Southwest Region University Transportation Center

Loading/Unloading Operations and Vehicle Queuing Processes at Container Ports

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16. Abstract

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

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EXECUTIVE SUMMARY

Increased global competition has resulted in shipping ports that are increasingly congested. To provide adequate space for the increased traffic, ports must either expand facilities or improve the efficiency of the operations. Because many ports are land constrained, the only available option—the one investigated in this report—is to improve operational efficiency.

In exploring ways in which ports can improve efficiency, we analyze the various elements associated with wharf crane operations. Looking in particular at the Port of Houston and the Port of New Orleans, we collected historical crane performance records for 1989, including general descriptions of each ship serviced and detailed accounts of how many (and what type of) containers were moved to or from the ship. This information was then used to develop an econometric model to predict the net productivity of the wharf crane based on ship characteristics and on the distribution of container moves expected between the storage yard and the wharf crane. While the resulting model proved inadequate for use as a forecasting tool, it did identify several variables having statistically significant influence on the net productivity of the wharf crane. For example, we learned that the number of outbound container moves, the number of inbound container moves, the type of ship being serviced, the number of ships being serviced simultaneously, and the stevedoring company contracted to service the ship—all have significant impact on crane productivity. And although the model is site-specific for the Barbours Cut Terminal in the Port of Houston, we expect that the same variables would have similar effects at other national container ports.

ABSTRACT

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

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

GROWTH OF CONTAINERIZATION

Although produce and cargo have always been consolidated to minimize stowage, it was not until the European Industrial Revolution, beginning in the mid-18th century, that containerization technology entered into the modern era. Yet surprisingly, even then the rapid development of transportation technology did not bring about a significant change in the way cargo was shipped. Occasionally, goods were consolidated into larger units that were placed by longshoremen or by crane on railroad flatcars, barges, trucks, and ships. But more often, freight of different shapes and sizes was routinely stored in a ship's hold or in boxcars; upon arriving at its destination, the freight was again moved, piece by piece, by longshoremen. The utilization of break-bulk cargo continued well into the 1900's, almost 100 years after the development of the steamship.

During the Second World War, ocean freight transportation increased even more dramatically. And though the growth resulted in greater stowage capacities, merchant shipping continued to use the traditional break-bulk method of storing cargo [Ref 1]. One consequence of increased stowage capacity was the delay that ships faced while waiting in port for their cargo to be transferred. After the war, intermodal transportation began to undergo significant changes.

In the mid-1950's, Malcolm McLean, the founder of McLean Trucking Company, developed a new approach to cargo shipping. Realizing that freight haulers could enjoy substantial savings if the loading and unloading requirements of cargo were simplified, McLean proposed that cargo of all types be placed in a container suitable for transport over rail, land, or ocean (the cargo would not be restowed in other containers). Additionally, in his system containers would be moved to and from a ship by gantry cranes, with railroad cars then used to carry the chassis and container in a piggyback fashion to the next destination. In April 1956, the *SS Maxton*, using these methods, successfully transported 66 containers from New York to Houston. The concept of containerization caught on rapidly, and, by 1965, McLean had created a new container shipping company, Sea-Land Service, Inc., that maintained regular routes throughout the U.S. east coast [Ref 2].

Stimulated by McLean's intermodal example, the freight industry underwent a container revolution from roughly 1965 to 1972 [Ref 3]. The revolution was sustained and reinforced by the particular benefits of containerization: since a ship whose cargo was in containers could be loaded and unloaded by modern wharf cranes, the amount of time a ship was in port was significantly reduced [Ref 4].

This reduction in transfer delays attracted increasing numbers of customers who saw the value and the security of containers. At the same time, the capacity of containerships increased dramatically, to 3,000 TEU's (twenty-foot equivalent unit) [Ref 5]. These higher-capacity containerships were designed not only to transport the highest number of containers possible, but also to guarantee that the containers could be loaded and unloaded at maximum speed. By placing container guides and permanent castings in the hold and on the deck of a ship, shipyard technicians transformed general cargo vessels into cellularized ships, so that the stacking and securing of containers was made much easier. While some ships were being created or transformed into high-capacity cellularized containerships, others (non-cellularized and roll-on/roll-off) retained portions of their decks or holds to allow for more flexible cargo systems. These flexible cargo systems allowed semi-bulk commodities such as forestry products, steel, and vehicles to be transported alongside the containers. Along with the cellularized ships, these non-cellularized and roll-on/roll-off (ro/ro) vessels comprise the three types of containerships used in the modern fleet.

Since the mid-1970's, several technological innovations have further improved the movement of containerized cargo. Cellularized containerships have continued to increase in size, with current capacities ranging over 4,500 TEU's. Cranes that traditionally operated from the vessel itself have been replaced by larger, more efficient wharf gantry cranes owned and operated by the port entity. Most containers transport only general cargo from origin to destination, but there are also specialized containers that safely transport hazardous materials, liquified products, refrigerated and perishable goods, and dry bulk commodities such as grain. Wharf cranes using cables and flat racks can even move oversized cargo such as boats and heavy machinery.

Today the overwhelming majority (over 70 percent) [Ref 6] of general cargo entering or exiting the United States is containerized. The number of containers that were moved through U.S. ports increased steadily from 1970 to 1983, with the exception of a slight downturn in 1975. Figure 1.1 illustrates that the steady growth resulted in a five-fold increase in the total number of containers moving through the U.S. from 1970 to 1983. In 1983, over 4 million TEU's (39.9 million long tons) were transported through U.S. ports [Ref 7]. The growth of containerization in the U.S. since 1983 is borne out by statistics from The Port of Houston and The Port of New Orleans, two of the nation's busiest ports.

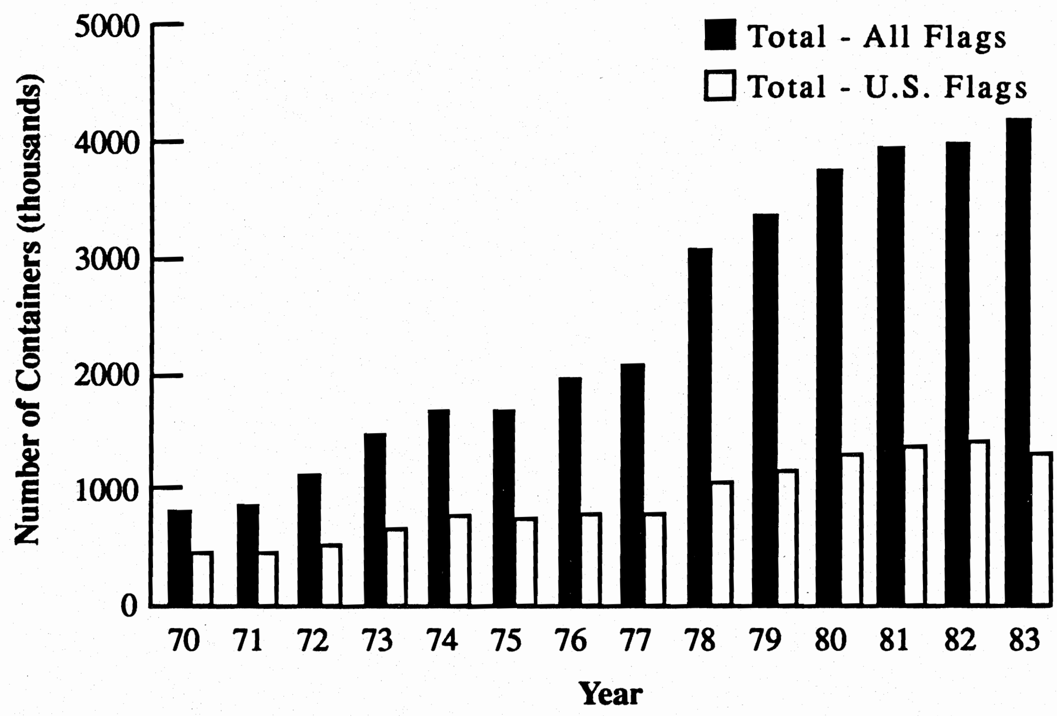


Figure 1.1. Total number of containers moving through the U.S. from 1970 to 1983. (Note: Statistics available for only the years shown.)

The Port of Houston's Barbours Cut Container Terminal and The Port of New Orleans' France Road Container Terminal [Ref 8] have grown significantly in the last 20 years. For example, the number of containers handled by Barbours Cut increased from 14,000 TEU's in 1972, to 127,000 TEU's in 1983 [Ref 9], and to over 500,000 TEU's in 1990 [Ref 10]. Similarly, the number of containers handled by The Port of New Orleans grew from 11,000 TEU's in 1972 to 84,000 TEU's in 1983 [Ref 11], and to over 157,000 TEU's in 1990 [Ref 12]. The down side of such growth is obvious: as ports increase container traffic, the congestion within the ports also increases, resulting in inefficient operations. Some U.S. container ports have responded to the congestion with expanded facilities. However, many ports, constrained by available land area, are unable to expand.

As mentioned, congestion within ports results in inefficient operations and, thus, longer-than-necessary delays for ships in service or awaiting service. Port authorities have recently placed ship turnaround time as one of the most important factors considered in selecting a port [Ref 13]. The detrimental effects of extensive port delays were realized early in the container revolution:

> No single cause more directly affects the cost of living of a maritime country than the speed with which ships are turned round in her ports. More than half of the price of an imported article is made up of costs of the transportation that has linked the producer with the consumer. At no point in the chain can costs so easily get out of control as at the port—the vital link that enables sea-going traffic to be transferred to road or rail: this is the primary function of all ports, whatever their shape or size. The speed at which this physical transfer takes place is the criterion of the port's efficiency [Ref 14].

The goals, then, of port operators and researchers include the reduction of turnaround time for ships by improving loading and unloading operations. This goal of reducing turnaround time for ships can be achieved by improving the coordination of such port subsystems as crane operations, container storage strategies, and modal interfaces.

OBJECTIVES

This report explores the various operations relating to wharf gantry cranes. Specifically, it focuses on the forecasting, simulation, and theoretical queuing models that describe the loading and unloading procedures employed by most container ports. These models are tools that can assist the researcher or port operator when labor and operational questions arise. Underlying each of these models are exploratory analyses of unique data sets that describe the operations of two of the nation's busiest container ports.

As indicated, one underlying goal of container port research is the reduction of vessel turnaround times. In keeping with that goal, this paper provides a study of the loading and unloading operations surrounding the wharf crane. Predictive and analytical models are explored that can assist port managers in making operational and labor decisions. Extensive use is made of simulation tools and mathematical queuing models.

LITERATURE REVIEW

The literature review that follows is divided into two sections. The first section provides an overview of the pertinent literature related to general port operations and the operations specifically applicable to container ports. The second section summarizes the body of literature underlying the simulation and queuing model tools used in this report.

General Port Operations

Because of the relatively recent emergence of containerization as a dominant force in the freight industry, there are few publications that deal specifically with containerships or container port operations. In the seventies and early eighties, the majority of ocean shipping literature was dedicated to bulk cargoes. Oram and Baker [Ref 15] provided one of the first detailed accounts of the development of containerization as well as valuable information about the equipment used in the container freight industry and about the potential for heavy international container traffic. Whittaker [Ref 16] introduced the "through" concept of containerization and studied, in great detail, the economics and logistics of containerization. The through concept of containerization is a formalization of the intermodal concept that cargo should be stored in a container that facilitates the free movement from mode to mode with standardized equipment and procedures. Detailed studies in freight traffic and in the management and logistics of container operations on the ocean side of the port were provided by Gilman [Ref 17] and Frankel [Ref 18]. Frankel was the first to pinpoint the critical issues of taking advantage of modern communications, monitoring, information storage and retrieval, and computing technology in the container industry. Beyond these four general accounts of containerization, the available literature can be naturally categorized into one of the following port subsystems: water-side access, land-side access, ship loading and unloading, and storage.

Detailed analysis of port operations began with Atkins [Ref 19] who documented land-side operations, including comparisons of storage yard strategies and container handling equipment. Grounded and chassis storage systems are described and compared, as are all operations related to the storage of containers [Ref 20]. The massive movement of containers within and between storage yards often creates empty chassis imbalances, particularly when chassis storage techniques are employed, or when roll-on / roll-off vessels are serviced. Corbett [Ref 21] addressed both the problem of storing empty chassis and the equipment used in the process.

Studies of general port productivity began to appear in the mid-eighties. Marcus [Ref 22] discussed the role of port research and proposed a research framework for ports in less developed countries, with a particular emphasis on container ports. Several studies have been undertaken by Daganzo and co-workers at the University of California at Berkeley. Specifically, Daganzo [Ref 23] showed that the delay imposed on ships by various crane operating strategies can vary considerably, and he presented a simple method of calculating the maximum berth throughout, during periods of congestion. Crane operating strategies refer to the way cranes move about the holds of a ship while loading and unloading containers. Peterkofsky [Ref 24] created a computer solution for the crane scheduling problem that assigns cranes to the holds of a ship. Daganzo [Ref 25], and Peterkofsky and Daganzo [Ref 26] also presented analytical solutions and strategies for the crane scheduling problem.

Queuing models that focus on the water-side of the port system and that describe ship access to a port are provided by Easa [Ref 27] and Sabria [Ref 28]. Daganzo [Ref 29] pulls together much of this research in a queuing study of multipurpose seaports that service two traffic types and that give priority to liners (type one).

The storage system of the land/water interface has received less attention than the water-side for several reasons. First, it is often easy to apply water-side analyses to both container ships and bulk vessels. In other words, very similar analyses can be applied to both situations. Second, many simulation models and storage analyses are created under private contract and are not published in public sources. Two exceptions are Nehrling [Ref 30], and Hammesfahr and Clayton [Ref 31]. Nehrling developed a detailed loading and unloading simulation model consisting of the ship, containers, container handling vehicles, storage yards, and wharf cranes. The model was created using General Purpose Simulation System (GPSS) in such a way that physical system constraints were established by the user. More than ten years later, Hammesfahr and Clayton employed the Queueing-Graphical Evaluation and Review Technique (Q-GERT) simulation package to model storage operations that included a rail interface with the storage yard.

The number of restows required, when storing containers, is directly affected by the original placement of the containers in the yard. The allocation of storage space in a container port directly affects the speed at which export containers may be extracted from the yard, and thus the speed at which ships can be turned around. The minimum storage space required for specific storage strategies is explored by Taleb-Ibrahimi, Castilho, and Daganzo [Ref 32].

Because of the relatively recent emergence of the container industry, there exists a significant lack of quality research regarding the subsystems of the container port entity. The notable exceptions include the studies performed at the University of California, which were mentioned in the above paragraphs. This report also explores mathematical models of the queuing phenomena that are prevalent within container ports. The following section reviews the queuing literature that underlies several of the approaches taken. Because of the extensive amount of material published on cyclic and network queues, the review is not intended to be comprehensive. The discussion will, however, highlight the significant developments that simplify the analysis of cyclic queues in the port.

Applicable Queuing Literature

The first paper dealing with cyclic queues was probably published in 1954 in the *Operations Research Quarterly* by J. Taylor and R.R.P. Jackson. Since that time, hundreds of papers have been published on the many variations of network queues, including cyclic queues. One of the most recent and broad reviews of network queue literature was written by Koenigsberg [Ref 33]. Modern queuing theory has developed to the point that it is relatively simple to obtain approximate performance measures for many different applications, including cyclic queues. A cyclic queue is a special condition of a network queue that has no theoretical beginning nor end; the customers simply visit each service facility (in a specified order), repeating the process until the system is terminated.

The simplest queuing systems to analyze are those that can be modeled as Poisson processes. Open and closed cyclic queuing networks are no exception. For this reason, the vast majority of network queue research has been made under the Poisson assumption. It has been proven that a system with Poisson arrivals, as well as independent and identically distributed exponential service times, also releases customers according to a Poisson distribution with the same rate as the arrivals. Many authors claim that this proof can be justified in one's mind, but Burke [Ref 34] provides a formal analytical proof of this result for both single-server and multi-server queues. A similar proof is provided by Jackson [Ref 35], who extended it to the open network (a network in which customers are allowed to enter or to exit any station from outside the system). Jackson shows that if the customers entering the system from outside the network do so according to a Poisson distribution, "the waiting line lengths of the departments are independent, and are exactly like those of the 'ordinary' multi-server systems that they resemble."

The most common cyclic queue that has been analyzed is a system with two stages, specifically the classic two stage machine repair problem. Although the two stage cyclic queue seems rather limiting, there are variations that allow it to be widely applicable. For example, models can be modified to recognize the existence of feedback in the network, blocking between service stages, "outside" arrivals of vehicles, and transient operations. Several classic texts that present discussions of general queues and the aforementioned variations are Saaty [Ref 36], Kleinrock [Ref 37], and Gross and Harris [Ref 38].

Early in the research of network queues, Hunt [Ref 39] reported on four specific cases, namely, infinite queue permissibility, no allowable queues, finite queues, and the production line.

The analysis was limited to an open network, and the results were as recognizable as those for a classic queuing system. The most important results are for infinite and finite queues where methods of determining steady-state probabilities are presented with approximations of the mean number of units in the system. All queues in Hunt's model operate under FIFO (first in/first out) conditions with no defections and no delays between stages.

Koenigsberg has completed many papers on various applications of cyclic queues. In one of his earliest papers, Koenigsberg [Ref 40] treated a problem that was similar to that of the model considered by Hunt (though Koenigsberg's problem was for a cyclic queue). The actual example discussed by Koenigsberg is that of a machine repair problem with two stations. Recognizing this as a cyclic queue, Koenigsberg introduced the concept as follows: the arrival rate at the repair facility remains Poisson, but the rate is now proportional to the number of machines in service. It is assumed that there are no transit times between stages; a similar assumption was made for the Hunt model.

Kleinrock [Ref 41] studied a very similar model and obtained exact results for two stages with queue capacity of arbitrary size and blocking from one service stage to the next. A performance measure, R, defined a ratio of the expected time for processing the N customers in the multi-processor system, to the expected time it would take a single processor by itself to serve N customers. This measure is explored thoroughly for one server and multiple servers in each stage.

Two papers were published together on closely related topics by Gordon and Newell [Ref 42, 43]. Both papers apply to a cyclic queue with many stages in series, each with one or more servers in parallel. Also, each of the servers in both papers have the same service rate. The first of the papers illustrates that a closed cyclic system with N customers is "stochastically equivalent to open systems in which the number of customers cannot exceed N." The authors show that as N increases the distribution of the customers in the system, the system is regulated by the stage with the slowest effective service rate. The second paper applies the duality concept to a system in which the effects of blocking are significant. The paper closes with a comparison of two extreme cases: one in which there is no blocking possible and the other in which the distribution of customers is determined completely by the effect of blocking.

All of the above systems have assumed steady-state conditions. This is a questionable assumption for many systems. Short work shifts, mechanical breakdowns, and employee mistakes are only a few examples of why a system stops frequently, preventing steady-state conditions from being sustained. Maher and Cabrera [Ref 44] considered the effects and the importance of transient behavior. Results are presented for M/M/1, D/D/1, M/D/1, and E/M/1 systems, since they apply to an earth moving application. For a specific example, correction factors for the optimal number of trucks in the system are determined from the steady-state solution.

Another assumption of the aforementioned papers is that there are no transit times between stages. It is difficult to say how often this actually occurs. For example, when vehicles or pedestrians are the customers of the system, zero transit times are obviously not valid. Surprisingly, there has been very little research completed that considers the effects of transit or lag times. Maher and Cabrera [Ref 45] successfully analyzed a cyclic queue with transit times and discovered that the production rate of the system does not depend on individual transit times; instead, it depends on the sum of the mean transit times. The validity of this proof is that the production of a cyclic queue is not dependent on individual stage mean transit times, but on the total mean (all stages combined) transit times. In other words, all transit stages do not need to be modeled in specific order in the network model. Instead, they may be grouped together and modeled as one single transit stage, without affecting the performance of the model. This holds true for any distribution of transit times. The authors also present an explicit expression for a two stage example to determine the average production rate for steady-state operations. Posner and Bernholtz [Ref 46, 47] provided research of a similar nature by considering transit time in finite queuing networks (1968, p. 962-976) and several classes of units (1968, p. 977-985). The second paper expands the results of the first by considering exponential and general transit times.

