFTCargoes
                                                         1
Bulk_Cargoes        Warehouse_A          RANDOM 1
MOVE WITH Forklifts FOR 3 MIN THEN FREE


Bulk_Cargoes        Warehouse_B          RANDOM
MOVE WITH Forklifts FOR 2 MIN THEN FREE


Bulk_Cargoes        Warehouse_C          RANDOM
MOVE WITH Forklifts FOR 4 MIN THEN FREE


Bulk_Cargoes        Warehouse_D          RANDOM
MOVE WITH Forklifts FOR 7 MIN THEN FREE


Bulk_Cargoes        Warehouse_E          RANDOM
MOVE WITH Forklifts FOR 2 MIN THEN FREE
```

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```
Bulk_Cargoes          Warehouse_F          RANDOM
MOVE WITH Forklifts FOR 2 MIN THEN FREE


Bulk_Cargoes          Transit_shed         RANDOM
MOVE WITH Forklifts FOR 2 MIN THEN FREE
 Bulk_Cargoes          Warehouse_A          WAIT 50 MIN
                                                                          1
Bulk_Cargoes          Truckspot_WH_A       MOST 1
MOVE WITH Forklifts FOR 1 MIN THEN FREE


Bulk_Cargoes          Railyard_1_bulk      MOST
MOVE WITH Forklifts FOR 1 MIN THEN FREE
 Bulk_Cargoes          Truckspot_WH_A       GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes
                                           JOIN 1 Trucks_Empty
                                           //JOIN

Cargo_on_Trucks_Macro Bulk_Cargoes
                                           //RENAME AS
ET_AfterLoaded
                                           WAIT 10 MIN

                                                                          1
ET_AfterLoaded        Truck_restplace      FIRST 1
MOVE ON PortNet

 Bulk_Cargoes          Warehouse_B          WAIT 50 MIN
                                                                          1
Bulk_Cargoes          Truckspot_WH_B       RANDOM 1
MOVE WITH Forklifts FOR 1 MIN THEN FREE


Bulk_Cargoes          Railyard_1_bulk      RANDOM
MOVE WITH Forklifts FOR 10 MIN THEN FREE

 Bulk_Cargoes          Truckspot_WH_B       GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes
                                           JOIN 1 Trucks_Empty
                                           //JOIN

Cargo_on_Trucks_Macro Bulk_Cargoes
                                           //RENAME AS
ET_AfterLoaded
                                           WAIT 10 MIN
                                                                          1
ET_AfterLoaded        Truck_restplace      FIRST 1
MOVE ON PortNet
```

```
 Bulk_Cargoes          Warehouse_C          WAIT 50 MIN
                                                                    1
Bulk_Cargoes          Truckspot_WH_C       RANDOM 1
MOVE WITH Forklifts FOR 1 MIN THEN FREE

Bulk_Cargoes          Railyard_1_bulk      RANDOM
MOVE WITH Forklifts FOR 6 MIN THEN FREE

 Bulk_Cargoes          Truckspot_WH_C       GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes

                                            JOIN 1 Trucks_Empty

                                            //JOIN
Cargo_on_Trucks_Macro Bulk_Cargoes
                                            //RENAME AS
ET_AfterLoaded
                                            WAIT 10 MIN
                                                                    1
ET_AfterLoaded        Truck_restplace      FIRST 1
MOVE ON PortNet

 Bulk_Cargoes          Warehouse_D          WAIT 50 MIN
                                                                    1
Bulk_Cargoes          Truckspot_WH_D       MOST 1
MOVE WITH Forklifts FOR 1 MIN THEN FREE

Bulk_Cargoes          Railyard_1_bulk      MOST
MOVE WITH Forklifts FOR 5 MIN THEN FREE

 Bulk_Cargoes          Truckspot_WH_D       GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes

                                            JOIN 1 Trucks_Empty
                                            //JOIN
Cargo_on_Trucks_Macro Bulk_Cargoes
                                            //RENAME ET_AfterLoaded
                                            WAIT 10 MIN

                                                                    1
ET_AfterLoaded        Truck_restplace      FIRST 1
MOVE ON PortNet

 Bulk_Cargoes          Warehouse_E          WAIT 50 MIN
                                                                    1
Bulk_Cargoes          Truckspot_WH_E       MOST 1
MOVE WITH Forklifts FOR 1 MIN THEN FREE

Bulk_Cargoes          Railyard_1_bulk      MOST
MOVE WITH Forklifts FOR 4 MIN THEN FREE
```

```
 Bulk_Cargoes         Truckspot_WH_E      GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes

                                         JOIN 1 Trucks_Empty
                                         //JOIN

Cargo_on_Trucks_Macro Bulk_Cargoes

                                         //RENAME ET_AfterLoaded
                                         WAIT 10 MIN
                                                                1
ET_AfterLoaded       Truck_restplace     FIRST 1
MOVE ON PortNet


 Bulk_Cargoes         Warehouse_F         WAIT 50 MIN

                                                                1

Bulk_Cargoes         Truckspot_WH_F      MOST 1
MOVE WITH Forklifts FOR 1 MIN THEN FREE

Bulk_Cargoes         Railyard_1_bulk     MOST
MOVE WITH Forklifts FOR 5 MIN THEN FREE

 Bulk_Cargoes         Truckspot_WH_F      GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes

                                         JOIN 1 Trucks_Empty
                                         //JOIN

Cargo_on_Trucks_Macro Bulk_Cargoes

                                         //RENAME ET_AfterLoaded
                                         WAIT 10 MIN
                                                                1
ET_AfterLoaded       Truck_restplace     FIRST 1
MOVE ON PortNet

 Bulk_Cargoes         Transit_shed        GROUP
Cargo_on_Trucks_Macro AS Bulk_Cargoes

                                         JOIN 1 Trucks_Empty
                                         //JOIN

Cargo_on_Trucks_Macro Bulk_Cargoes

                                         //RENAME ET_AfterLoaded
                                         WAIT

Cargo_Waiting_on_Transit

                                         USE Forklifts FOR 10 min
                                                                1
ET_AfterLoaded       Truck_restplace     FIRST 1
MOVE ON PortNet

 Ship                Berth_7             WAIT UNTIL v_Dock7 = 0
```