An interesting perspective on cyclic queue applications is provided by Daskin and Walton [Ref 48]. Two models are applied to the example of small tankers servicing very large crude carriers (VLCC's) by shuttling between the VLCC and the shore. Thus, it is a two stage cyclic queue with rather large transit times. Two models are used, one that models the VLCC delays and another that analyzes the delays placed on the small tankers. The authors provide results for the common performance measures (L, W, L_q, and W_q). Finite queues were assumed in the analysis.

Carmichael [Ref 49] provides an excellent reference illustrating the analysis of numerous cyclic and network queues. Specifically, Carmichael thoroughly explores queues that are prevalent in many engineering applications including earthmoving, quarrying, concreting, and mining operations. Most importantly, the presence of transit times is thoroughly discussed. The same is true for McNickle and Woollons [Ref 50] who studied the queuing of forestry trucks at a single-lane weighbridge. Exponential interarrival and service times are assumed in both of these references.

The small number of cyclic models that consider transit times between stages can be explained. Part of the reason is simply that transit times can easily be modeled as a separate stage of the network. This increases the number of stages in the queuing network; nevertheless, the concepts presented in this review still apply. Throughout this report, transit stages are included in all models as a stage in the cyclic queue.

RESEARCH APPROACH

This research report investigates the operation of container port wharf cranes. The assumption of exponential service times at wharf gantry cranes is tested. The testing of the assumption is accomplished by collecting descriptive time/event data for several cranes and several ships at two Gulf container ports: The Port of Houston's Barbours Cut Terminal and The Port of New Orleans' France Road Terminal. Descriptions of all wharf crane operations are derived from field data; researchers record the time of occurrence of specific events with hand held computers. Additionally, historical data are used in an effort to develop an econometric model that forecasts crane productivity under user-specified conditions.

The remainder of this report is structured as a loose chronological presentation of the past year's effort. Chapter 2 provides an overview of the operations within the container storage yard that are pertinent to subsequent research. Chapter 3 presents the analysis and development of an econometric model that identifies the variables that significantly affect crane productivity. Chapter 4 includes a description of the data collection efforts that form the basis of the remainder of the report. The results of the field data analysis include summaries of interarrival, service, and backcycle distributions that show that Poisson-based assumptions are not always valid. Chapter 5 employs several analysis techniques in order to model wharf crane activities; these techniques include simulation models, closed cyclic queues, and single-server network queues. Recommendations for reducing congestion are based on the field data. Chapter 6 summarizes the results and recommendations stemming from the data analyses and incorporates suggestions for continued research on wharf crane productivity.

CHAPTER 2. OVERVIEW OF PORT OPERATIONS

The container port, which provides the interface between railroads, ocean-going ships, and over-the-road trucks, represents a critical link in the intermodal chain. As discussed in Chapter 1, the profitability of a containership's journey depends on the speed at which the ship can be serviced at the port. Quick servicing, in turn, depends on how effectively operations within the port are coordinated. These operations relate primarily to the storage yard and to the gantry crane.

In this chapter we discuss these port operations, focusing specifically on the process of loading and unloading a containership by means of wharf gantry cranes. Most of the operations reported in this chapter describe the operations at The Port of Houston's Barbours Cut Terminal and The Port of New Orleans' France Road Terminal—ports that were data collection sites for this study. Barbours Cut is a dedicated container port located in La Porte, Texas, at the mouth of the Houston ship channel, while the France Road Terminal is located on Industrial Canal in New Orleans, Louisiana.

WHARF CRANE OPERATIONS AND DELAYS

Gantry cranes that service containerships provide, arguably, the single most important operation associated with the loading and unloading a ship. They represent the only means of moving containers to or from a ship, with the exception of those ships that have roll-on/roll-off (ro/ro) capabilities. When a crane breaks down, work ceases until the repair is made or until another crane is positioned to continue service.

Access into the ship is provided by a cable suspended carriage, shown in Figure 2.1, which is specifically designed to pick up and release containers from top corner castings. The carriage expands to accept both 20 and 40 feet containers (over 90 percent of the containers moved in the U.S. are either 8.5 x 8.5 x 20 or 8.5 x 8.5 x 40 feet). Containers of greater length, such as 48 and 52 feet, can be moved by most cranes, though older cranes may be limited by the clearance between the crane's legs. The expansion or contraction of the container carriage can be done, with negligible delays, while the carriage is in motion. The container carriage is also used to move specialty containers such as flat beds or oversized cargo; however, cables must be manually attached to the carriage and the castings of the flat bed at ground level or within the ship. The delay experienced here is obviously greater than that caused by changing the carriage length.

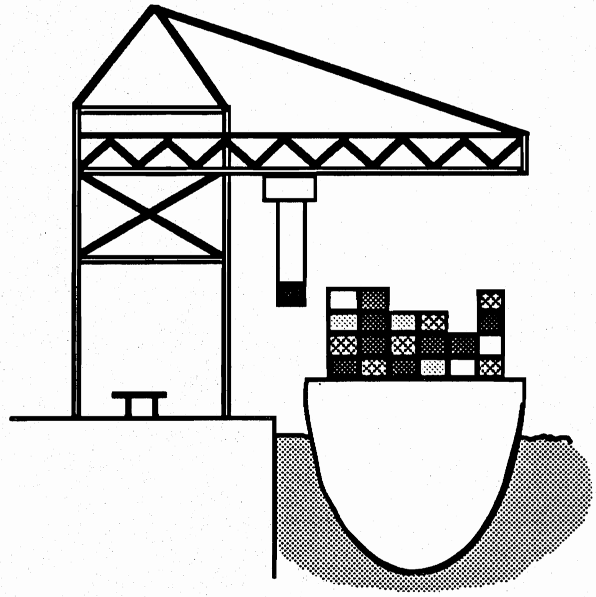


Figure 2.1 Wharf crane servicing the deck of a containership. An empty chasis waits for the container underneath the crane.

Containers stacked in a ship's hold or on a ship's deck are secured in several ways in order to prevent them (the containers) from being damaged at sea. Locking corner castings are placed between stacked containers in non-cellularized or ro/ro ships to align the containers and to provide a place to brace the containers. The cross braces are then secured to the floor of the ship, and, finally, the hatch covers are put back in place. (Cellularized ships do not require corner castings or cross braces, since permanent guides and locks—which allow containers to be stowed more densely and more efficiently than in non-cellularized cargo vessels—are already on board.)

The delays created by bracing the container stacks are usually negligible, since most of the work can be completed while the crane is retrieving the next container. Noticeable delays occur only when corner castings or cross braces must be delivered from the ground to the longshoremen working in the ship.

Another activity that interrupts operations is the movement of the crane from one bay to another bay of a ship. (Usually, wharf cranes are rail mounted to allow movement laterally along the ship.) The time spent moving a wharf crane from one bay to the next is on the order of a one container move, which ranges from one to three minutes; this moving process will be shown later. Another delay related to crane operations is that of hatch cover placement. Hatch covers are placed over (not on) the containers stacked in the holds of the ship. Thus, hatch covers form the decks of containerships, on which containers are stacked three or four high. To gain access to the holds of a ship in service, the supervisor of the operation will have the hatch covers removed and then placed on the ground directly behind the crane. This operation usually takes five minutes to complete, and occurs up to twelve or more times per ship, depending on the size of the ship and the number of containers moved into the port.

Finally, the order or the sequence of the removal of the containers from a ship can occasionally cause delay for the wharf cranes for two reasons. First, the wharf crane may be required to make one or more container moves within the ship to uncover the desired container. This is known as a restow. The duration of the delay caused by a restow is determined by the number of restows required. Second, the sequence of the container moves can have profound effects on the stability of the ship. Ships without the equipment for automatically monitoring displacement, stability, trim, and heel pose a difficult problem for the crane operator when placing the carriage on the corner castings of the container. Thus, containers are normally handled sequentially—from one side of the ship to the other, and from one end to the other. This technique not only simplifies operations for the crane operator, but also minimizes the problem of keeping the ship level while it is being serviced.

STORAGE YARD OPERATIONS AND DELAYS

Storage yard operations are considerably more flexible than wharf crane operations owing to the numerous ways in which containers may be moved and stored within the yard. For example, containers may be stacked in the storage yard or stored on individual chassis. In a storage yard, gantry cranes, top-pick loaders, or straddle carriers are employed to stack the containers. As the following pages will show, the storage yard characteristics and anticipated yard throughput dictate the storage method.

Container Storage by Stacking

Stacking is the most common container storage method in U.S. ports. In this procedure, containers are stacked several levels deep with different types of containers and cargo placed in specific areas of the storage yard. For example, containers destined for a particular ship are placed together, with specialty containers, empty containers, and port specific containers stored in designated areas. Hazardous materials are typically stored away from the general cargo containers, as are flammable materials and refrigerated containers. Finally, within each of these subsections, twenty-foot and forty-foot containers are separated. Even with these many subdivisions, the efficiency of storage yard equipment is greatly increased by being able to service only one portion of the yard at a time. This efficiency is particularly desirable when yard gantry cranes are employed as the primary storage method. Stacking requires that close attention be paid to the location, or address, of the container to prevent multiple restows or misplaced containers. Without efficient ways to assign container addresses, multiple restows are likely.

At Barbours Cut Terminal in La Porte, Texas, the container stacking procedure is carried out primarily by yard gantry cranes. The yard gantry cranes operate similarly to the wharf gantry cranes, in that a suspended container carriage is used to place and to retract containers. The yard gantry crane allows containers to be stacked three deep, the fourth row being reserved for clearance of another container which is shown in Figure 2.2. The clear span of the yard crane provides space beneath the crane (known as the alley) for trucks to be serviced or queued.

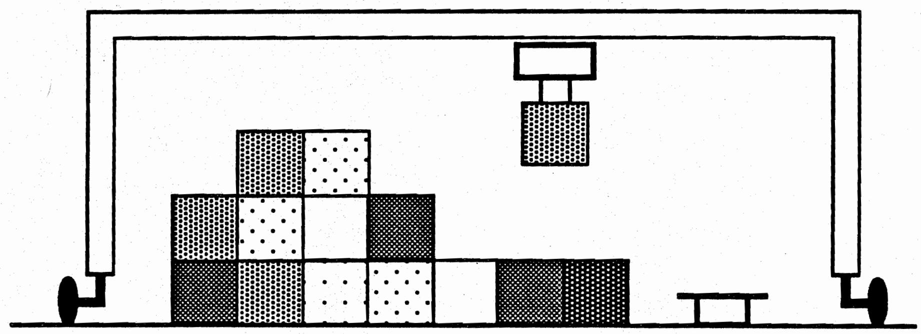


Figure 2.2 Rubber tired gantry crane servicing the container storage yard at Barbours Cut Terminal, La Porte, Texas.

There are two types of yard gantry cranes—rubber tire and rail mounted. Rubber tire gantry cranes (used at Barbours Cut Terminal) ensure flexibility and mobility—being able to move from one container bay to the next in a matter of minutes by traveling to the end of the bay and rotating all four tires in the desired direction. Because of the length of a container bay (more than 750 feet at Barbours Cut), it is important to minimize the time required to reach the end of the bay. A rail mounted gantry crane operates in the same way as the rubber tire gantry crane, with the exception of the rail mounted gantry crane's inability to maneuver quickly from bay to bay. However, the higher stability of the rail mounted crane translates into higher productivity and a denser container stacking.

In a way similar to wharf crane operations, containers are assigned specific addresses before entering the storage yard. The address is, again, very important in minimizing the number of restows. Restowing in the storage yard may be slightly faster than in the ship because of the absence of corner castings or cross braces. But bear in mind that more restows are typically required in the storage yard.

Another way to stack containers in the storage yard is through the use of straddle carriers. As the name implies, straddle carriers carry containers between their legs to the appropriate place in a storage yard bay. Containers are stacked two high so that there will be clearance for one loaded straddle carrier. The arrangement of the bays is similar to the aforementioned procedures, but with no alleys for truck passage. Thus, the only space between the single container width bays is the space for the legs of the straddle carrier.

A fourth way to store containers in the storage yard is through the use of top-pick loaders (employed at France Road Terminal). The top-pick loaders operate like a large fork lift and have been modified to pick up containers by the top corner castings. An additional modification is that the loaders are able to reach over one row of containers to place or to retrieve blocked containers. Bays are three containers wide so that they can be serviced from either side. Note that more space is required between the bays for the operation of loaders than for the operation of gantry cranes. This results in lower density container storage. The advantages of the top-pick loader over other stacking techniques include increased speed and maneuverability.

Finally, containers can be stacked with simple fork lifts. Typically used for empty containers or very light cargo, the fork lift provides excellent maneuverability, but the fork lift cannot place one container behind another; the top-pick loader or gantry cranes can place one container behind another. For stability reasons, fork lifts are only able to stack containers three high. Often, fork lifts operate in storage yards as an accessory unit, retrieving empty containers or occasionally moving cargo into a ro/ro vessel.

It is important to note that storage yard delays can be caused by commercial vehicles. Because the storage yard is the interface of ocean and over-the-road carriers, the stacking equipment must service both commercial vehicles and yard vehicles. Port managers usually detail stacking machinery to servicing either the yard vehicles or commercial vehicles, but not both simultaneously. However, there are circumstances whereby stacking equipment is required to load or to unload both types of vehicles. If the stacking vehicle must travel any distance to service another vehicle (such as the other end of the bay), the delay can be significant.

Container Chassis Storage

The alternative to stacking containers in container storage yards is to store the containers on the chassis that carried the container to the storage yard. This method of storage is employed at The Port of Houston and The Port of New Orleans on a limited basis. Specifically, The Port of Houston leases space adjacent to the Barbours Cut Terminal, and it leases equipment to Sea-Land, Inc., which exclusively employs the chassis method of storage. A similar arrangement exists at The Port of New Orleans, in that space and equipment are leased to Puerto Rico Marine Management, Inc. (PRiMMI), which also employs the chassis method of storage. It should be noted that the leased equipment includes the wharf crane's servicing of ships, but does not include the hundreds of chassis needed to store containers.

The primary advantage of chassis storage is the speed at which containers can be retrieved from the storage yard. There is no need for stacking equipment, since yard and commercial trucks simply locate the desired container and then hook onto it before transport. Parking and retrieving containers in this fashion results in a spatially random selection that decreases localized congestion in the storage yard. (Localized refers to the area surrounding yard cranes or surrounding a specific chassis and container.) In other words, there are no long queues forming in the storage yard and no waiting for service at a yard crane.

In spite of the advantages of chassis storage, there are significant drawbacks associated with this approach. The most prominent disadvantage is the large land area required to store the containers and to empty the chassis. Land-constrained container ports may not be able to accommodate chassis storage, and containers may have to be stacked in the storage yard. At terminals where high container throughput is expected, it is possible that the transit time to retrieve a container may become so long (based on the distance traveled in the storage yard) that the time saved by avoiding yard crane movements is negated. Also, each container moved to or from the ship requires a separate chassis, which means that after an export container is placed on the ship, an empty chassis must be temporarily stored. On the other hand, an additional chassis would have to be retrieved before receiving an import container from a ship. Consequently, there is a need for a separate storage area for empty chassis. Other disadvantages of the chassis system include higher capital costs and higher equipment maintenance costs owing to the number of highway-legal chassis required.

The advantages and disadvantages described above tend to result in chassis storage systems being employed by private container carriers. Despite the differences between container stacking and chassis storage techniques, the underlying operations of the two systems are related, so that they may be modeled similarly, which the remainder of this report describes.

TRACTOR AND CHASSIS OPERATIONS AND DELAYS

The third element of port operations presented in this chapter is the movement of containers between the wharf crane and the storage yard. This operation (connecting the wharf crane and the storage yard) forms a closed loop that is traveled by each yard truck servicing a ship. This cyclic process is illustrated by Figure 2.3. The transport between the storage yard and the wharf crane can have profound effects on terminal productivity. For example, too many trucks in the system create large queues at the crane(s) and lengthy waiting times for service. Conversely, too few trucks in the system will result in idle stacking equipment, a very expensive development for port operators and carriers.

A collection of trucks, called a gang, services each ship in the cyclic fashion described above. Each gang typically has six to eight members, depending on several operating characteristics such as the distance that containers are carried from the wharf crane, and the type of yard storage method employed. Because of the high cost of keeping a ship in port, it is important to keep the wharf crane operating without delay in order to turn the ship around as quickly as possible. This is normally done by keeping enough trucks in the gang so that at least one vehicle is ready for service at the wharf crane. One gang is assigned to each wharf crane servicing the ship. If yard cranes are employed in the storage yard, the same gang will be assigned to one or two yard cranes. Thus, the gang operates as little more than a shuttle between the yard and the wharf crane. If containers are stacked by top-pick loaders, or if chassis storage exists, the gang members will be required to drive to the appropriate storage location—not necessarily in the same area of the storage yard.

Occasionally, the productivity of shuttling containers from the wharf crane to the storage yard can be increased in several ways. First, trucks may be used to move two 20-foot containers at the same time. At the yard or wharf crane, the first container is placed at the front of the chassis, and the second container is placed on the back of the chassis. While the service time underneath the crane is lengthened (and thus, the length of time waiting in the queue), productivity is increased significantly (but not doubled). Double moves of this nature are, obviously, only possible for 20-foot containers. Because a ship may carry a limited number of 20-foot containers, double moves can be sustained for only a short period of time. The second form of double move occurs when a wharf crane, nearing completion of the removal of import containers from a hold, prepares to reverse the process by loading export containers. During that short interval, a truck can transport the imported container into the storage yard, pick up an export container, and deliver it back to the wharf crane. Again, productivity increases temporarily, though this type of double move is rare.

Delays caused by the movement of containers are usually negligible, because most delays are rooted at a crane or stacking vehicle. Exceptions include mechanical breakdowns and traveling to the wrong place in the storage yard. As shown in Chapter 3, another delay is caused by port congestion, owing to the large number of trucks present. Port congestion occurs frequently when several ships are in port or when two cranes are simultaneously servicing the same ship. Recommendations for reducing port congestion are presented in Chapter 5.

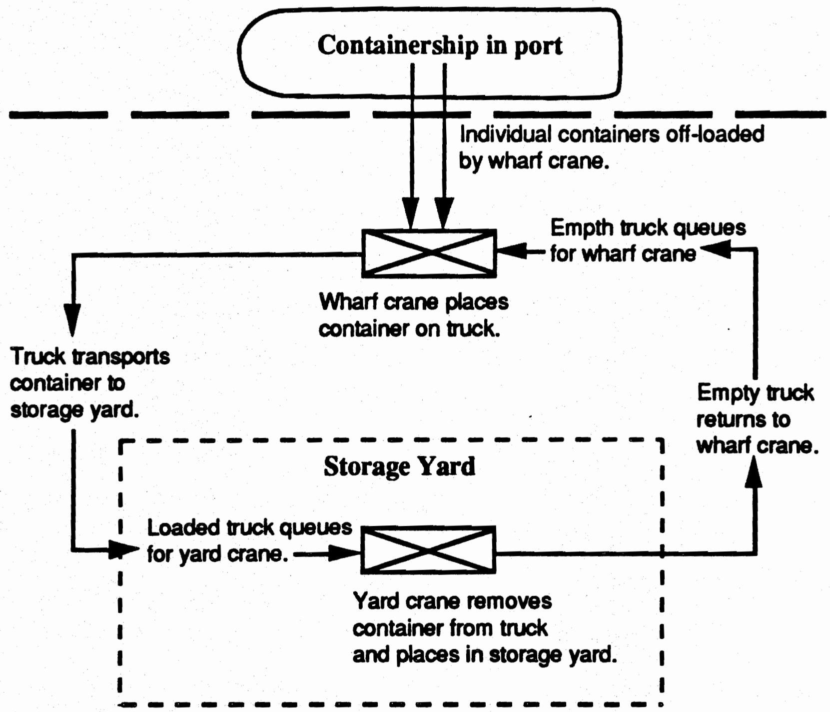


Figure 2.3 Ship loading procedure at Barbours Cut terminal.

CONCLUSIONS

The procedure of loading and unloading a ship in port is, conceptually, straightforward. The critical points in the cyclic system are the wharf crane and the storage yard. In the storage yard, it is important to assign an address to each container in order to minimize the number of restows. At the wharf crane, there must be enough vehicles servicing the crane to prevent periods of crane idleness. Breakdowns at either of these two stages have immediate and detrimental effects on the performance of the system by causing long periods of idleness. This phenomenon is explored in Chapter 4.

Variations in the system typically occur in the storage yard in the form of different storage techniques that are used to stack the containers. Despite the variations, all the systems may be modeled using the techniques described in Chapter 3 and Chapter 5.

The descriptive information provided in this chapter provides a foundation for the remainder of this report. As mentioned previously, the wharf gantry crane is a critical element of the loading and unloading cycle owing to the extreme cost of operating the crane. Factors that affect its performance are explored in the next chapter.

CHAPTER 3. THE PREDICTION OF WHARF CRANE PRODUCTIVITY

"The wharf crane is king" is a phrase commonly heard at container ports. Indeed, the wharf crane is the critical element of the container port and is served by all other port operations. Because the wharf crane is the only link between the storage yard and the ship, an improvement in wharf crane operations can minimize the time a ship requires to load or unload. When studying port loading/unloading operations, researchers commonly measure wharf crane productivity by the number of containers moved per hour.

In attempting to improve port operations, managers must make decisions, regarding labor and equipment assignments, that directly affect wharf crane productivity. A valuable tool for a port manager, then, would be one that predicts wharf crane productivity based on characteristics of the operating environment. Many questions must be answered before such a model can be developed. Does it matter what type of ship is being serviced? Do some stevedoring companies operate more efficiently than others? Is the number of import containers or export containers that constitute a shipment important? What effect does weather have on port operations? Does it matter how many total container moves there are for a specific ship? Does the mix of container sizes have any significant bearing?

In attempting to answer such questions, we analyzed wharf crane productivity data from The Port of Houston's Barbours Cut Terminal. This chapter summarizes the analyses and discusses the development of a linear model designed to predict wharf crane productivity based on ship characteristics and the work environment.

FACTORS THAT REDUCE CRANE PRODUCTIVITY

Chapter 2 of this report presented a description of the cyclic system that moves containers to and from the ship. The cycle consists of three operations; the efficiency of the operations are determined by underlying issues such as container addresses, ship type, and ship age. The effects of specific operations may not be directly quantifiable in the model presented in this chapter, but the effects can be understood by considering the more general variables presented below.

The first variable to be considered is congestion within the port. Congestion is caused by one of several factors. First, if several ships are in port simultaneously, there will be more trucks carrying containers to the storage yard. The result is increased congestion on the roads and alleys of the storage yard. Second, it is common to find two cranes servicing the same ship; one working the stern and the other working the bow of the ship. This arrangement results in more localized congestion (immediately surrounding the cranes) that may affect the crane's productivity. The implication of two cranes servicing the same ship is that trucks are not able to return to the wharf crane in a timely manner, forcing the crane to wait momentarily for a truck to arrive. To minimize wharf crane idleness, one or more trucks may be added to the cycle. In theory, however, adding a truck to the cycle contributes to the port congestion problem. In general, a congested port environment will likely reduce wharf crane productivity.

Another factor that may affect crane productivity is weather. As mentioned in Chapter 2, the carriage that picks up and moves containers is suspended from the crane by cables. Because the boom of a wharf crane is 150 feet or more in height, a container suspended near the ground will begin to swing in moderate winds. Despite the stabilizing cables that minimize the sway, moderate winds can decrease the ability of the crane operator to place the container on corner locks or on a chassis. Other adverse weather conditions also have negative effects on wharf crane productivity. The presence of <u>light</u> snow, rain, or fog should not affect operations; however, if weather conditions worsen so that the visibility of crane operators is limited, productivity will likely decrease. For example, should severe thunderstorms occur that include heavy lightning or winds over fifty miles per hour, operations must completely cease until appropriate operating conditions return.

The distribution of loaded containers may also affect crane productivity for two reasons. First, the time required to move the simple weight of a loaded container may be greater than that of an empty container. Therefore, if a high number of loaded containers were to be moved from a ship—compared with the same number of empty containers—crane productivity would decrease. Second, recall that empty containers and loaded containers are stored at different places within the yard. Depending on which container is being delivered further away, the ratio of empty containers (or loaded containers) to the total number of containers for a specific ship is expected to affect crane productivity. Also, recall that outbound and inbound containers are stored in independent areas of the yard. Thus, the ratio of outbound containers (or inbound containers) to the total number of containers, or to one another, is also expected to affect crane productivity.

Another factor that may significantly affect crane productivity is ship type. Because cellularized vessels have container guides that expedite the process of stacking containers in the ship, a cellularized vessel should facilitate higher crane productivity.

It is possible, though not likely, that the time of year can influence crane productivity. For example, the summer months may promote higher productivity rates than the winter months owing to weather, employee performance, or seasonal fluctuations in the demand for containerized cargo. The collection and reduction of data used in determining the effects of these, and other closely related variables, are discussed in the following section.

DATA COLLECTION AND REDUCTION

The Port of Houston's Barbours Cut Terminal ("Barbours Cut") is the largest container port serving the Gulf of Mexico region. The port owns eight wharf cranes and maintains four berths with two more to be added. (It is common to have two cranes per berth operating at a port, allowing two cranes to simultaneously service a ship.) Like most ports, Barbours Cut maintains daily records of activities. Included in this information is a record of the ships that are in port each day and a summary of the services provided to each ship. Data of this nature were provided for a one year period (1989 calendar year) by the port managers of Barbours Cut; the data formed the initial data set used in this analysis.

Each entry of the data set corresponds to the service provided to each ship that berthed at the port. These entries resulted in an original data set consisting of 352 observations. It takes approximately six weeks for a vessel to make a round trip back to Barbours Cut depending on what other ports the vessel serves. Thus, it is likely that several observations will be recorded over a one year span for the same vessel. The data set that results is cross-sectional with respect to providing the same information for all ships; and a time series, in that a ship can be included in the data set several times throughout the year.

The original pooled data set provided information including, but not limited to, the following variables (the parenthetical names are variable names used in Statistical Analysis System [SAS] software throughout this analysis):

1) Date (DATE) - The date the vessel berthed at Barbours Cut.
2) Vessel name (VESSEL)—The name and shipping line of each vessel.
3) Ship type (CELL, NONCELL, RORO)—Cellular, non-cellularized, or ro/ro vessels.
4) Load out (LOADOUT)—The number of loaded containers moved from the storage yard to the vessel.
5) Empty out (MTOUT)—The number of empty containers moved from the storage yard to the vessel.
6) Load in (LOADIN)—The number of loaded containers moved from the vessel to the storage yard.
7) Empty in (MTIN)—The number of empty containers moved from the vessel to the storage yard.
8) Other moves (OTHER)—The number of special moves made to or from the vessel. These moves are made by the crane but include flat beds, oversized containers, etc., that require special adjustments or lifting with cables.

9) Ro/ro moves (ROMOVE)—The number of moves made that did not require the use of a wharf crane.

10) Total moves (TOTMOVE)—The total number of containerized moves to or from the vessel.

TOTMOVE = LOADOUT + MTOUT+ LOADIN + MTIN + OTHER - ROMOVE

11) Net productivity (NETPROD)—The net productivity achieved by the wharf crane only while the crane is in operation (container moves / hour).

12) Gross productivity (GPROD)—The gross productivity achieved by the wharf crane from the beginning of service to the end of service. This includes the periods of downtime for breaks, equipment failure, ro/ro moves, etc. (container moves / hour).

13) Stevedoring company (STEVE1-STEVE6)—The stevedoring company hired to service the vessel. To maintain anonymity, the names have been changed to numbers one through six.

A total of eight observations were removed from the data set. Four observations were removed because the total number of moves, TOTMOVE, was zero for each observation, which resulted in crane productivity measurements of zero moves per hour. After being used in SAS regression models, four more observations were dropped which resulted (from having zero total inbound moves or zero total outbound moves) in division by zero. With these minor modifications and assumptions, a total of 344 observations composed the final data set used in the analysis. A univariate analysis of the pertinent variables and the final proposed model are included in the following section.

Information for the above variables was manually entered into an SAS data file. To minimize the risk of human error, the entered data was checked for extreme data points that could have resulted from omitting decimals or otherwise mis-entering values.

The variables corresponding to the date, type of ship, and stevedoring company were transformed into qualitative, or dummy variables. The date of the ship's arrival was broken down to represent seasons of the year (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec) in order to reveal any seasonal effects on productivity. A detailed discussion of this procedure is presented in the next section.

Supplementary records (also provided by Barbours Cut) were used to determine the type of each ship and to determine the appropriate dummy variable. There were minor inconsistencies in the supplementary records; that is, several ships were recorded as being of more than one type. Although this error only occurred in a few cases, one of several options were followed in designating a ship type. First, if there were multiple entries of the ship throughout the year, the most frequent designation could be used to determine the ship type, that is, if the ship Falstria was designated as a cellularized ship five times and as a non-cellularized ship twice, the assumption would be made that the ship was cellularized. Possibly a more accurate method relies on the fact that shipping lines tend to own only one type of container vessel. In other words, each shipping company that services Barbours Cut normally has only one ship type in its fleet. Thus, based on the individual shipping line, verification may be made of the ship type.

Other dummy variables represented in the model correspond to those stevedoring companies that were contracted to service a ship. The stevedoring company employs the longshoremen responsible for loading or unloading the ship. There is evidence that one shipping company employs only one stevedoring company, and this allows an accurate assumption to be made, if discrepancies exist in the records. Despite the near one-to-one correspondence between shipping companies and ship types (and thus, stevedoring companies), there is not a strong empirical collinearity in the sample between the ship type and the stevedoring company. Thus, they may both be considered in the model without detrimental implications.

Another variable was added to the original data set to capture the effects of wind on crane productivity—the most difficult of the variables to quantify for several reasons. First, publicly available climatological data are not maintained by the U.S. Department of Commerce for the city of La Porte, where Barbours Cut Terminal is located. The nearest available climatological data are from the Houston Intercontinental Airport, Galveston, Port Arthur, or Corpus Christi. Despite the similarities of being coastal cities, the data from Port Arthur and Corpus Christi were deemed inaccurate owing to the geographic distance from La Porte. Galveston data was preferred over the Houston data because of Galveston's coastal location. However, climatological data for Galveston did not include average daily measurements of wind, the primary motivation for looking into the effects of weather on port productivity. Thus, climatological data were used from the Houston Intercontinental Airport [Ref 51]. The measurement of wind velocities are in miles per hour and represent the average speed over a 24-hour period based on at least 21 observations at hourly intervals. Information on rain and fog were not considered in the model because it was not possible to determine when the rain or fog occurred during the day. While this is also true for wind measurements, the wind conditions were considered more consistent than those of rain or fog. In other words, it is believed that the presence of rain or fog is short-lived in comparison to that of wind. Thus, only the data for wind were considered in the model.

GENERAL MODEL AND *A PRIORI* EXPECTATIONS

The model pursued in this report is one that predicts the crane productivity for a vessel in port given information about the ship's characteristics and concurrent port activities. The dependent variable selected for analysis is crane productivity, measured in container moves per hour. As mentioned in previous sections, there are two ways to measure crane productivity: gross productivity and net productivity. Gross productivity is defined as follows:

$$\text{GPROD} = \frac{\text{(total number of containers moved by crane)}}{\text{(total elapsed vessel service time)}}$$

Note that the gross productivity includes time that is spent carrying out ro/ro operations that do not require crane participation. Similarly, delays due to breaks, maintenance or other operations are included in this definition. If the crane is not moving containers during ro/ro and miscellaneous operations, the gross productivity will be deflated and difficult to predict with available data. Net productivity is defined similarly as follows:

$$\text{NETPROD} = \frac{\text{(total number of containers moved by crane)}}{\text{(total time spent by crane servicing vessel)}}$$

The obvious difference between the two definitions is that net productivity does not include the time that the crane is out of operation because of maintenance or ro/ro moves. For this reason, net productivity was selected as the independent variable for analysis.

Many of the variables that should appear in a model predicting crane net productivity have already been discussed. These variables, and others, are included in the following general model:

NETPROD = *f* (weather, ship type, container distribution, congestion, other factors)

The probable maximum net productivity accomplished under ideal conditions approaches 45 containers per hour, based on field observations and data analysis. Ideal conditions simply mean having containers lined up in order of delivery, no adverse weather conditions, no mechanical breakdowns or delays, and no idle periods waiting for empty trucks to arrive. These conditions rarely exist, or rarely can be maintained for extended periods of time. Other factors include operator experience, yard crane operations, automatic leveling capabilities of the vessel, and stevedoring companies. Because the model above includes variables that generally decrease productivity, the majority of the slope coefficients are expected to be negative, which is discussed in the following paragraphs.

Ideally, information for weather variables would include precipitation, fog, and wind. For reasons previously discussed, the only weather variable included in this model is wind, measured as the daily average wind speed (mph). The expected sign of the slope coefficient of any adverse weather condition variables—such as rain, high winds, or fog—is negative.

To account for port congestion, the DATE variable was used to estimate how many ships were in port each day. It is expected that additional ships in port on a given day will decrease crane productivity because of port congestion. The number of ships in port on a given day was estimated according to the frequency of the specific date in the data set. In other words, if February 13 appeared three times in the 1989 data set, each of the observations were assigned values that three ships were in port at once. Recall, however, that the date refers to the day that a ship *enters* port. In the event that a ship remains in port for more than one day (which is usually the case) the succeeding days will not be properly represented in the COUNT variable created for this purpose. Continuing to investigate the above example will illustrate this problem. Assume one of the three ships is scheduled to remain in port two days (February 13-14). And assume that a fourth ship arrives on February 14. Because the dataset shows only dates of arrival, February 13 (for three ships) and February 14 (for the fourth ship), it is recorded that there are three ships in port on February 13 and one on February 14. Thus, it would be beneficial if the duration of a ship's time in port were known in order to more accurately ascertain the implications of congestion. Nonetheless, the variable COUNT was included in the model analyses. The expected sign of the slope coefficient would be negative, meaning that as the number of ships in port increases, the crane productivity decreases.

Container load distribution refers to the distribution of loaded, empty, inbound, outbound, refrigerated, hazardous and specialty containers that will be moved to or from the vessel. As previously discussed, each of these containers is stored in different areas of the storage yard. Because outbound containers are typically stored further away from the wharf crane, a high percentage of outbound container moves may reduce crane productivity, if there are not enough trucks servicing the ship. This suggests a negative slope coefficient. Conversely, a high percentage of inbound containers may facilitate higher productivity levels, implying a positive slope coefficient. Along these same lines, a high percentage of empty containers (that are stored farthest away from the ship) may decrease crane productivity. However, empty containers, because of their lower weight, can be moved faster than fully loaded containers, which may offset reductions in productivity brought about by moving empty containers to remote parts of the storage yard. Hence, it is difficult to predict the sign of the slope coefficient for variables representing the number of empty containers in a vessel. The variables of the original data set were used to create the following new variables that defined percentages and ratios of each type of container:

1) (RLOADSUM) The ratio of the total number of loaded container moves to the total number of container moves.

2) (RMTSUM) The ratio of the total number of empty container moves to the total number of container moves.

3) (ROTHSUM) The ratio of the total number of non-container moves (ro/ro or special container moves) to the total number of container moves.

4) (ROUTSUM) The ratio of the total number of outbound container moves to the total number of container moves.

5) (RINSUM) The ratio of the total number of inbound container moves to the total number of container moves.

6) (ROUTIN) The ratio of the total number of outbound container moves to the total number of inbound container moves.

7) (CELLNON) A dummy variable representing any ship that is not a cellularized ship. Note that this includes non-cellularized and ro/ro ships.

8) (COUNT) A variable representing the number of ships being serviced simultaneously at the port.

The combination of these derived variables and the original variables make up the data set used in the development of the final model. The expected sign of the slope coefficients for the pertinent variables are summarized in Table 3.1. Statistical exploration of the data represented by these variables, and a description of the iterative process that led to the final model specification are included in the following section.

DEVELOPMENT AND INTERPRETATION OF MODEL

Frequency counts were performed for the dummy variables FIRST, SECOND, THIRD, FOURTH, CELL, NONCELL, RORO, and STEVE1-STEVE6. In reference to seasonal visits at the port, first, second, third, and fourth quarters had 86, 81, 90, and 87 vessels respectively. An analysis of the COUNT variable tallies 140 days with one arrival, 140 days with two arrivals, 48 days with three arrivals, and 16 days with four arrivals. Recall that the number of arrivals are used as a proxy for the number of ships being serviced simultaneously. The results of analyses of pertinent quantitative variables are summarized in Table 3.2. Note that the inclusion of a variable in the table does not guarantee that the variable will be used in the final model.

TABLE 3.1. EXPECTED INFLUENCE OF INDEPENDENT VARIABLES ON NET PRODUCTIVITY

Independent Variable	Sign	Rationale
RLOADSUM	-(?)	Negative impact of loaded container may be negated depending on storage address in yard.
RMTSUM	+(?)	Negative impact of distance from the wharf crane may be negated by the speed at which empties can be moved.
ROTHSUM	-	Negative impact will only be noticed when modeling GPROD as the dependent variable.
ROUTIN	-	Outbound containers are stored further away from the ship than inbound containers and thus require more delivery time.
CELLNON	-	Cellular ships are typically the most efficient to service.
STEVE#	+/-	Specific companies may operate faster or slower than others.
COUNT	-	The more ships that are in port, the greater the congestion.
FIRST, etc.	?	It is expected that there are no significant seasonal influences.
WIND	-	Cranes cannot control a suspended container as well in high winds.

TABLE 3.2. UNIVARIATE ANALYSIS OF SELECTED VARIABLES

Variable	Mean	Standard Deviation	Max/Min
NETPROD	26.02	4.76	39.27/4.00
GPROD	21.91	5.47	36.77/2.82
LOADOUT	189.95	143.11	915/0
MTOUT	16.36	36.08	453/0
LOADIN	112.50	107.26	1543/0
MTIN	96.99	118.77	1012/0
OTHER	30.43	45.17	520/0
ROMOVE	5.77	21.11	225/0
WIND	8.55	2.77	17.8/3.0

Many models were explored based on the variables presented thus far in the chapter. The results of several models have been summarized in Table 3.3 to facilitate discussion of the procedure. The dependent variable in each of the models is NETPROD, although models using GPROD as the dependent variable were tested. The models using GPROD typically demonstrated lower predictive powers. The reason for the lower predictive powers is the added variability introduced by the time not directly attributed to moving containers. In other words, proper independent variables were not available to describe operations such as crane down times, ro/ro moves, and specialty container moves.

Dummy variables FIRST, SECOND, and THIRD were created to determine if there were seasonal effects on crane productivity. The reader may note that these dummy variables do not appear in Table 3.3. In models not represented by the table, the seasonal variables were included. However, these variables never proved to have any statistical significance; this is in agreement with *a priori* expectations that there are no seasonal effects on net productivity. If seasonal effects were significant, differences in productivity levels during each quarter would be seen in a time series plot. In Figure 3.1, such seasonal trends are obviously not present.

The inclusion or exclusion of variables that describe the distribution of containers on the vessel was often dictated by collinearity constraints. For example, the variables RLOADSUM, RMTSUM, ROUTSUM, and RINSUM could not all be included in the same model simultaneously. Algebraically, the inclusion of all variables would result in variables being double counted, resulting in division by zero and a detrimental error in SLAM. The same is true for other combinations of container distribution variables.

The three ship type dummy variables—CELL, NONCELL, and RORO—were combined into dummy variables that represented cellularized vessels and vessels that are not cellularized. Slightly different from a non-cellularized specification, the CELLNON variable includes non-cellularized vessels and ro/ro vessels. The consolidation was made to reduce the number of variables considered in the model. The justification for expecting the ship type to affect crane productivity is provided by Figure 3.2. There are two significant features to note in Figure 3.2. First, the higher capacity of cellularized container ships is suggested by the higher number of container moves made to and from the vessel. Second, the higher productivity levels of cellularized ships (over ro/ro and non-cellularized ships) is illustrated. The higher productivity levels are illustrated more clearly in Figure 3.3, which condenses the information in Figure 3.2 in order to illustrate the variance of the productivity levels for each of the three ship types. Each of the ship types exhibits a moderate variance; however, the average productivity of cellularized ships over non-cellularized and ro/ro ships illustrates that the variable will likely be significant in the final model. The high variance for ro/ro vessels is attributable to the range of ways containers are stacked on the vessel; either in a fashion similar to that of non-cellularized vessels (cross-braced and locked) or occasionally like that of a cellularized vessel (container guides).