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```
                                        //JOIN N(150, 20)
E_Bulk_Cargoes
                                                                      1
Ship                    Ship_outer_harbour FIRST 1
DISPLAY 1156

Ship_Leaving_Time

DEC v_7ship

  Ship                  Berth_6              WAIT UNTIL v_Dock6 = 0
                                             //JOIN N(1500, 200)
E_Bulk_Cargoes


                                                                      1
Ship                    Ship_outer_harbour FIRST 1
Ship_Leaving_Time

//DEC v_6ship

  Ship                  Berth_5              WAIT UNTIL v_Dock5 = 0
                                             //JOIN N(150, 20)
E_Bulk_Cargoes
                                                                      1.
Ship                    Ship_outer_harbour FIRST 1
Ship_Leaving_Time

DEC v_5ship

  Ship                  Berth_4              WAIT UNTIL v_Dock4 = 0
                                             //JOIN N(150, 20)
E_Bulk_Cargoes

                                             DISPLAY 1
                                                                      1
Ship                    Ship_outer_harbour FIRST 1
DEC v_4ship

Ship_Leaving_Time

//Attr = 1


  Ship                  Berth_3              WAIT UNTIL v_Dock3 = 0
                                             //JOIN
Num_of_ExFContainers E_Full_Containers, 99
                                             //JOIN
Num_of_ExEContainers E_Empty_Containers, 89
```

```
                                                                         1
Ship                 Ship_outer_harbour FIRST 1
Ship_Leaving_Time

DEC v_3ship

  Ship                 Berth_2              WAIT UNTIL v_Doc2 = 0
                                            //JOIN
Num_of_ExFContainers E_Full_Containers, 99
                                            //JOIN
Num_of_ExEContainers E_Empty_Containers, 89
                                                                         1
Ship                 Ship_outer_harbour FIRST 1
Ship_Leaving_Time