TABLE 3.3. REGRESSION MODELS EXPLAINING NET PRODUCTIVITY OF WHARF CRANES

(The parenthetical numbers are t-statistics.)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
INTERCEPT	25.86	25.97	24.91	29.80	25.46	27.19
	(14.61)	(15.81)	(17.02)	(32.63)	(16.62)	(35.98)
RLOADSUM	-2.42		-2.45		-2.90	
	(-1.39)		(-1.53)		(-1.72)	
RMTSUM	5.31		5.22		5.82	
	(2.87)		(3.10)		(3.23)	
ROUTSUM		-1.15				
		(-0.66)				
RINSUM		2.51				
		(1.50)				
ROTHSUM	-0.02	0.74		-0.27	0.06	
	(-0.01)	(0.48)		(-0.21)	(0.04)	
ROUTIN				-0.26		-0.29
				(-2.72)		(-3.23)
CELLNON	-0.25	-1.99		-4.22		-1.68
	(-0.34)	(-3.20)		(-9.03)		(-2.73)
COUNT	-0.44	-0.37		-0.46		-0.44
	(-1.71)	(-1.40)		(-1.69)		(-1.67)
WIND	0.01			-0.01		
	(0.09)			(-0.15)		
STEVE1	0.47		0.48			
	(0.58)		(0.60)			
STEVE2	4.47	3.26	4.72		4.37	3.18
	(5.37)	(4.89)	(8.52)		(8.62)	(4.89)
STEVE3	-3.88	-2.87	-3.97		-4.56	-2.28
	(-4.31)	(-3.60)	(-4.60)		(-5.56)	(-3.17)
STEVE4	3.19	2.56	3.35		2.93	2.48
	(3.45)	(3.19)	(4.44)		(1.72)	(3.10)
STEVE5	1.23		1.53			
	(1.11)		(1.60)			
Adjusted R^2	0.3193	0.2890	0.3210	0.2102	0.3177	0.2909

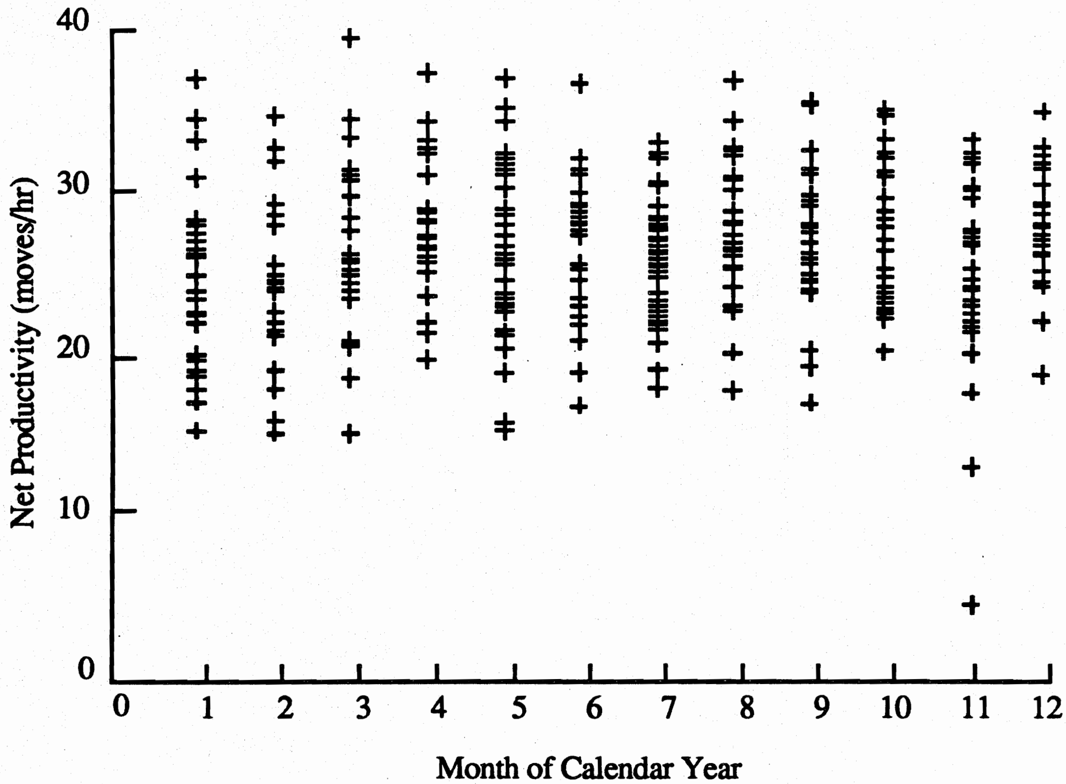


Figure 3.1 **Seasonal effects on wharf crane productivity. The consistency between each quarter suggests that there are no significant seasonal effects. Sample is 352 observations.**

It is expected that significant variables would include container distribution, stevedoring company, congestion, ship type, and weather variables, which were discussed previously. The variables, listed in Table 3.3, correspond to linear relationships, which are represented in the model below. Note that β_n is used to designate the intercept and slope coefficients for quantitative variables, whereas a_n is used to designate the slope coefficient for dummy variables.

$$NETPROD=\beta_1 + \beta_2(RLOADSUM)+\beta_3(RMTSUM)+...+a_{15}(STEVE)+\varepsilon$$

(The discussion of model results continues following Figure 3.2 and Figure 3.3.)

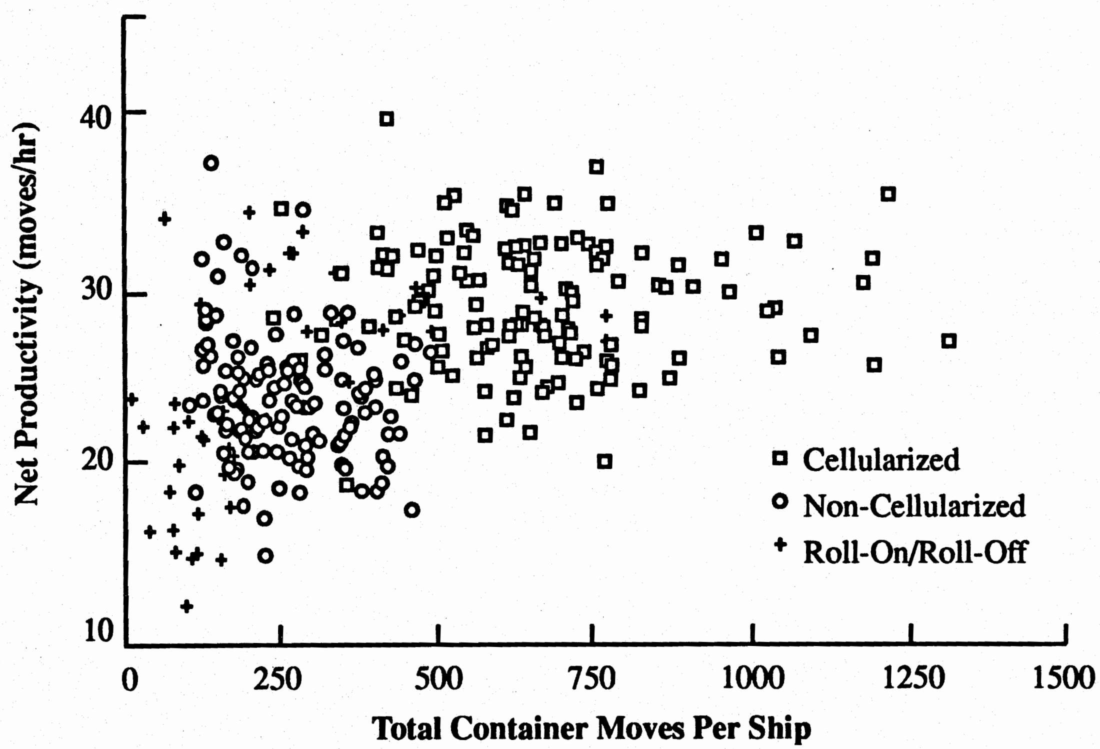


Figure 3.2 Wharf crane productivity and vessel capacity for each ship type. Sample is 303 observations.

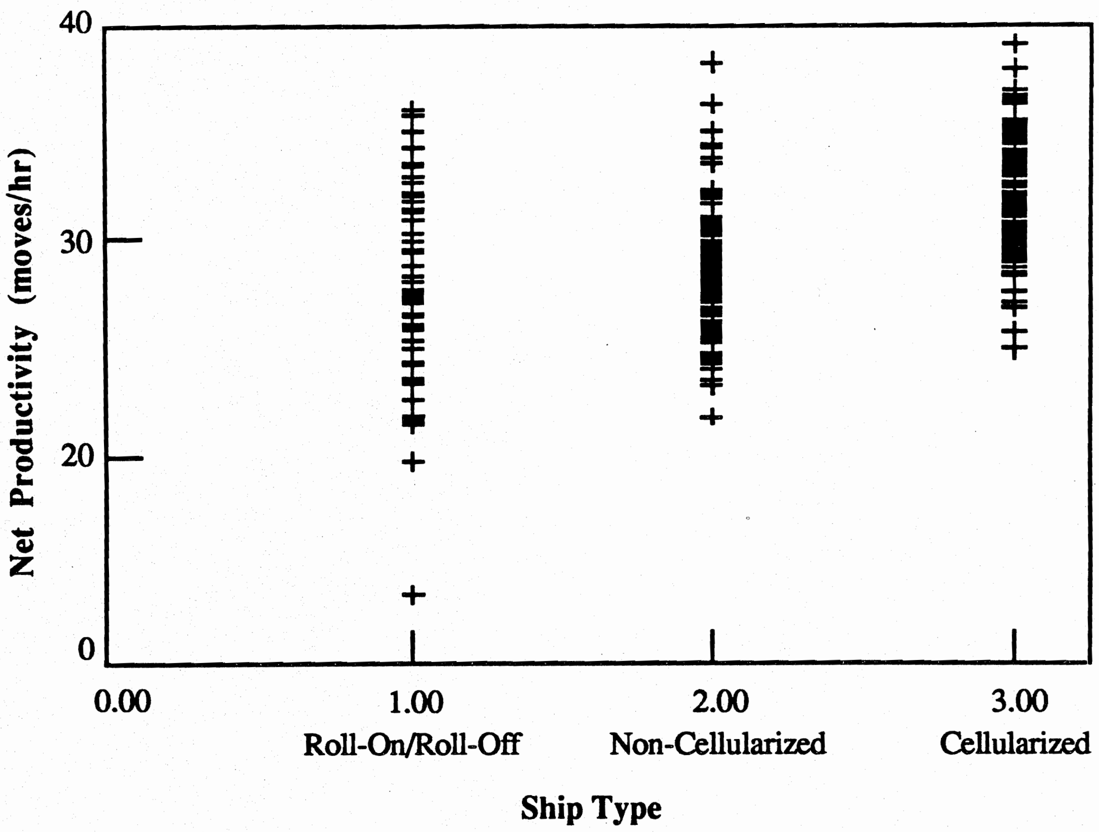


Figure 3.3 Wharf crane productivity according to ship type. Sample is 303 observations.

The first models explored were similar to the model represented in Table 3.3. The models incorporated combinations of all stevedoring companies, COUNT, CELLNON, and container load distributions. The WIND variable was also present in some of the models. No heteroscedasticity or multicollinearity appeared—based on visual inspection of residual plots—in the models. The adjusted R^2 statistic did not fall below 0.30 in the models; however, the only variables that were statistically significant (a=0.10) were the intercept, RMTSUM, COUNT, and STEVE 2 through 4. All coefficient signs matched prior expectations, with the exception of WIND, which was positive but statistically insignificant.

Similar results were obtained in the second type of model that represents an exploration of the ratios of outbound, inbound, and other container moves to the total number of moves. The WIND variable was dropped from consideration in type two models, based on its insignificance in the first type of models. If there were a better source of wind data, the WIND variable would probably have a statistically significant influence on crane productivity and would be included in all models.

In type two models, note the slight decrease in the adjusted R^2 (now slightly below 0.30) and that (compared with type one models) there is one less statistically significant variable (a=0.10). This result occurs even though there are three less statistically significant variables included. Note also that CELLNON is now statistically significant and COUNT is no longer statistically significant. The reverse is true in type one models. All signs agree with expectations except ROTHSUM, which is not statistically significant (a=0.10).

A slightly different approach was used with Model 3. All stevedoring companies were again considered, along with the same container distribution descriptions as Model 1. The absence of variables CELLNON, COUNT, and WIND is the reason the model is conceptually inadequate. RMTSUM and stevedoring companies 2, 3, and 4 are the only statistically significant variables in this model.

Again a slightly different approach to the problem was taken, regarding Model 4. All of the stevedoring company variables were dropped from Model 4, although ship type, congestion, and weather variables were retained; Model 4 incorporated only ratios representing "other" container moves and the ratio of outbound containers to inbound containers. Inadequate in many ways, this model captures very few of the variables considered important in *a priori* evaluations. Two facts explain the significantly lower adjusted R^2 from other models: 1) the only container load distribution variables are ROTHSUM and ROUTIN; and 2) there are no stevedoring company variables. However, all coefficient signs did match *a priori* expectations.

Model 5 was used to explain net productivity, based only on stevedoring companies and a complete description of container load distributions. The investigation was carried out by including the variables RLOADSUM, RMTSUM, ROTHSUM, and STEVE 2 through 4. All variables were statistically significant (a=0.10) with the exception of ROTHSUM. This result adds validity to the assumption that "other" (or non-container) moves do not influence net productivity. Instead, "other" moves would be influential only when modeling gross productivity. This assumption is further verified by virtually every gross productivity model that included the ROTHSUM variable, since these models demonstrated that the ROTHSUM variable was statistically significant. (The results of gross productivity models are not shown.) The adjusted R^2 (=0.32) for this model was one of the highest. However, it is the author's opinion that the cost of excluding CELLNON and COUNT is greater than the benefit of a higher adjusted R^2 statistic.

Model 6 is the last model represented in Table 3.3. The variable ROUTIN, mentioned in Model 4, is a combination of the variables ROUTSUM and RINSUM. The variables were merged in order to make the model as parsimonious as possible. The model contains six independent variables, all of which are statistically significant at a=0.10. All coefficient signs are in agreement with *a priori* expectations, and all variables expected to be significant are included in the model with the exception of WIND. Nevertheless, the adjusted R^2 (=0.29) is too low for the model to be used as a predictive tool. There was no visible heteroscedasticity in residual plots, nor any signs of autocorrelation or multicollinearity in the data. The final form of the model is presented below. The parenthetical numbers are t-statistics for each of the variables.

$$\begin{aligned} NETPROD = 27.19 - \underset{(-3.23)}{0.29(ROUTIN)} - \underset{(-2.73)}{1.68(CELLNON)} - \underset{(-1.67)}{0.44(COUNT)} + \\ \underset{(4.86)}{3.18(STEVE2)} - \underset{(-3.17)}{2.28(STEVE3)} + \underset{(3.10)}{2.48(STEVE4)} + \varepsilon \end{aligned}$$

The model is easily interpretable, with the possible exception of the ROUTIN variable. Recall that ROUTIN is defined as the ratio of the number of outbound containers to the number of inbound containers. The ROUTIN coefficient implies that for every unit increase in the ratio of outbound to inbound containers, the net productivity will decrease 0.29 containers per hour. (Note that this ratio does <u>not</u> have to remain in the range 0<ROUTIN<1 as is the case with the other ratio variables.) The coefficient for the variable COUNT indicates that every additional ship in port decreases crane productivity by 0.44 container moves per hour. Similarly, the coefficient for CELLNON indicates that if a ship is <u>not</u> a cellularized ship, crane productivity will decrease 1.68 container moves per hour.

The most profound result is found in the STEVE variable. The coefficients for specific stevedoring companies indicate that if companies 2, 3, or 4 are servicing the ship, the crane productivity will be altered +3.18, -2.28, and +2.46 container moves per hour, respectively, in comparison with the sixth stevedoring company. These comparative results indicate that the single most significant influence on crane productivity is the stevedoring company that is selected to service the ship.

The seemingly small coefficients should not be overlooked; they are significant. Considering only the CELLNON variable, we find that a non-cellularized ship can decrease crane productivity by over 5 percent (based on -1.68 / 27.19 = 0.062). Similar estimations can be made for all other variables in the model.

There are three more important items to note. First, based on the exploration of all model types represented in Table 3.3, it is clear that the model specification is somewhat fragile. This conclusion was derived from the behavior of parameter estimates and their levels of significance. From model to model, the magnitude of the slope coefficient estimates varied more than expected. At the same time, variables often gained and lost significance when other variables were placed in the model. As mentioned before, there was no multicollinearity detected in the data, based on collinearity diagnostics performed using SAS. The somewhat high level of fragility was another motivation for developing (according to a priori expectations as opposed to blindly increasing the adjusted R^2 statistic) a model that included the highest possible number of pertinent variables.

The second item is in reference to the stevedoring company variable. It was not possible to predict the sign of the stevedore coefficients because of the varying performances of the particular companies that were studied. In other words, one stevedoring company may have more experienced crane operators than other companies and, thus, will be able to attain higher productivity levels. Thus, the inclusion of stevedoring companies 2, 3, and 4 in the model is site specific for The Port of Houston. The point remains, however, that a stevedoring company can have statistically significant influences on crane productivity.

Third, the variable WIND was not significant in any model, contrary to *a priori* expectations. There are three reasons for this lack of statistical significance. First, the daily average wind speed was not sufficiently specific, that is, with regard to time of day. A 24-hour average wind speed may not be appropriate in determining the influence of wind speed on an 8-hour or 12-hour work day. However, it is not clear how this problem can be remedied, given existing historical climatological data. For instance, data would have to be collected in the field and applied to a new data set that corresponds to the same days, if the use of historical climatological data did not remedy this wind speed problem. Second, it is possible that the discrepancies between Houston Intercontinental Airport and the city of La Porte are greater than expected. Third, it is also possible that moderate winds do not slow down crane operations at all, which is the implication of the exploratory models.

MODEL CRITIQUE

There are several ways in which the model could be improved. First, the effects of weather on crane productivity could be explored in greater detail, especially if data were available specifically for La Porte, Texas. Such data may be available from the National Oceanic and Atmospheric Administration; however, the turnaround period for securing this type of information made it impossible for the data to be considered in this model. If accurate weather data could be obtained, variables describing wind, and possibly rain, would very likely become statistically significant in the model.

Second, a more accurate description of port congestion would probably result in a stronger model. Recall that the COUNT variable included in the model counted the number of ships that arrived on a given day. Field data that described the number of ships in service on a given day or, better yet, that described the number of wharf cranes operating on a given day would strengthen the significance of the variable in the model.

Third, a more detailed description of the capabilities of the ship could improve the model. The description should convey the ability of the ship to automatically maintain proper trim and heel. This information may be deduced from the ship's age, since most modern ships are able automatically to monitor and to maintain their position in the water.

Finally, the data used in this analysis were not without limitations. There were a few inconsistencies (described in the Data Collection and Reduction section) in the description of ship type. The criteria used by Barbours Cut for determining ship type should be explored, and adjustments should be made, if necessary. This is particularly important now that it has been shown that the type of ship does have a significant influence on crane productivity. The high number of observations composing the data set that was used in the analysis is very appropriate. One year of time series data is more than sufficient for this type of analysis.

Because the data were collected at only one port, the issue of biased data must be considered. By expanding this type of model to include other national ports, any bias could be overcome. This process would require that variables describing specific stevedoring companies be dropped from the model, and that variables describing yard layout, container storage techniques, and other specific port identifiers be included in the model.

SUMMARY

The data set provided by The Port of Houston, Barbours Cut Terminal was used to develop a model that might possibly predict the net wharf crane productivity associated with a given ship. The final model suggests that the following are statistically significant variables:

1) the number of outbound container moves;
2) the number of inbound container moves;
3) the type of ship being serviced;
4) the number of ships being serviced simultaneously;
5) the stevedoring company servicing the ship.

It is surprising that the WIND variable could not be considered in the final model. It is likely that data limitations resulted in an unfair test of the wind variable. We hypothesized that if more appropriate data were substituted into the data set, the wind variable would prove to have a statistically significant influence on crane productivity. The validity of this hypothesis could be explored by collecting detailed wind, rain, and fog data specifically for the city of La Porte, Texas.

The power of the model is probably not high enough to enable its use as a predictive tool. The model does, however, illuminate several variables that have statistically significant effects on wharf crane productivity. The proposed model is based on data from The Port of Houston's Barbours Cut Terminal. Thus, the model is site specific, particularly with regard to the stevedoring companies represented. It should also be noted that the model is fragile to its specification. Thus, care must be taken in modifying the model so that variables do not become statistically insignificant. It would be possible to broaden the scope of the model, if data were collected from other U.S. container ports. This model expansion would require dropping site specific variables such as stevedoring companies. Conversely, variables would be added that specify the port in question, storage yard characteristics, and equipment information.

To explore further wharf crane productivity and to develop methods of improving wharf crane operations, theoretical models of actual truck movement must be studied. To reach that goal, it is important to collect field statistics and field data to validate theoretical models. Data have been collected regarding the cyclic operations at the container port. A description of the data collection process and the results of the data analysis are presented in Chapter 4.

CHAPTER 4. DATA ACQUISITION AND ANALYSIS

The vast majority of queuing theory applications are built upon exponential distributions that describe the service and arrival processes of the system. One reason for the exponential assumptions is that the resulting models are mathematically straightforward; in addition, the models typically produce closed form solutions, for both single server systems and cyclic queues. Despite the simplifying effects of the exponential distribution, the validity of using the exponential distribution at the container port (or any queuing application) needs to be established first. To determine the validity of any distribution, a time-motion study must be performed to obtain the interarrival and service time distributions at the service facility of interest. At the container port, the service facility is the wharf crane. To date, there have been no published works documenting the arrival and service processes of vehicles at the wharf crane. Completed wharf crane performance studies have assumed, without validation, Poisson arrivals (resulting in exponential interarrival times) and exponential service times. One objective of this research effort is to determine whether these assumptions are appropriate. If they are not, it will be necessary to determine what distributions can be used to accurately describe the system.

In keeping with that goal, we recorded arrival and service times for all vehicles servicing specific wharf cranes for over 30 hours during multiple visits to Barbours Cut Terminal and the France Road Terminal. The data collection procedure and the results of the data analyses are included in this chapter.

DESIGN OF EXPERIMENT

As previously indicated, a corollary objective of this study was to explore the service time and interarrival time distributions that characterize the formation of queues at the wharf crane. Throughout this report, it is assumed that the customer is the truck that delivers containers to and from the wharf crane, and the server is the wharf crane. Because it can move only one container at a time, the wharf crane has been termed a single-server facility. The service that the truck receives is either the removal of a container from the chassis of the truck or the placement of a container onto the chassis.

The collection of interarrival and service times is conceptually straightforward: the service time is the difference between service completions of succeeding vehicles. The assumption is that a vehicle in queue begins service immediately after the preceding vehicle completes service. Thus, the service time of a vehicle includes the time it takes to move from the queue to the service facility, known as the move-up time. Note that the vehicle currently in service does not move up immediately (while exporting containers) for safety reasons. Instead, it waits until the container from the preceding truck has been lifted and moved away from the truck service position. Although the vehicle may not actually be moving into position, its service time has begun. Similarly, the interarrival time is the time gap between consecutive arrivals of trucks into a queue or at the wharf crane if no queue exists.

DATA COLLECTION METHODOLOGY

To track the desired information, researchers must record the time that each vehicle enters the queue or the service stage, and exits the service stage. Similarly, a vehicle identifier must be assigned that allows each vehicle to be manually tracked at a later date. Vehicle identification could easily be accomplished by recording the truck or chassis number of each vehicle in the gang. However, these service stage events often occur within a matter of seconds, making a manual recording procedure, such as stopwatches and notetaking, undesirable. Instead, hand-held Hewlett-Packard 48SX computers were used for this purpose. The computers are programmable and have a continuous running clock (hours, minutes, and seconds) that allows the time of events to be recorded with the push of a button. They can also interface with desktop computers to download data.

PROGRAMMING THE HEWLETT-PACKARD 48SX

The calculators are programmed so that minimal training is required to use the program, and so that the calculators remain flexible enough for collecting data at any crane or port activity without needing to be re-programmed. Once the program is initiated, the screen displays a message to "Enter Event. Truck." At this time, the user is expected to carry out the following procedures:

(1) identify the vehicle preparing to complete an activity by the number painted on the truck or chassis;
(2) type the number into the calculator moments prior to the activity;
(3) type the code number that describes the event, separated from the truck identification number by a decimal;
(4) at the occurrence of the event, press ENTER.

After these procedures are completed, two things happen that prepare the calculator for the next entry. First, at the moment the ENTER key is pressed, the computer time is assigned to the TRUCK.EVENT label and then is stored in a file with all previously entered codes. Second, the program cycles and the ENTER EVENT.TRUCK message reappears. The message remains on the screen until the next event occurs. The program is aborted at the touch of a key, at which time all entries are saved in one file for future access. The two-part program, presented in Figure 4.1, can easily be edited to provide a more elaborate program. The main program, PORT, runs the subroutine a pre-specified number of times (shown as 500) before the user is required to store the data in a separate file. At 100 entries, the user is provided a simple beep (0.1 seconds in duration at 880 hz) that indicates how many entries have been logged. These numbers can be changed according to the user's preference. The subroutine is equally straightforward: it simply records the clock time (h.mmss) and immediately places the two-part entry (code and time) into a list; the code is stored in the list until all entries are saved in one file.

Program name: PORT	Subroutine: DAT
DO DAT	"ENTER EVENT.TRUCK"
IF DEPTH 100 > THEN 880.1	INPUT TIME HMS->
BEEP	2 >LIST
END	
UNTIL DEPTH 500	

Figure 4.1. Data collection program for the Hewlett-Packard 48SX calculator. Similar programs may be used for data collection at yard cranes, entry gates, or any related operation.

There are several advantages concerning the structure of the program that should be noted. First, the truck identification and event numbers—moments before the event's occurrence—are typed (but not entered) into the calculator; this requires a certain amount of foresight. However, it frees the user to press ENTER at a more accurate approximation of the time of the event. Another notable aspect of the program format is that any key on the calculator could have been pre-programmed to enter a specific code when activated, saving the user the trouble of memorizing the code or of referencing an event code summary sheet to determine the proper code. This option was not exercised, since the activities at the port can change suddenly, causing the user to struggle to recode keys or to restart another program. With the ENTER EVENT.TRUCK option used in the previous program, the code could be adjusted in the field simply by adding or changing a number. The latter option was deemed much more flexible and was employed in this procedure. Also, the referencing of an event code summary is as time-consuming as looking for the correct event key on the calculator.

Defining the events is an important step in the time-motion study because of the need to be consistent throughout the study. Attaining this consistency becomes increasingly difficult as more people become involved in the data collection. Although only three graduate students were involved in the data collection, it was nonetheless important to precisely define what constitutes each event. When appropriate, the motion of wheels was used as the basis for event occurrences, which is described in Table 4.1. In addition to the events previously described, there are numerous events that did not directly involve the trucks but still needed to be recorded for model validation purposes. Examples of these events are as follows: periods of crane idleness, or the time during which cranes move from one bay to the next. The codes used for all of these events, and the description of their occurrence are summarized in Table 4.1.

The code 999 (or any other 'note' code) proved to be very valuable while collecting data. Its primary purpose was to record special events; this was accomplished by providing the user with a small tape recorder or notepad, by which the approximate time and a brief description of the event could be recorded for future reference. Examples of special events might be hatch cover removal, refreshment breaks, accidents at the facility, or special container moves.

DATA COLLECTION PROCEDURE

As mentioned, three graduate students collected data at each of the ports. Each student was familiar with port operations before the data collection effort began. Several locations within the port, serving this specific research effort as well as two closely related projects, were selected for data collection. The majority of the data in this report was collected at the wharf cranes. The other two locations where data were collected were at yard cranes and entry gates into each of the ports.

The data collection locations in the yard were determined by sight requirements and safety concerns. Recall that the vehicle identification number was the number painted on the door of each vehicle, or it was the number painted on the chassis of each truck. Obviously, the truck number is used when the chassis method of storage is employed, since the truck is the only common element of the process. However, it was preferable to use the chassis number because it appeared on both sides of the chassis, whereas the truck number did not always appear on all sides of the vehicle. The numbers are painted on the equipment and are normally three or four inches high. The relatively small size of the numbers required that the people collecting data be quite close to the operations in order to be able to easily read the numbers. The optimal location

TABLE 4.1. EVENT DESCRIPTIONS AND CODES USED IN DATA COLLECTION

Code	Description of Event
1	Vehicle enters queue. (Wheels of vehicle stop rotating upon arrival in queue or in service position.)
2	Vehicle completes move up procedure. (Wheels of vehicle stop rotating upon arrival at the service position beneath the crane.)
3	Vehicle departs service. (Wheels of vehicle rotate beginning the trip from the crane to the storage yard.)
3.1	Service completion of the first container during double container moves. (Placement of the container on an awaiting chassis — vehicle remains in position for the second container.)
3.2	Service completion of the second container during double container moves. (Wheels of vehicle rotate following the placement of the second container on the chassis.)
4	Beginning of crane movement from one bay to another. (Wheels rotate.)
5	Completion of crane movement from one bay to another. (Wheels stop rotating after the final position is reached.)
6.0	Beginning of crane idle period with no container. (Container carriage is empty and hanging idle.)
6.1	Beginning of crane idle period with one container. (Container carriage is loaded and hanging idle.)
7.0	End of crane idle period with no container. (Container carriage begins movement.)
7.1	End of crane idle period with one container. (Container carriage begins movement.)
8	A vehicle that was in the queue balks. (Wheels of vehicle rotate.)
999	Special event or comment about crane operations.

for data collection, then, was slightly to the side of the wharf crane—from the side of the wharf crane, vehicles entered the queue. This location, and the suggested yard crane data collection site are illustrated in Figure 4.2.

The safety issue associated with data collection is a result of the rapid movement of trucks surrounding the wharf cranes and throughout the port entity. It was clear that a person is not safe walking in the area since the right-of-way is always given to the truck. Thus, students remained in mid-sized cars during the data collection. The cars not only provide a shelter for the students, but also a way to move quickly to safety, or from one ship to another if operations cease at either ship.

The only significant problem encountered during the data collection process occurred in the storage yard. The alleys that allow truck passage between the stacks are narrow and do not always ensure the safe passage of both a truck and an automobile. Also, the great length of the alleys (over 500 feet) precluded unrestricted viewing of the yard crane operations. Because the yard crane method of service is employed only at the Barbours Cut Terminal, the France Road facility did not have the problems associated with yard crane operations.

The visibility problems at the Barbours Cut Terminal resulted in very little data being collected in the storage yard. The only storage yard data that was collected was obtained from the container bays nearest the wharf cranes. It was possible to collect data at this location because the trucks actually delivered the containers to the wharf side of the stack, which was visible to the students collecting the data. There were occasional opportunities to collect data at the yard crane, but the data collected was deemed unusable because of the very short duration and the sporadic nature of the operations at the crane being watched. Note also that <u>any</u> data collection in a storage yard required at least two students—one drives the vehicle and the other(s) collects the data.

THE DATA SET

Although data for this research effort was collected at the Port of Houston's Barbours Cut Terminal and the Port of New Orleans' France Road Terminal, four different operating entities were represented. At the Barbours Cut Terminal, data were collected at the wharves that serve the public container storage area and at the wharf that serves Sea-Land, Inc., a private container shipping company. Recall that Barbours Cut employs yard gantry cranes, whereas Sea-Land uses the chassis method of storage. The wharf crane equipment and the land area are leased to Sea-Land by The Port of Houston. The same situation exists at The Port of New Orleans in that Puerto Rico Marine Management, Inc. (PRiMMI) operates adjacent to the France Road Terminal.

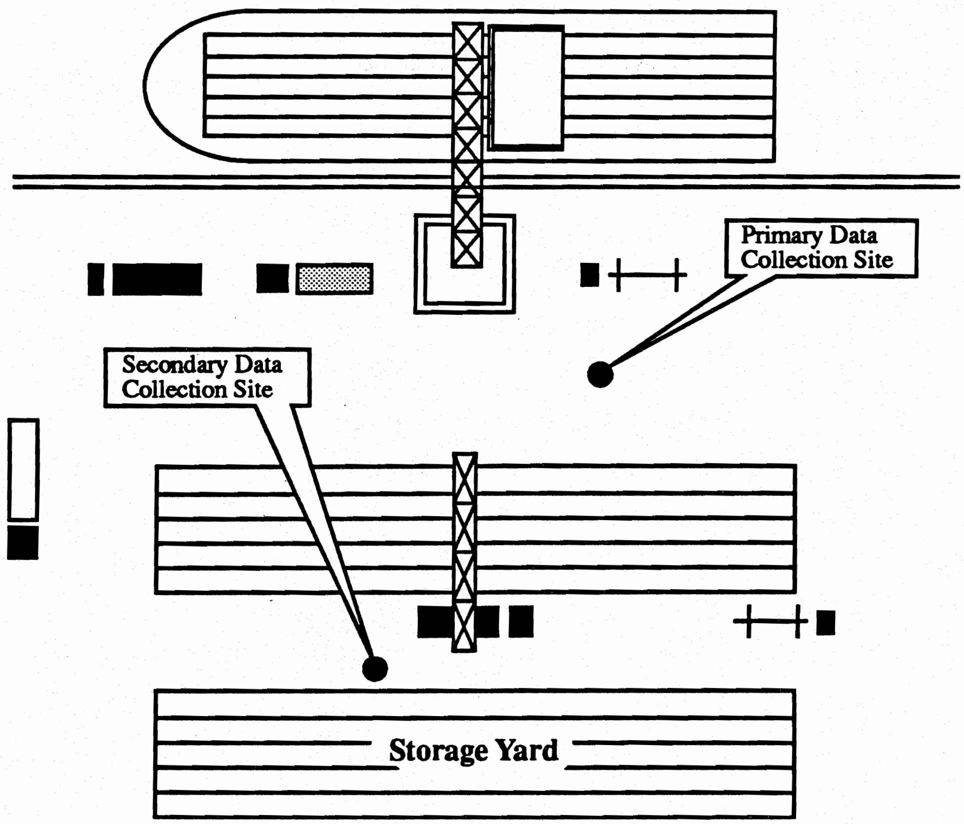


Figure 4.2 Primary and secondary data location sites. Note that limited data were also collected at the entry gate to the yard, not shown in this figure.

PRiMMI operates as a private container company which leases land and wharf crane equipment from The Port of New Orleans. Bear in mind that the France Road Terminal stacks containers with a top-pick loader, whereas PRiMMI stores the containers on individual chassis.

The multiple visits to the ports resulted in a total of sixteen data files. To label each of the files consistently, a specific system was developed and used throughout this report. Each file name includes the date it was created as well as an identifier for the time of day it was created (a.m. or p.m.). Also, because several data files might be created in a single morning or afternoon, a file number was added as an extension. The result was a seven or eight character code such as Feb11a.1. This file name is translated as the first file that was created on February 11 in the a.m. hours. All files created in January or February (9 total) represent operations at The Port of Houston, and the files created in March (7 total) represent operations at The Port of New Orleans.

Transfer of the Data to the Macintosh

Each of the Hewlett-Packard calculators used in the data collection procedure was equipped with a total of 64K of battery powered memory. The Hewlett-Packard calculators had more than enough power to record and to preserve the data until it could be transferred to desktop computers, where an analysis of the data took place. The transfer of the data from the Hewlett Packard calculators to the desktop computers was simple and error free, owing to the power of the hand-held calculators. With a Macintosh interface cable, the calculators were able to transfer the data in a matter of seconds. After being transferred to the Macintosh, a text editing program such as QUED was used to transform the data into a format that could be read by Excel.

Several steps were involved in putting the data into the proper format. Recall that each observation was recorded so that the event code and the truck identification number were separated by a decimal. Each of these entries had to be broken into two separate numbers. After this transformation (and the removal of unwanted brackets and file name identifiers), each entry contained three separate numbers suitable for the spreadsheet: the event code, the vehicle, and the clock time. Once these data were in the spreadsheet, the data reduction and editing procedure could begin.

Error Detection and Editing of Data

Despite every effort to enter the data accurately, there are several ways that errors in data collection can occur. The reasons for these errors, how they are detected in the data set, and corrective actions (if any) are discussed in this section.

The difficulty in identifying mistakes is that the accuracy of the time entries must be determined correctly, so that the process will be adequately described. The phenomenon of trucks inching forward instead of stopping completely or of human errors that delay an entry are only two examples of how time entries might be inaccurately recorded. How accurate must a time entry be to correctly describe the process? Is a tolerance of plus or minus (±) two seconds sufficient so that mistakes within that range result in no more than 'white noise' in the stochastic system? It was decided that small estimations (± two seconds) were permissible. If a larger estimation was required, the person collecting the data was asked to note the estimation on the mini-cassette recorder or on paper and to identify the truck number and the time of the entry. This practice allowed the exact entry to be identified and marked as an estimated time. Because estimated entries cannot be corrected, it was decided that estimated entries must not be used in determining interarrival times, service times, or backcycle times. [The backcycle time is simply the time that it takes the truck to exit the service position and return to the queue at the wharf crane. If no queue exists, it is simply the time lapse between exiting service and arriving back into service at the wharf crane. Note that each of these backcycle times include the time it takes to travel through the yard delivering or retrieving containers.] Note that one estimated arrival time results in the discarding of two interarrival times, which is illustrated by the following example. Suppose that arrival times t_1, t_2, and t_3 are recorded and that time t_2 is identified as an estimated entry. The interarrival times t_{12} (=t_2-t_1) and t_{23} (=t_3-t_2), therefore, are both incorrect, since they are determined by the t_2 entry. The same is true for service times.

Another data entry mistake could be the incorrect entry of a vehicle number. If this type of mistake is recognized by the person collecting data, a simple note can again be made, and the data can be corrected after it is transferred into the spreadsheet. If the mistake was not recognized by the person collecting the data, the mistake could be found by tracing each vehicle through the system during data inspection. Consider the following example: a vehicle is recorded as appearing in the queue and proceeding to the server. However, a different vehicle number is put down next to complete service. It is likely that a mistake has been made in entering the number of the vehicle that completed service. There is another way to verify the vehicle number; recall that only six to eight trucks make up a gang, making it possible to keep a list of the vehicles in the gang. If a vehicle number does not appear in the list, it is possible that the vehicle number is incorrect. Note, however, that it is also possible that a different chassis or vehicle entered the system. In this case, later records should be checked to determine whether the vehicle number reappears.

A very similar procedure was used to correct event coding mistakes. Again, if the mistake was not recognized by the data collector, individual vehicle tracking would illuminate the mistake. Mistakes can occur, to cite two examples, when vehicles are recorded as having entered the queue twice or when complete service is recorded before service had actually begun. In either of these errors, the correction is made by simply re-coding the event when the incorrect order is found. The time entry is correct (so the researcher assumes), but a mistake has been made in entering the event code.

Event coding mistakes could be identified by determining how many vehicles are in queue or in service (known as the system state) at a given time. The system state could be used as a check in two ways. First, if the queue length exceeded the total number of vehicles in the gang, there would be an imbalance of too many arrivals and not enough service completions in the record. If this occurred, the codes would be checked and corrected immediately, if indeed a mistake had been found. The other possible check would highlight problems when the number of vehicles in service exceeded one, or dropped below zero. This occurrence represented a shortage of service completions or a surplus of service entries for the first case, and a surplus of service completions or a shortage of service entries for the second case. The system state is shown for all of the data presented in Appendix A. All vehicle identification mistakes and event coding mistakes that were identified were corrected using the procedures described above.

The last type of error is related to accurately describing the crane's operations. The problems associated with collecting crane movement data are of the time estimation type. It was very difficult to discern when specific crane movements began or ended for several reasons. First, the lateral movements of the crane are very slow, making it difficult from any distance to see when motion begins or stops. Second, the crane movements are often very short in duration, and they occur without warning, making it easy to completely miss the movement if other operations are being viewed. One such example is the adjustment of the crane's lateral position that occurs when the ship's position changes during loading or unloading. For these reasons, it is difficult to determine exactly how long a crane is idle or how much time is spent in relocating a crane, based on the field data. With the data corrections described above, the analysis can proceed.

INITIAL DATA ANALYSIS

The analysis of the field data begins by considering the level of service that each ship receives. This section includes exploration of crane productivity measures and the tabulation of service times, interarrival times, and backcycle times. The tabulation of such information leads directly into the next section, in which an argument is made for testing the information to determine what distribution most accurately describes the process in question.