DEC v_2ship

  Ship                 Berth_1              WAIT UNTIL v_Dock1 = 0
                                            //WAIT UNTIL v_1ship = 0
                                            //JOIN N(150, 20)
E_Bulk_Cargoes
                                            //Attr = 1
                                                                         1
Ship                 Ship_outer_harbour FIRST 1.
DEC v_1ship

Ship_Leaving_Time

DISPLAY 888

  Ship                 Floating_berth       JOIN 8 E_Car
                                            //WAIT UNTIL v_FloatBerth
= 0
                                            //JOIN Car_Leaving_Macro
E_Car
                                                                         1
Ship                 Ship_outer_harbour FIRST 1
Ship_Leaving_Time

DEC v_FloatShip

DISPLAY 88

  Ship                 Ship_outer_harbour                                1
Ship                 EXIT                 FIRST 1
  ET_AfterLoaded       Truck_restplace    Wait 2 min                     1
ET_AfterLoaded       Truck_OutGate        FIRST 1
MOVE ON PortNet
```

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```
   ET_AfterLoaded        Truck_OutGate       WAIT N(2, .5) MIN
                                                                    1
ET_AfterLoaded        EXIT                FIRST 1
  FT_AfterCrelease    Truck_restplace                               1
FT_AfterCrelease      Truck_OutGate       FIRST 1
  FT_AfterCrelease    Truck_OutGate        WAIT 2 MIN
                                                                    1
FT_AfterCrelease      EXIT                FIRST 1
  Trains              Railyard             JOIN 270 Bulk_Cargoes
                                           INC v_Trains
                                           WAIT 60 MIN             1
Trains                EXIT                FIRST 1
  Bulk_Cargoes        Railyard_1_bulk      INC v_TBulk
                                                                    1
Bulk_Cargoes          Railyard            JOIN 1


****************************************************************
***************
*                               Arrivals
*
****************************************************************
***************


   Entity            Location     Qty each
First Time Occurrences Frequency  Logic
   ----------------  -----------  ----------------------------------
------------  ----------  ----------  ---------------
   Ship              Ship_Counter 1; Seven_Ships_per_week
1 day        inf          1 wk
   Full_Containers Dock_side2
   Cars              Berth_1
   Trucks_Full       Truck_Gate   N(100,20); Truck_Arrival_Cycle
1 day        inf          1 wk
   Trucks_Empty      Truck_Gate   N(2850,150); Truck_Arrival_Cycle
1 day        inf          1 wk
   Trains            Railyard     1; Train_Arrival_Cycle
3 day        INF          1 wk


****************************************************************
***************
*                            Shift Assignments
*
****************************************************************
***************


   Locations  Resources  Shift Files                    Priorities
Disable Logic
```

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```
          ---------- ---------- ------------------------------ ------------
- ------- ------------------
                              C:\ProMod4\models\shifts.sft 99,99,99,99
No


*****************************************************************
***************
*                              Attributes
*
*****************************************************************
***************


    ID           Type           Classification
    ----------   ------------   ---------------
    Attr         Integer        Location


*****************************************************************
***************
*                              Variables (global)
*
*****************************************************************
***************