The procedure for calculating the service, interarrival, and backcycle times was carried out for all sixteen data files, which represent 31 hours 10 minutes of data collection. The individual data files covered time periods ranging from only 30 consecutive minutes to upward of 5 hours. Data files that represent over 4 hours of operations are rare because most port operations completely cease during the lunch hour and end for the day at 5:00 p.m., unless evening operations are scheduled. (Data files of 5 hours were created at PRiMMI, a private company that often services ships nonstop until unloading/loading has been completed.)

More importantly, observation periods were normally terminated when operations were halted for maintenance or for other unknown reasons. These interruptions in crane operations suggest that steady-state operations are not maintained for significant periods of time, a topic explored in greater detail in the next chapter. This phenomenon, of course, has negative repercussions on the efficiency of the operations.

The primary quantities of interest in this chapter are the service, interarrival, and backcycle times for each observation. After all of the individual times were calculated, they were grouped together for initial data analyses. Table 4.2 summarizes the results of the initial data analysis.

Seven ships were represented in the sixteen data files, all of which were cellularized vessels. The crane productivity for these ships averaged 28.6 container moves/hr with a standard deviation of 6.1 moves/hr. The maximum productivity achieved was 37.1 moves/hr for the observation period. The ship being serviced was the *Act III*, and the associated data file, Mar7p.2, represented 1 hour 20 minutes of data, a substantial period of time during which high productivity was maintained. The minimum productivity occurred while servicing the *Yu He* (Feb12a.2). The crane productivity was only 13.3 moves/hr over a span of 1 hour 7 minutes. It should be noted, however, that this data file included at least one significant delay that would decrease the reported crane productivity. The suggestion that the crane productivity is not correctly represented by this statistic is supported by the fact that the crane provided the fastest average service time of all data files (40 sec/truck).

From the information presented in Table 4.2, the average service time is the performance characteristic with the least variance; this result was expected since there are significantly fewer factors—compared with interarrival and backcycle times—controlling the rate at which a crane can operate. Interarrival and backcycle times are dependent on storage yard operations and the transit time to and from the storage yard. The average of the mean service times is 1 minute 18 seconds per truck with a standard deviation of 0 minutes 23 seconds per truck. The shortest mean service time is 40 seconds per truck, and the longest mean service time is 1 minute 55 seconds per truck; both were calculated for each individual file. In a similar fashion, the average mean interarrival time is 2 minutes 12 seconds per truck with a standard deviation of 0 minutes 32 seconds. The maximum mean interarrival time is 3 minutes 53 seconds per truck, and the minimum mean interarrival time is 1 minute 36 seconds. Similarly, the average mean backcycle time is 9 minutes 2 seconds per truck with a standard deviation of 4 minutes 5 seconds per truck. The maximum mean backcycle time is 17 minutes 49 seconds per truck, and the minimum is 3 minutes 45 seconds per truck. A slight correlation of the mean interarrival times and the mean backcycle times is suggested by the fact that the maximum mean of each occurred in the same data file (Feb12a.2 servicing the *Yu He*). Similarly, the file with the minimum mean backcycle time (Mar8a.2) is paired with the seventh lowest mean interarrival time. The implication is simply that as backcycle times increase, the interarrival times also increase. This is in accordance with the expectations presented in Chapter 2.

TABLE 4.2 SUMMARY STATISTICS OF WHARF CRANE OPERATIONS

File	Crane+	Ship Served	Moves/hr	Service Times #Obs	Service Times Mean	Service Times St Dev	Interarrival Times #Obs	Interarrival Times Mean	Interarrival Times St Dev	Backcyle Times #Obs	Backcyle Times Mean	Backcyle Times St Dev
Jan7p.1	3 (7)	Falstria	26.2	60	1:40	1:20	59	2:36	2:05	50	12:39	8:57
Jan7p.2	4 (7)	Falstria	28.7	37	1:17	1:11	39	2:05	1:49	26	11:13	3:23
Feb11a.1	3 (5)	Bonn Express	30.5	41	1:44	0:42	44	1:50	1:05	34	5:13	1:43
Feb11a.2	4 (5)	Bonn Express	27.9	37	1:09	0:45	38	2:10	1:40	21	9:34	10:26
Feb11p.1	3 (5)	Bonn Express	28.0	74	1:40	1:31	74	2:37	2:21	62	12:02	7:58
Feb12a.1	1 (–)	Yu He	23.8	27	1:23	1:22	29	2:35	2:09	6	16:36	2:47
Feb12a.2	1 (–)	Yu He	13.25	15	0:40	0:25	16	3:53	5:44	11	17:49	11:35
Feb12a.3	6 (7)	Newark Bay (Sea Land)	36.3	22	1:40	0:34	22	1:36	1:12	16	6:22	1:22
Feb12p.1	6 (8)	Newark Bay (Sea Land)	33.3	53	1:33	1:03	48	1:51	2:27	39	6:35	1:35
Mar7p.1	3 (6)	Act III	36.2	30	0:48	0:21	27	1:49	2:02	17	9:24	6:21
Mar7p.2	3 (6)	Act III	37.1	47	1:00	0:26	43	1:49	2:45	43	5:00	2:58
Mar8a.1	3 (6)	TNT Express	24.1	25	1:32	0:41	21	2:03	1:36	21	8:09	4:51
Mar8a.2	3 (6)	TNT Express	33.2	17	1:50	0:49	14	2:00	1:09	14	3:44	0:30
Mar8p.1	2 (6)	TNT Express	24.1	61	1:25	1:02	65	2:19	2:41	47	6:27	4:46
Mar9p.1	2 (6)	Guayama (PRiMMI)	25.1	118	2:09	1:22	97	2:15	1:44	89	6:31	2:04
Mar9p.2	3 (6)	Guayama (PRiMMI)	29.7	128	1:36	1:12	136	1:57	1:54	133	7:20	4:48

+Parenthetical values refer to the number of vehicles in the gang servicing the ship

With this initial data analysis as a background, we can now turn to more detailed analyses that determine the distributions of the service, interarrival, and backcycle times. These analyses are critical in correctly specifying the theoretical queuing models that are used in studying port operations.

DISTRIBUTION TESTING

The Erlang distribution is an appropriate alternative to the exponential distribution in modeling a queuing process. This is particularly true when there is no prior information that can describe the process, other than by known distributions (such as constant, uniform, or normal). The Erlang distribution is frequently used because the density function is specified by two parameters, resulting in a very wide range of possible processes that can be modeled. This section explores the Erlang distribution's applicability to wharf crane operations.

NON-PARAMETRIC TESTING PROCEDURE

The difficulty in determining which theoretical distribution best describes the service, interarrival, or backcycle processes is this: there are no population characteristics that would allow basic statistical tests to be performed. For this reason, non-parametric statistical techniques are necessary to test the sample data's similarity to various theoretical distributions. There are two non-parametric tests that are commonly used to test the shape of various distributions. The most common is the chi-square test. However, a more powerful test, and one that is used for the majority of this analysis, is the Kolmogorov-Smirnov test. The Kolmogorov-Smirnov test procedure, which has a decided advantage over other tests, is discussed in the following pages.

The chi-square test was used only in the early phases of the testing procedure. After the data files were created in January and February, the chi-square test was used to determine whether exponential interarrival and service times were appropriate. The standard procedure for this type of test is to first break the possible times into k categories. The actual frequency of occurrence of each category is then compared with the expected frequency of occurrence. The expected frequency of occurrence is determined by setting the mean of the theoretical exponential distribution so that it is equal to the sample mean. The chi-square statistic is then calculated to test the null hypothesis that the distribution is exponential. Note that the chi-square procedure may be followed for any theoretical distribution whose density function is known. The chi-square test was performed on all of the data files only as a goodness-of-fit test with the exponential distribution. The results of the chi-square test showed that some, but not all, of the service and interarrival distributions were exponential. Thus, other distributions must be tested in order to identify the distribution which most adequately describes the process. The results of the chi-square tests are not included in this report, since the exponential distribution is a part of subsequent testing procedures.

The Kolmogorov-Smirnov test (K-S test), employed to test other distributions, has the following advantages over the chi-square test. First, the rule of five must be upheld when using the chi-square test. The rule of five requires that the expected frequency of every category considered in the test be at least five. Where necessary, categories are combined to satisfy the condition. The drawback may be obvious. In smaller samples, such as the ones found in this data set, it may be impossible to meet the requirements of the chi-square test without limiting the categories to only two or three. But a small number of categories is not appropriate for this type of test. Thus, only the larger data files could be tested with the chi-square procedure. The second reason is closely related to the first. The K-S test, without using any categories, can compare the theoretical and the sample distributions. In its testing procedure, the K-S test considers the cumulative distribution function, which means that significantly smaller samples can be tested.

K-S TESTING METHODOLOGY AND THE ERLANG DISTRIBUTION

The K-S procedure is actually used to perform two different types of tests. The Kolmogorov type test compares a theoretical, or hypothesized, distribution with a sample distribution. The Smirnov type test, on the other hand, is used to compare two sample distributions. Although the tests compare slightly different distributions, the same procedure is used for both. In the tests discussed in the remainder of this report, the null hypothesis is that data were drawn from the tested distribution. The alternate hypothesis is that the data were not drawn from the distribution being tested.

The K-S test operates by comparing the cumulative distribution functions of the theoretical and the sample distributions. The test statistic, D, is the maximum absolute difference between the two distributions, which is expressed in Equation 4.1. The theoretical distribution is represented by F(t), and the sample distribution is G(t).

$$D = \max \left| F(t) - G(t) \right| \tag{4.1}$$

The service, interarrival, and backcycle times of each data file were tested for seven different Erlang distributions. Recall that the density of the Erlang distribution is specified by two parameters: a rate parameter, R, and a shape parameter, *k*, where *k* is a positive integer [Ref 52]. The rate parameter is the inverse of the mean of the sample under consideration. If the service times of a data file were being tested, the rate parameter would be the inverse of the mean service time. The mean service rate is commonly represented by m, whereas the mean arrival rate is represented by l. The probability density function for the Erlang distribution is as follows:

$$f(t) = \frac{R(Rt)^{k-1} e^{-Rt}}{(k-1)!} (t \geq 0) \tag{4.2}$$

where

$$E(T) = \frac{k}{R} \text{ and var } (T) = \frac{k}{R^2}$$

An investigation of the Erlang probability density function (pdf) reveals several pertinent facts. First, the Erlang distribution with a shape parameter of *k* =1 reduces to the exponential distribution. Second, as the shape parameter *k* increases, the variance of the pdf decreases. Although not as obvious as in the previous statement, an increase in the shape parameter also causes the distribution to behave more like a normal distribution. This is illustrated in Figure 4.6, which is presented later in this section. Third, for extremely large values of *k*, the Erlang distribution approaches a constant distribution (zero variance).

The shape parameter of the Erlang distribution has a powerful, yet simple interpretation. Consider a process that is described by an Erlang distribution with parameter *k*. The process is actually comprised of a series of *k* exponential phases. Each of the *k* phases follow identically distributed exponential random variables, each with a mean of (1 / m*k*). Only one customer at a time is allowed in the system of phases, and each customer must complete all *k* phases of the system. Thus, the Erlang distribution describes the total time that a customer spends in service.

It is also worth mentioning the hyper-exponential distribution. The interpretation of a hyper-exponential distribution is the reverse of the Erlang distribution. The hyper-exponential distribution effectively models a process with *k* independently distributed exponential service phases operating parallel to one another. Any customer who enters the system is serviced by only one of the phases. As with the Erlang distribution, only one customer may be served at a time. The result is a mean service time with an increasing variance (as the number of possible phases increases) over the exponential distribution. Having reviewed several distributions and the K-S test procedure, we can now begin to discuss the actual testing of the data files.

Distribution Testing Procedure

The service, interarrival, and backcycle times of each data file were compared with the Erlang distribution, shape parameters 1 through 7, in order to test for similarities. Recall that this includes the exponential distribution. [Throughout the remainder of this text, the Erlang distribution with shape parameter *k* will be referred to as E(k) or Erlang(k).] Having completed the initial data analyses, the researchers decided that the hyper-exponential distribution would not be considered in the distribution testing procedure. The reason for this exclusion is that the variance of the majority of the data files was not large enough to warrant considering the hyper-exponential distribution. (Of the more than 50 tests run, only two of the sample distributions could possibly be modeled as hyper-exponential.)

The exponential distribution and E(2) through E(7) were tested for similarity against the sample data. The wide range that these seven distributions represent are illustrated in Figure 4.3. As mentioned previously, the K-S test does not test the probability density functions that are illustrated in the figure. Rather, the K-S test considers the cumulative distribution function (cdf). The corresponding cdf of each distribution is illustrated in Figure 4.4.

The K-S test is illustrated by considering the testing of the service time distribution for one data file. It is structured so that the null hypothesis is as follows: the sample data comes from a population which is E(*k*) distributed. The procedure is identical for all other data files and for each type of test completed (service, interarrival, or backcycle times). Because of the repetitive nature of these calculations, it was advantageous to use the spreadsheet for this procedure. The format of the K-S test is illustrated in Figure 4.5 by means of a sample of the field data.

The first step is to place the service times in ascending order. These times are then used to determine the sample cumulative distribution function. Next, the expected frequency of each individual time entry is calculated according to the specified theoretical distribution. Because the pdf (and thus the cdf) of each of the theoretical distributions is dependent on a shape parameter *k* and a rate parameter *R*, the rate parameter is simply the inverse of the mean sample service times and is calculated for each separate data file. The rate parameter, and a shape parameter (1-7) are used in the Erlang cdf to determine the expected cumulative frequency. The expected frequency of each distribution is shown in every other column of the spreadsheet in Figure 4.5.

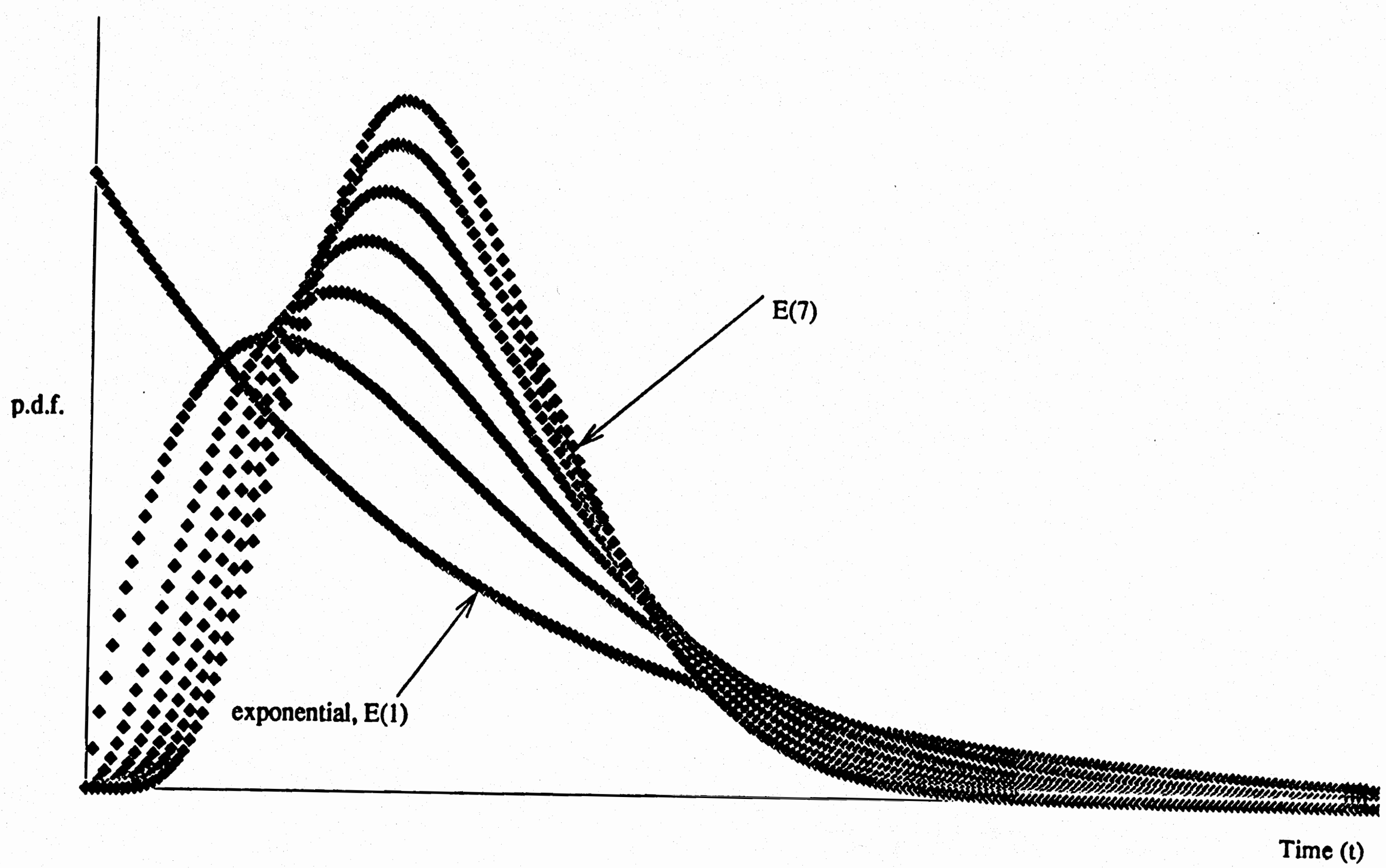


Figure 4.3 Probability Distribution Functions for Erlang(1) through Erlang(7)

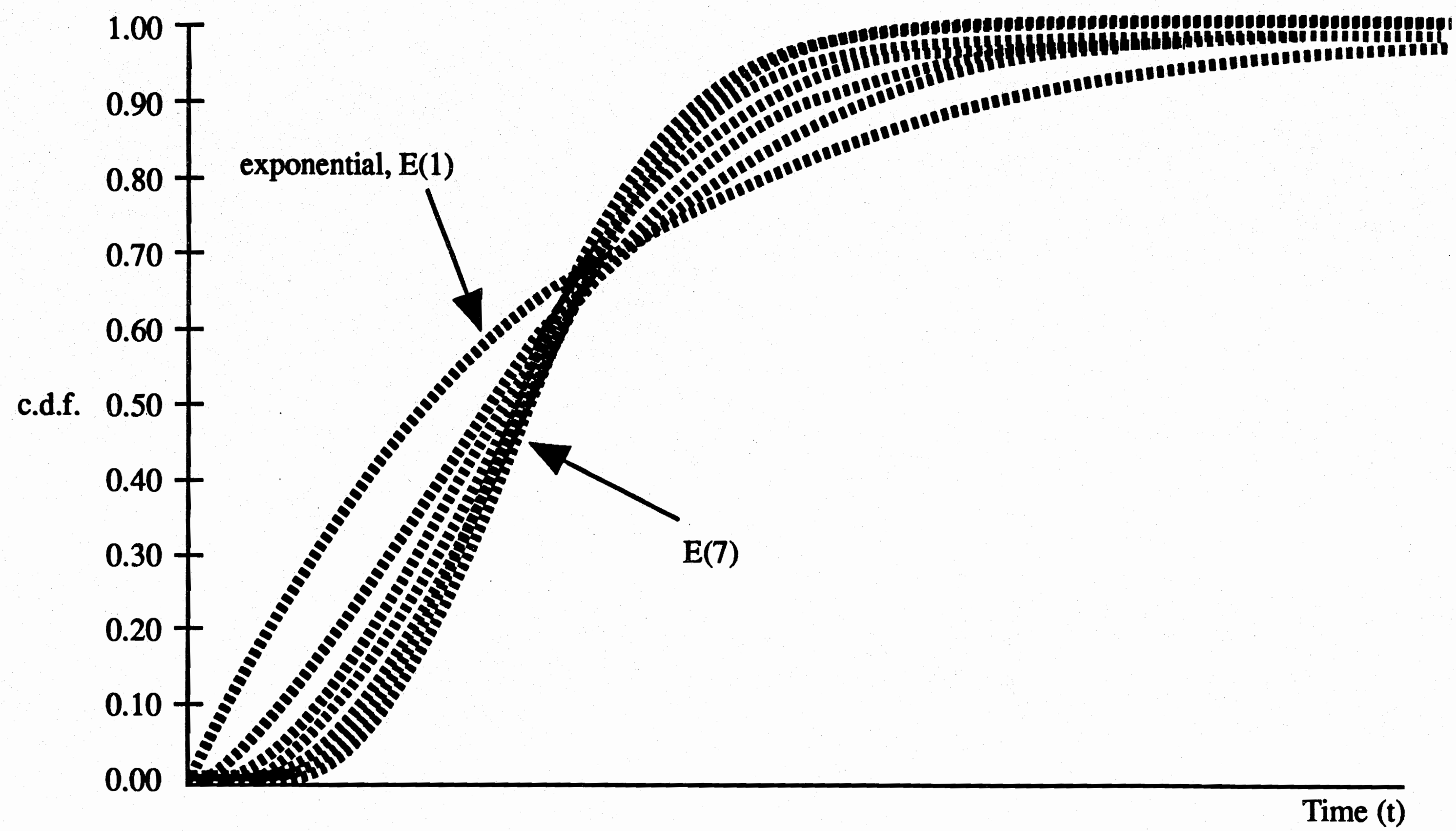


Figure 4.4 Cumulative Distribution Functions for Erlang(1) through Erlang(7)

ave =	0.64	truck/min													
	915.08	truck/day													
Time	Sample Freq.	Expo. Freq.	Expo. Deviation	E(2) Freq.	E(2) Deviation	E(3) Freq.	E(3) Deviation	E(4) Freq.	E(4) Deviation	E(5) Freq.	E(5) Deviation	E(6) Freq.	E(6) Deviation	E(7) Freq.	E(7) Deviation
0:00:32	0.04	0.2869	0.2485	0.1476	0.1092	0.8300	0.0445	0.4850	0.0101	0.0291	0.0093	0.0176	0.0208	0.0108	0.0276
0:00:40	0.08	0.3481	0.2712	0.2114	0.1345	0.1391	0.0622	0.0949	0.0180	0.0663	0.0107	0.0467	0.0303	0.0333	0.0437
0:00:44	0.12	0.3746	0.2592	0.2417	0.1263	0.1684	0.0530	0.1214	0.0060	0.0895	0.0259	0.0665	0.0489	0.0500	0.0654
0:00:49	0.15	0.4035	0.2496	0.2765	0.1226	0.2038	0.0499	0.1551	0.0012	0.1204	0.0334	0.0943	0.0595	0.0746	0.0792
0:00:49	0.19	0.4074	0.2151	0.2814	0.0891	0.2089	0.0166	0.1601	0.0322	0.1252	0.0672	0.0987	0.0936	0.0786	0.1137
0:00:53	0.23	0.4273	0.1965	0.3064	0.0756	0.2355	0.0047	0.1865	0.0443	0.1506	0.0802	0.1225	0.1082	0.1007	0.1301
0:00:54	0.27	0.4385	0.1693	0.3208	0.0516	0.2511	0.0181	0.2024	0.0668	0.1662	0.1030	0.1375	0.1317	0.1149	0.1503
0:00:59	0.31	0.4673	0.1596	0.3587	0.0150	0.2933	0.0143	0.2465	0.0612	0.2106	0.0971	0.1812	0.1264	0.1573	0.1503
0:01:04	0.35	0.4939	0.1478	0.3950	0.0489	0.3350	0.0112	0.2912	0.0549	0.2571	0.0891	0.2285	0.1177	0.2046	0.1415
0:01:11	0.38	0.5277	0.1431	0.4423	0.0576	0.3908	0.0061	0.3529	0.0317	0.3229	0.0617	0.2972	0.0874	0.2753	0.1093
0:01:15	0.42	0.5476	0.1245	0.4706	0.0476	0.4249	0.0019	0.3914	0.0317	0.3648	0.0583	0.3418	0.0812	0.3222	0.1009
0:01:20	0.46	0.5720	0.1105	0.5060	0.0444	0.4680	0.0064	0.4405	0.0210	0.4189	0.0426	0.4002	0.0613		0.0773
0:01:21	0.50	0.5751	0.0751	0.5104	0.0104	0.4735	0.0265	0.4468	0.0532	0.4260	0.0740	0.4078	0.0922	0.3924	0.1076
0:01:23	0.54	0.5384	0.0449	0.5225	0.0160	0.4883	0.0502	0.4639	0.0746	0.4449	0.0935	0.4285	0.1100	0.4145	0.1240
0:01:28	0.58	0.6058	0.0288	0.5552	0.0217	0.5287	0.0482	0.5107	0.0662	0.4972	0.0798	0.4856	0.0913	0.4760	0.1010
0:01:30	0.62	0.6126	0.0028	0.5652	0.0502	0.5411	0.0743	0.5250	0.0904	0.5132	0.1022	0.5032	0.1122	0.4950	0.1204
0:01:30	0.65	0.6128	0.0410	0.5656	0.0883	0.5415	0.1123	0.5255	0.1283	0.5138	0.1400	0.5038	0.1500	0.4957	0.1582
0:01:40	0.69	0.6535	0.0388	0.6254	0.6690	0.6158	0.0765	0.6118	0.0805	0.6106	0.0817	0.6101	0.0822	0.6107	0.0817
0:01:40	0.73	0.6547	0.0761	0.6272	0.1036	0.6180	0.1128	0.6144	0.1164	0.6134	0.1173	0.6132	0.1175	0.6140	0.1168
0:01:53	0.77	0.6976	0.0717	0.6898	0.0795	0.6951	0.0742	0.7033	0.0659	0.7124	0.0568	0.7211	0.0481	0.7299	0.0394
0:02:15	0.81	0.7610	0.0467	0.7793	0.0284	0.8018	0.0059	0.8225	0.0148	0.8409	0.0332	0.8568	0.0491	0.8710	0.0633
0:02:23	0.85	0.7794	0.0668	0.8042	0.0420	0.8302	0.0160	0.8528	0.0066	0.8721	0.0260	0.8884	0.0422	0.9024	0.0562
0:02:25	0.88	0.7856	0.0991	0.8124	0.0722	0.8394	0.0452	0.8624	0.0222	0.8819	0.0028	0.8980	0.0134	0.9118	0.0272
0:02:44	0.92	0.8230	0.1000	0.8602	0.0628	0.8909	0.0322	0.9144	0.0087	0.9325	0.0094	0.9463	0.0233	0.9572	0.0341
0:03:20	0.96	0.8791	0.0824	0.9237	0.0379	0.9516	0.0100	0.9689	0.0073	0.9798	0.0183	0.9868	0.0252	0.9913	0.0298
0:04:13	1.00	0.9316	0.0684	0.9702	0.0298	0.9867	0.0133	0.9940	0.0060	0.9972	0.0028	0.9987	0.0013	0.9994	0.0006
26		max deviation =	0.2712		0.1345		0.1128		0.1283		0.1400		0.1500		0.1582
		test statistic =	0.2590												
		mean =	0:01:34												
		st dev =	0:00:52												
		parameter est. =	3.25												

Figure 4.5 K-S Test for Sample Data File

The difference between the sample cdf and the theoretical cdf for each time entry is then calculated adjacent to the theoretical cdf. The maximum deviation is then determined for each theoretical distribution and is listed near the bottom of the spreadsheet. The test statistic illustrates the trend toward the distribution that best fits the sample data. In the example of Figure 4.5, the best fit is the E(3) distribution, with a maximum deviation of D=0.1128 from the sample distribution. This is less than the test statistic of 0.259 (a=0.05), as are several other distributions.

To illustrate this graphically, the service and interarrival time distributions are illustrated for the Mar7p.2 and Feb12p.1 data files, respectively. These files were selected because of the range of distributions represented. The best fit distribution for the service times is E(7), and the best fit distribution for the interarrival times is the exponential distribution. Figures 4.6 and 4.7 compare the sample distribution with the theoretical distribution. Similar graphic illustrations for all data files and distribution tests are included in Appendix B.

Although the primary objective of the test is to determine which distribution best describes the service, we decided to test interarrival, backcycle times, and several other items. Whenever double moves were captured within a data file, tests were performed on single, double, and combined service and interarrival times. Also, if two or more data files were created for the same ship, the tallied service and interarrival times were combined, and the tests performed again on the new data file.

There are several implications related to combining files. First, the sample size increases, which strengthens the distribution test. Second, when files are combined, the resulting distribution is one that describes a more general process. Put another way, the service time distribution of Feb11a.1 is associated with crane number three, which serviced the *Bonn Express*. If the file is combined with Feb11a.2 (crane number four servicing the *Bonn Express*), the resulting service time distribution is one that may describe more accurately the service process of the entire ship. These data are compared to the individual file that only describes the service process of one crane. The results of all of the aforementioned distribution tests are discussed in the next section.

DISTRIBUTION TEST RESULTS

Because of the high number of tests performed (a total of 70), the results will be presented in three groups: service times, interarrival times, and backcycle times. The distribution test results for each of these groups are presented in Tables 4.3, 4.4, and 4.5, respectively. Each of these tables represent statistical tests for a significance level of a=0.05. Note that the majority

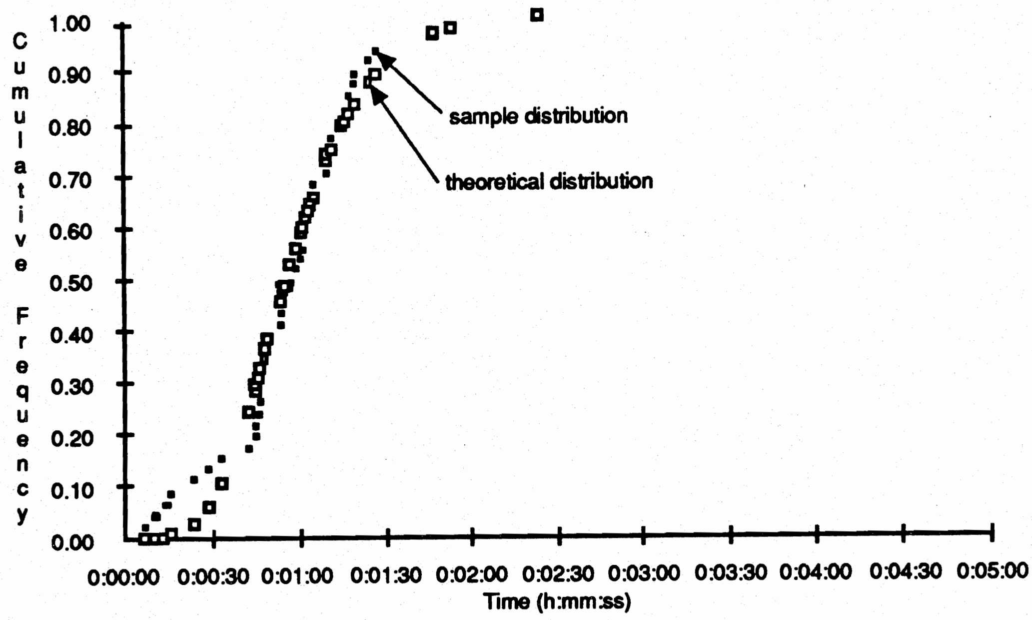


Figure 4.6 Service times for Mar7p.2. Best fit is the E(7) distribution. Sample is 47 observations.

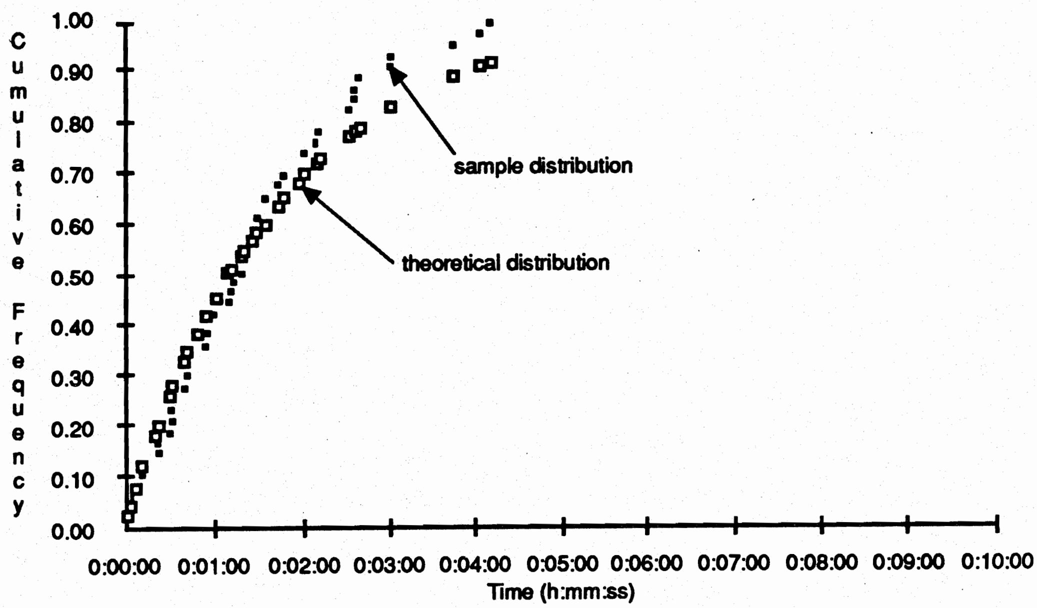


Figure 4.7 Interval times for Feb12p.1. Best fit is the exponential distribution. Sample is 48 observations.

TABLE 4.3. RESULTS OF SERVICE TIME DISTRIBUTION TESTS FOR EACH DATA FILE. THE BOXES IDENTIFY THE MINIMUM DEVIATION BETWEEN THE THEORETICAL AND SAMPLE DISTRIBUTIONS

Data File	K-S Statistic	E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)
Jan7p.1	0.1756	0.1442	0.0704	0.1364	0.1770	0.2074	0.2366	0.2607
Jan7p.2	0.2180	0.1648	0.1582	0.1493	0.1760	0.2051	0.2300	0.2513
Feb11a.1	0.2124	0.3443	0.2427	0.1952	0.1611	0.1512	0.1433	0.1353
Feb11a.2	0.2180	0.2283	0.1548	0.1348	0.1203	0.1467	0.1747	0.1965
Feb11p.1	0.1581	0.1654	0.1144	0.1165	0.1476	0.1715	0.1920	0.2062
Feb12a.1	0.2540	0.1986	0.1784	0.1901	0.2344	0.2689	0.2977	0.3217
Feb12a.2	0.3380	0.2625	0.1524	0.1885	0.2227	0.2506	0.2747	0.2952
Feb12a.3	0.2510	0.4580	0.3628	0.3050	0.2628	0.2296	0.2029	0.1984
Feb12p.1	0.1868	0.3526	0.2450	0.2360	0.2344	0.2309	0.2271	0.2227
Mar7p.1	0.2420	0.2648	0.1985	0.1665	0.1439	0.1265	0.1169	0.1308
Mar7p.2	0.1984	0.3391	0.2528	0.2018	0.1642	0.1344	0.1089	0.0872
Mar8a.1	0.2640	0.3000	0.1681	0.0948	0.0952	0.0998	0.1057	0.1114
Mar8a.2	0.3180	0.4271	0.3253	0.2635	0.2187	0.1839	0.1691	0.1651
Mar8p.1	0.1741	0.1544	0.0703	0.1194	0.1563	0.1876	0.2143	0.2369
Mar9p.1-single	0.1327	0.3799	0.2540	0.1816	0.1918	0.2039	0.2143	0.2227
Mar9p.1-double	0.3610	0.4377	0.3469	0.2934	0.2630	0.2389	0.2181	0.2002
Mar9p.1-all	0.1252	0.3647	0.2348	0.1616	0.1592	0.1767	0.1919	0.2052
Mar9p.2-single	0.1366	0.2116	0.1079	0.1294	0.1494	0.1715	0.1914	0.2085
Mar9p.2-double	0.2460	0.3986	0.2793	0.2089	0.1601	0.1240	0.1148	0.1256
Mar9p.2-all	0.1202	0.1751	0.0787	0.1342	0.1765	0.2117	0.2409	0.2649
Falstria	0.1381	0.1691	0.1655	0.2189	0.2581	0.2892	0.3156	0.3381
Bonn Express	0.1099	0.1876	0.1329	0.1293	0.1241	0.1346	0.1522	0.1660
Yu He	0.2174	0.2144	0.1210	0.1845	0.2321	0.2683	0.2975	0.3212
Newark Bay	0.1540	0.3580	0.2472	0.2043	0.1895	0.1752	0.1624	0.1514
Act III	0.1540	0.2801	0.1575	0.0860	0.0631	0.0593	0.0807	0.1040
TNT Express	0.1321	0.1542	0.1615	0.1989	0.2260	0.2516	0.2806	0.3046
Guayama	0.0934	0.2457	0.1062	0.1014	0.1110	0.1255	0.1385	0.1625

TABLE 4.4. RESULTS OF INTERARRIVAL TIME DISTRIBUTION TESTS FOR EACH DATA FILE. THE BOXES IDENTIFY THE MINIMUM DEVIATION BETWEEN THE THEORETICAL AND SAMPLE DISTRIBUTIONS

Data File	K-S Statistic	E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)
Jan7p.1	0.1771	0.0892	0.1008	0.1737	0.2223	0.2566	0.2824	0.3017
Jan7p.2	0.2130	0.1107	0.1008	0.1480	0.1967	0.2317	0.2584	0.2786
Feb11a.1	0.2050	0.2388	0.1161	0.0749	0.1187	0.1529	0.1815	0.2054
Feb11a.2	0.2150	0.1568	0.1189	0.1180	0.1546	0.1759	0.1911	0.2043
Feb11p.1	0.1581	0.1442	0.1110	0.1343	0.1813	0.2160	0.2427	0.2645
Feb12a.1	0.2460	0.1263	0.1256	0.1580	0.1926	0.2222	0.2493	0.2723
Feb12a.2	0.3270	0.2819	0.3551	0.4035	0.4392	0.4674	0.4917	0.5125
Feb12a.3	0.2810	0.1479	0.0880	0.1523	0.1986	0.2343	0.2636	0.2875
Feb12p.1	0.1963	0.0978	0.1160	0.1839	0.2268	0.2540	0.2722	0.2902
Mar7p.1	0.2540	0.1562	0.2000	0.2466	0.2881	0.3234	0.3525	0.3765
Mar7p.2	0.2074	0.2438	0.2782	0.2926	0.3354	0.3717	0.4008	0.4242
Mar8a.1	0.2870	0.1727	0.1170	0.1334	0.1603	0.1955	0.2247	0.2487
Mar8a.2	0.3490	0.1886	0.1178	0.1289	0.1382	0.1412	0.1581	0.1803
Mar8p.1	0.1687	0.0925	0.1279	0.2011	0.2481	0.2800	0.3030	0.3224
Mar9p.1-single	0.1521	0.1282	0.0851	0.1195	0.1545	0.1813	0.2048	0.2272
Mar9p.1-double	0.3180	0.0641	0.1742	0.2327	0.2614	0.2966	0.3255	0.3484
Mar9p.1-all	0.1381	0.1094	0.0740	0.1343	0.1730	0.2062	0.2326	0.2525
Mar9p.2-single	0.1309	0.0522	0.1129	0.1793	0.2186	0.2546	0.2828	0.3047
Mar9p.2-double	0.2500	0.1802	0.1950	0.2329	0.2588	0.2716	0.2869	0.3076
Mar9p.2-all	0.1166	0.0551	0.1269	0.1896	0.2251	0.2528	0.2801	0.3011
Falstria	0.1374	0.0884	0.0953	0.1554	0.1992	0.2334	0.2620	0.2859
Bonn Express	0.1089	0.1554	0.0895	0.0951	0.1441	0.1797	0.2081	0.2313
Yu He	0.2027	0.1586	0.1452	0.1654	0.2131	0.2493	0.2786	0.3022
Newark Bay	0.1626	0.0927	0.0910	0.1493	0.1982	0.2342	0.2623	0.2842
Act III	0.1626	0.1761	0.2088	0.2482	0.2958	0.3320	0.3612	0.3849
TNT Express	0.1360	0.1055	0.0708	0.1438	0.1923	0.2265	0.2520	0.2711
Guayama	0.0992	0.0810	0.0841	0.1493	0.1854	0.2145	0.2426	0.2651

TABLE 4.5. RESULTS OF BACKCYCLE TIME DISTRIBUTION TESTS FOR EACH DATA FILE. THE BOXES IDENTIFY THE MINIMUM DEVIATION BETWEEN THE THEORETICAL AND SAMPLE DISTRIBUTIONS

Data File	K-S Statistic	E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)
Jan7p.1	0.1923	0.2085	0.1183	0.1572	0.1854	0.2076	0.2296	0.2434
Jan7p.2	0.2590	0.3580	0.2660	0.2103	0.1694	0.1372	0.1099	0.1040
Feb11a.1	0.2270	0.4128	0.3057	0.2442	0.2002	0.1659	0.1443	0.1569
Feb11a.2	0.2870	0.2328	0.3391	0.4082	0.4566	0.4929	0.5218	0.5448
Feb11p.1	0.1727	0.2845	0.1518	0.1583	0.1597	0.1604	0.1894	0.2125
Feb12a.1	no test performed							
Feb12a.2	no test performed							
Feb12a.3	0.3270	0.2328	0.3391	0.4082	0.4566	0.4929	0.5218	0.5448
Feb12p.1	0.2130	0.4264	0.3312	0.2734	0.2310	0.1978	0.1698	0.1463
Mar7p.1	0.3180	0.2111	0.1338	0.2013	0.2494	0.2857	0.3148	0.3382
Mar7p.2	0.2074	0.3869	0.2615	0.2278	0.2592	0.2857	0.3086	0.3282
Mar8a.1	0.2870	0.2501	0.1106	0.1451	0.1932	0.2268	0.2517	0.2701
Mar8a.2	0.3490	0.4730	0.3947	0.3480	0.3137	0.2865	0.2631	0.2430
Mar8p.1	0.1984	0.2369	0.1066	0.1081	0.1306	0.1666	0.1947	0.2166
Mar9p.1	0.1442	0.4470	0.3433	0.2804	0.2350	0.2008	0.1730	0.1620
Mar9p.2	0.1179	0.3799	0.2584	0.1872	0.1907	0.2000	0.2086	0.2171

of the files that were tested allow several possible distributions. However, the best-fit distribution is considered the distribution with the smallest maximum deviation. For example, in Table 4.3, the best fit distribution of Feb12a.1 service times is the E(2) distribution, highlighted with a black box. However, the null hypotheses that the exponential, E(3), and E(4) distributions are the same as the sample distribution cannot be rejected at the a=0.05 significance level.