    ID               Type         Initial value Stats
    --------------   ------------  ------------- -----------
    v_iShips         Integer       0             Time Series
    v_iFTCargoes     Integer       0             Time Series
    v_iFTContainers  Integer       0             Time Series
    v_iFTAutos       Integer       0             Time Series
    v_iInFTrucks     Integer       0             Time Series
    v_iInETrucks     Integer       0             Time Series
    v_7ship          Integer       0             Time Series
    v_6ship          Integer       0             Time Series
    v_5ship          Integer       0             Time Series
    v_4ship          Integer       0             Time Series
    v_3ship          Integer       0             Time Series
    v_2ship          Integer       0             Time Series
    v_1ship          Integer       0             Time Series
    v_FloatShip      Integer       0             Time Series
    v_Dock3          Integer       0             Time Series
    v_Doc2           Integer       0             Time Series
    v_Dock1          Integer       0             Time Series
    v_Dock4          Integer       0             Time Series
    v_Dock5          Integer       0             Time Series
    v_Dock6          Integer       0             Time Series
    v_Dock7          Integer       0             Time Series
```

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```
v_FloatBerth      Integer         0              Time Series
v_EAuto           Integer         0              Time Series
v_TBulk           Integer         0              Time Series
v_Trains          Integer         0              Time Series


*****************************************************************
****************
*                                    Macros
*
*****************************************************************
****************

  ID                                        Text
  ------------------------------------      ------------
  Num_of_forklifts                          90
  Num_of_yardhass                           12
  Num_of_toploaders                         4
  Num_of_InFContainers                      N(895,50)
  Trucks_Checkin_Macro                      WAIT 2 min
  Cargo_import_Macro                        N(2890,120)
  Cargo_Unloading_Time_From_Ship            WAIT .12 min
  Cargo_import_Macro2                       N(1960,130)
  Num_of_InEContainers                      N(50,20)
  Num_of_ExFContainers                      N(30,5)
  Num_of_ExEContainers                      N(20,5)

  Car_Arrival_Macro                         N(1440,175)
  Cargo_on_Trucks_Macro                     12
  Warehouse_to_Dockside_Macro               //MOVE WITH Forklifts FOR 2
MIN THEN FREE

                                            IF v_7ship > 0 THEN
                                            {
                                            //MOVE WITH Forklifts FOR 2
MIN

                                            }
                                            ELSE IF v_6ship > 0 THEN
                                            {
                                             //MOVE WITH Forklifts FOR 2
MIN

                                            }
                                            ELSE IF v_5ship > 0 THEN
                                            {
                                             //MOVE FOR 2 min
                                            }
                                            ELSE IF v_4ship > 0 THEN
                                            {
                                             //MOVE FOR 2 min
```

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```
                                          }
                                          ELSE IF v_1ship > 0 THEN
                                          {
                                           WAIT 2 min
                                          }


   Car_load_unload_on_trucks          WAIT N(30,15) min
   Ship_DockingTime_Macros            WAIT N(50,25) min
   Cargo_loadunload_Forklift_macr     WAIT N(.5,.25) min

   Cargo_Loading_on_Ships             WAIT N(2,1) min

   Ship_Leaving_Time                  MOVE FOR N(30, 10) min

   Car_Leaving_Macro                  N(100, 40)
   Cargo_Waiting_on_Transit           N(200, 100) MIN
```

```
************************************************************
****************
*                              Arrival Cycles
*
************************************************************
****************
```

ID Value	Qty / %	Cumulative	Time (Hours)	
Seven_Ships_per_week	Quantity	No	6	0
			10	2
			30	0
			33	1
			55	0
			57	1
			78	0
			80	1
			102	0
			104	1
			166	0
			168	1
Eight_Ships_per_week	Quantity	No	6	0
			10	2
			30	0
			33	1
			55	0
			57	2
			78	0

			80	1
			102	0
			104	1
			166	0
			168	1
Nine_Ships_per_week	Quantity	No	6	0
			10	2
			30	0
			33	2
			55	0
			57	2
			78	0
			80	2
			102	0
			104	1
			166	0
			168	0
Ten_ships_per_week	Quantity	No	6	0
			10	2
			30	0
			33	2
			55	0
			57	2
			78	0
			80	2
			102	0
			104	1
			166	0
			168	1
Truck_Arrival_Cycle	Percent	No	7	0
			9	4
			13	11
			15	3
			17	2
			30	0
			33	6
			37	10
			42	4
			54	0
			58	6
			66	14
			78	0
			80	5
			90	15
			101	0
			105	6
			114	14
			168	0
Train_Arrival_Cycle	Quantity	No	24	1

```
                                          48              1
                                          72              1
                                          96              1
                                         120              1
                                         144              1
                                         168              1


*********************************************************************
***************
*                              External Files
*
*********************************************************************
****************

  ID              Type                  File Name
Prompt
  ----------      -----------------     -----------------------------  -----
------
  (null)          Shift                 C:\ProMod4\models\shifts.sft


*********************************************************************
*
*
*                                  Streams
*
*********************************************************************

  Stream #        Seed #                Reset
  -----------     -------------         -------------
  1               23                    Yes
  2               37                    Yes
  3               54                    No
```

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