The testing procedure does not consider Erlang distributions with a shape parameter greater than 7. In Chapter 5, it is shown that in queuing models, the analysis of Erlang distributions with high shape parameters becomes extremely laborious. For this reason, the analysis has been limited to E(1)-E(7). However, by stopping at the E(7) distribution, it may be unclear which of the following two is more accurate: E(7) or an Erlang distribution with a higher shape parameter. [In other words, it is possible that the maximum deviation (shown in Tables 4.3 - 4.5) continues to converge beyond the E(7) distribution. Thus, it may not be obvious which theoretical distribution minimized the deviation from the sample distribution.] There is a second way to estimate which shape parameter minimizes the deviation from the sample distribution. Carmichael (1987) illustrates a simple derivation leading to the following estimation for *k*:

$$k = \frac{(\text{mean})^2}{(\text{st dev})^2} \tag{4.3}$$

There are two disadvantages to estimating the shape parameter in this fashion. First, the person doing the estimating must know that the process can be described by the Erlang distribution. Second, when *k* is estimated by the mean and variance of the sample, it is more sensitive to outliers in the sample data file. The K-S test, on the other hand, is based on the cumulative distribution of the sample and, therefore, is less sensitive to extreme values. This phenomenon becomes very important in the simulation model discussions included in Chapter 5. However, it is important to keep this procedure in mind throughout the following analyses.

Service Time Distributions

An investigation of the service time distributions reveals that there is no consistency in the shape parameters of the Erlang distributions that is accepted by the K-S test. Put another way, there is no indication that the service times at wharf cranes can be predicted or modeled as one distribution. This is verified by the fact that every single distribution was rejected by at least five of the data files. Considering the sixteen original data files, the following frequency of service time distributions were determined:

Distribution	E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)	None
Frequency	0	6	2	1	0	1	4	2

Obviously, there is no consistency regarding which distribution best describes the service process, based on the sixteen original data files. There are several files that reject the exponential distribution as the tested distribution, and others that reject the E(7) distribution. Note that two of the four files that tested successfully as E(7) distributions represented the operations of Sea-land, Inc. It was expected that these operations would result in tighter distributions because of the chassis storage system. [The term 'efficient' refers to the variance of the distribution. A distribution with a smaller variance is considered more efficient.] Generally, with the chassis storage system, more vehicles are placed in the gang which ensures less crane idle time.

The PRiMMI data files (Mar9p.1 and Mar9p.2) were broken into single and double moves to determine whether they follow different distributions. Based on the differences found in the Mar9p.2 distributions, it was found that the PRiMMI data files do follow different distributions. This suggests that single and double moves must be modeled separately.

There is one other important point to make that supports the trend that exponential service times are not always appropriate. It was previously mentioned that several distributions test 'acceptable' for each data file, in addition to the actual best-fit distribution. It is interesting to note, however, that eleven of the sixteen data files indicate that the null hypothesis (service times are exponentially distributed) can be rejected. This statement is based on the observation that the deviation for the exponential distribution is greater than the test statistic in nine of the sixteen files. This is a high number of data files that cannot be represented with exponentially distributed service times.

All data files associated with the same ship were combined and tested to determine whether specific ships resulted in specific service distributions. The results show that of the seven ships represented, only three tested successfully. The *Yu He, Newark Bay,* and *TNT Express* had E(2), E(7), and E(5) service time distributions, respectively. The premise that service times are not necessarily exponentially distributed is supported by these tests for two reasons. First, four of the seven ships did not test successfully with any of the seven distributions. Second, the ships that did successfully test (for any distribution) did not test as exponentially distributed service times.

As previously mentioned, the shape parameter can be estimated using Equation 4.3. However, it was suggested that the estimate may not be reliable and should be used more as a comparison tool than as a decision tool. Table 4.6 illustrates the inconsistency between Equation 4.3 and the K-S test results. The estimate of k for seven of the sixteen data files corresponds to distributions that were rejected because they were similar to the sample distribution. Thus, the parameter estimate should be used with care and only as a comparative tool.

The last service time distribution test performed was on a data set that contained all service time observations. The test was inconclusive, since no distribution was accepted as statistically similar to the sample distribution. It is possible that a hyper-exponential distribution would be applicable. However, the variability in the mean service times suggests that the service time is too general of a process to be modeled with only one distribution; that is, it is very unlikely that a single distribution could specifically and accurately describe the service process for any ship.

The most significant conclusion that may be drawn from the service time distribution tests is that the process is not necessarily exponentially distributed; the conclusion is significant, since many studies do assume that the process is exponentially distributed. The test results indicate that very tight distributions (high k) or very broad distributions (exponential or E(2)) are generally appropriate to model the process. It is likely that there are underlying factors responsible for this division. Specifically, there is probably a relationship between the level of congestion in the port and the service time distribution. Because the available data cannot accurately quantify the congestion (see Chapter 3), it will not be possible to explore this hypothesis in this study. The point remains, however, that the service times are often inaccurately described by the exponential distribution. It is important, therefore, to have a knowledge of the service time distribution so that accurate queuing models or simulation models can be formed.

Interarrival Time Distributions

Interarrival time distribution tests were performed for those data files that included the service time distributions. The results, however, were much more consistent for the interarrival time distributions. The increased consistency is apparent in Table 4.4, which results in the following distribution frequency:

Distribution	E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)	None
Frequency	7	7	2	0	0	0	0	0

TABLE 4.6. COMPARISON OF SHAPE PARAMETER BASED ON K-S TEST RESULTS AND ESTIMATED SHAPE PARAMETER USING EQUATION 4.3

		Service Times			Distribution	
File	Ship	# obs *	Mean	St Dev	K-S	Estimate
Jan7p.1	*Falstria*	60	1:40	1:20	E(2)	1.56
Jan7p.2	*Falstria*	37	1:17	1:11	E(3)	1.18
Feb11a.1	*Bonn Express*	41	1:44	0:42	E(7)	6.04
Feb11a.2	*Bonn Express*	37	1:09	0:45	E(4)	2.34
Feb11p.1	*Bonn Express*	74	1:40	1:31	E(2)	1.20
Feb12a.1	*Yu He*	27	1:23	1:22	E(2)	1.02
Feb12a.2	*Yu He*	15	0:40	0:25	E(2)	2.56
Feb12a.3	*Newark Bay*	22	1:40	0:34	E(7)	8.65
	(Sea Land)					
Feb12p.1	*Newark Bay*	53	1:33	1:03	none	2.18
	(Sea Land)					
Mar7p.1	*Act III*	30	0:48	0:21	E(6)	5.22
Mar7p.2	*Act III*	47	1:00	0:26	E(7)	5.21
Mar8a.1	*TNT Express*	25	1:32	0:41	E(3)	5.04
Mar8a.2	*TNT Express*	17	1:50	0:49	E(7)	5.04
Mar8p.1	*TNT Express*	61	1:25	1:02	E(2)	1.88
Mar9p.1	*Guayama*	118	2:09	1:22	none	2.49
	(PRiMMI)					
Mar9p.2	*Guayama*	128	1:36	1:12	E(2)	1.79
	(PRiMMI)					

*The parenthetical values indicate the inclusion of at least one outlier.

All files that were tested for interarrival time distributions tested successfully, including the two data files that did not test successfully for the service times owing to the presence of single and double moves. Note that even when the interarrival times for single and double moves were tested separately, the same distribution as the combined times were specified. In other words, single and double moves did not have the same effect on interarrival times as they did on service times. (Note again that different service time distributions were specified for single and double moves.)

That exponential interarrival times are more appropriate than exponential service times is supported by the following observation. Only two of the data files that were tested (Feb11a.1 and *Bonn Express*) can reject the exponential distribution as statistically similar to the sample distribution.

The last data file tested for interarrival time distributions combined all individual files. The test was again inconclusive since no distribution was accepted as statistically similar to the combined sample distribution. The distribution tests on individual files indicate that exponentially distributed interarrival times is a much more solid assumption than exponentially distributed service times.

Backcycle Time Distributions

Backcycle time distributions appear to be less consistent than the interarrival distributions, yet more consistent than the service time distributions—illustrated by the distribution summary below. For the actual test results, refer to Table 4.5. Only fourteen data files are included in the above summary, since two data files (Feb12a.1 and Feb12a.2) contained an insufficient number of observations (six and eleven observations, respectively) and therefore could not produce strong tests.

Distribution	E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)	None
Frequency	2	5	0	0	0	1	3	3

The three unknown distributions correspond to the files Mar7p.2, Mar9p.1, and Mar9p.2. The first of the files represent stacking operations using top pick loaders, and the last two files are associated with chassis storage operations at PRiMMI. However, it does not appear that there is any correlation between container storage techniques and backcycle time distributions. An investigation of the test results of these three files indicates that the Mar7p.2 and Mar9p.2 files do not correspond to any of the Erlang distributions considered in the testing procedure. However, it appears that the Mar9p.1 data file is converging toward an acceptable Erlang distribution with a high shape parameter. The shape parameter is estimated as $k \approx 10.0$. Because of the converging nature of the other deviations, it is reasonable that the E(10) distribution is the best fit distribution for the data file.

It is somewhat surprising that several data files tested successfully for distributions with the exception of exponential or E(2). It was expected that the backcycle times would be consistently exponential or E(2) because of the wide range of mean backcycle times, which are illustrated in Table 4.2. This wide range suggests that the backcycle time is dependent on the operations within the storage yard. Specifically, if containers are being delivered to a point in the yard that is near the wharf crane, the mean backcycle time probably will be considerably less. The variance of the backcycle time should decrease as the point of delivery in the storage yard draws nearer to the wharf crane. This would have the effect of increasing the shape parameter of the Erlang distribution.

Visual inspection of the test results do not indicate that such trends exist. The four data files that produced the highest parameter Erlang distributions are associated with mean backcycle times ranging from the smallest to the third largest. Mar8a.2 resulted in an E(7) distribution and is associated with a mean backcycle time of only 3 minutes 44 seconds. Jan7p.2 also resulted in an E(7) distribution, but it is associated with a mean backcycle time of 11 minutes 13 seconds. This wide range suggests that there may not be a relationship between the Erlang shape parameter and the location of storage yard deliveries, contrary to prior expectations. Obviously, there is not enough information to quantify such relationships.

It is very difficult to make any assumptions or predictions about the backcycle time distributions. It appears as though the best fit distribution might be as file specific as the service time distributions. This makes it increasingly difficult to form general models that are applicable to more than one ship.

CRITICISM OF DATA COLLECTION EXPERIMENT

The data collection effort progressed very smoothly and successfully, and the desired information was attained. Specifically, the Hewlett-Packard 48SX calculators performed above expectations. The user programmable capabilities of the calculators allow the equipment to be applied to a multitude of related activities. Despite the success of the data collection effort, there are several areas that could be improved.

First, and most importantly, this data collection effort resulted in time-motion studies for cellularized vessels only. This immediately raises the question: What are the implications for other ship types? It is possible that the service, interarrival, and backcycle time distributions would behave differently for ro/ro and non-cellularized vessels. The only way to determine if there are other effects is to continue the data collection effort for other vessels. Creating similar time-motion studies for different ship types (and different ports) will also remove any bias.

Second, it was mentioned that visibility, logistics, and safety concerns precluded the collection of data from yard cranes and storage yard operations. Such information could be used to explain the variability of backcycle time distributions. It would also mean that the cyclic queue could be more closely investigated so that transit times could be analyzed as another stage in the cycle. The collection of data in the storage yard would also allow a study of the effects of various storage container techniques on operational efficiency.

Third, the collection of storage yard data would also lead to similar queuing analyses of yard crane operations if the container stacking method of storage was employed.

Fourth, if this type of data collection effort is repeated, an account of how far a container is stored from the wharf crane should be kept during the data collection effort. This could be as basic as counting the number of bays between the storage location and the ship. This information would help explain the variability of the backcycle time distributions and might provide an explanation for the division in the service time distribution results.

SUMMARY

This chapter described the data collection process that forms the foundation for this report. The collected data constitutes a time-motion study of the service, arrival, and cycling processes surrounding the wharf gantry crane. Kolmogorov-Smirnov tests were used as goodness-of-fit tests to determine which theoretical distributions can or cannot be used to describe individual samples of the time-motion study. The distributions considered in the testing procedure were the exponential distribution, and the Erlang(2) through Erlang(7) distributions. The range of distributions were appropriate for the majority of the samples tested.

Based on the results of testing sixteen individual data files, this chapter showed that the service and backcycle time distributions are the most difficult to predict. Most importantly, this chapter demonstrated that the service time distribution at the wharf crane is not always exponential. The arrival process, on the other hand, appears to be properly represented by the Poisson distribution.

The information presented in this chapter lays the foundation for the simulation models and formal queuing models presented in Chapter 5.

CHAPTER 5. SIMULATION AND QUEUING MODELS OF WHARF CRANE OPERATIONS

This chapter explores various approaches to modeling the queue that forms at the wharf crane. It is divided into three sections, each of which represents common alternative approaches for modeling queuing systems. The first section describes the development of simulation models with varying levels of detail. The more detailed models include operational delays, a significant advantage over the mathematical models described in the second and third sections. The more detailed simulation models are then used to illustrate the potential for improved operations, with only minor changes to the system.

Section 2 presents mathematical approximations of the performance of a closed cyclic queue. Methods are also presented that allow multi-stage cyclic queues to be reduced for simplified analysis. However, the modeling of cyclic queues is restricted to the assumption of exponential service times. Based on the findings in Chapter 4, the assumption of exponential service times is not always an appropriate assumption. Therefore, it will be necessary to explore other mathematical alternatives.

The third section explores alternative queuing models that allow for distributions other than the exponential distribution. The third section includes the classic machine repair problem as a modeling alternative. Included in all three sections is a critique of the model presented and a discussion of the model performance.

SIMULATION MODELS

There are many advantages and disadvantages to using simulation as a modeling tool. One advantage is the ability to compare various scenarios once the base model has been formed. In the port specific application, the simulation model allows for operational delays such as hatch cover removal and mechanical adjustments—a significant advantage over the theoretical models presented later.

The first simulation models that are explored are very general, basic models. These models are potentially valuable to port operators because of their ease of development and use. However, a general model has many limitations that significantly restrict its capabilities. As a result, a more detailed model is developed and applied to two of the data files described in Chapter 4. Finally, a model of a hypothetical system is created that combines two detailed models, and this combination model is then used to illustrate how significant improvements can be accomplished with only a simple change to the system.

Simulation Model Development

All of the simulation models presented in this section were created using SLAM II, a *S*imulation *L*anguage for *A*lternative *M*odeling. SLAM is an advanced Fortran based simulation language that can be run on standard microcomputers and workstations. For an excellent reference on the use of SLAM, see Pritsker [Ref 53]. Recent improvements to SLAM include an interface that allows the user to graphically build the network, which is later translated by SLAM into a Fortran based code before the simulation is executed.

Simulation models of the queuing system can be driven with only a few parameters. These parameters describe the service and arrival processes of the entities in the system. SLAM accomplished this in one of two ways:

1) The entities or "customers" can be created according to a certain distribution and can be placed in the system upon their creation. After the entity passes through the system, it is terminated.
2) A predetermined number of entities are created and placed in the system where they remain until the simulation is complete.

The first of the two options is used in open-ended queues. If this first option were applied to the entry gate of a container storage yard, the creation of entities would correspond to the arrival of vehicles at the gate. A very large population of vehicles would eventually enter the system if the simulation were run for a long enough period of time. This is obviously not the case at the wharf crane, since only six to eight vehicles form a gang. Each member of the gang repeats the same cycle until port operations cease. Thus, the second method of creating entities is employed when modeling repetitive cycles. It is important to note that when entities exist in a repetitive system of services, the arrival process is inherently described by the system. Thus, it does not have to be described by a separate stage of the system.

When building the simulation model, the arrival process does not need to be specified since the container port is best described by the cyclic model that inherently defines the interarrival process. Therefore, the model can be calibrated by specifying only two processes: the wharf crane service time and the backcycle time. The interarrival time distributions will not be used until the third section of this chapter, when alternative queuing models will be explored.

Once the simulations have been executed, their performance is judged by comparing the average-time-in-queue statistic with the field data and the simulation model. This evaluation requires that the time in queue for each vehicle be calculated from the field data before validating the models. The average time in queue was selected as the primary model validation statistic. The average- time-in-queue statistic is very simple to extract from the data files. Other statistics commonly used to compare results are the average queue length and the crane utilization. [The crane utilization is defined as the percentage of time that the crane is actually in use.]

Another item to consider in the model development process is that of steady-state operations. The overwhelming majority of queuing literature is based on the assumption of steady-state operations. Steady-state operations are reached after a significant period of time—often referred to as the "start up" time. To have steady-state statistics reported by SLAM, the start up period is excluded from the period in which performance statistics are collected. Thus, simulation models make it possible to include or to exclude time dependent aspects of system operations.

It is difficult to determine how often steady-state conditions are maintained at the container port. When delays owing to hatch cover removals and mechanical problems occur, the system is often idle long enough so that vehicles have time to queue at the wharf crane before operations begin again. This system state (of all vehicles queued at the crane) also occurs at the beginning of each work shift and is obviously not a steady-state condition. The general simulation models were begun in the same state that existed at the beginning of the observation period in order to account for the start up period of the system. If a data file began with two vehicles in queue, the corresponding simulation model also began with two vehicles in queue.

General Simulation Models

The general simulation models were created to determine if a very simple, easy-to-use model could provide reasonable approximations of the actual system. The advantages of such a model include the efficiency with which it can be created, and the limited amount of information required for calibration. The disadvantage of the model is its inability to account for operational delays, double moves, or yard crane operations.

The ability of the model to describe the actual system is explored by examining fourteen of the sixteen data files described in Chapter 4. The two files that are omitted are the files for which no backcycle time distribution could be determined. The first step in the process involved creating the graphic network. The graphic network can take a form very similar to the actual system, which is the case with this model. The similarities are illustrated in Figure 5.1, which compares the arrangement of the actual system and the graphical SLAM equivalent.

The queue at the wharf crane is represented in SLAM by the node that takes the form of the letter Q in the top left corner of Figure 5.1 (b). The three identifiers in the QUEUE node are the initial number of entities in the queue (IQ), the capacity of the queue (QC), and the file number (IFL) within which the statistical arrays are stored. The term entity (used by SLAM) refers to the customer of the system. When applying the model in individual files, the simulation was begun with all entities (trucks) in queue at the wharf crane. One final comment about the QUEUE node is addressed to the movement of vehicles from the queue to the wharf crane. This movement is made instantaneously by SLAM, which includes the move up period in the definition of the service time—a common practice for most queuing models.

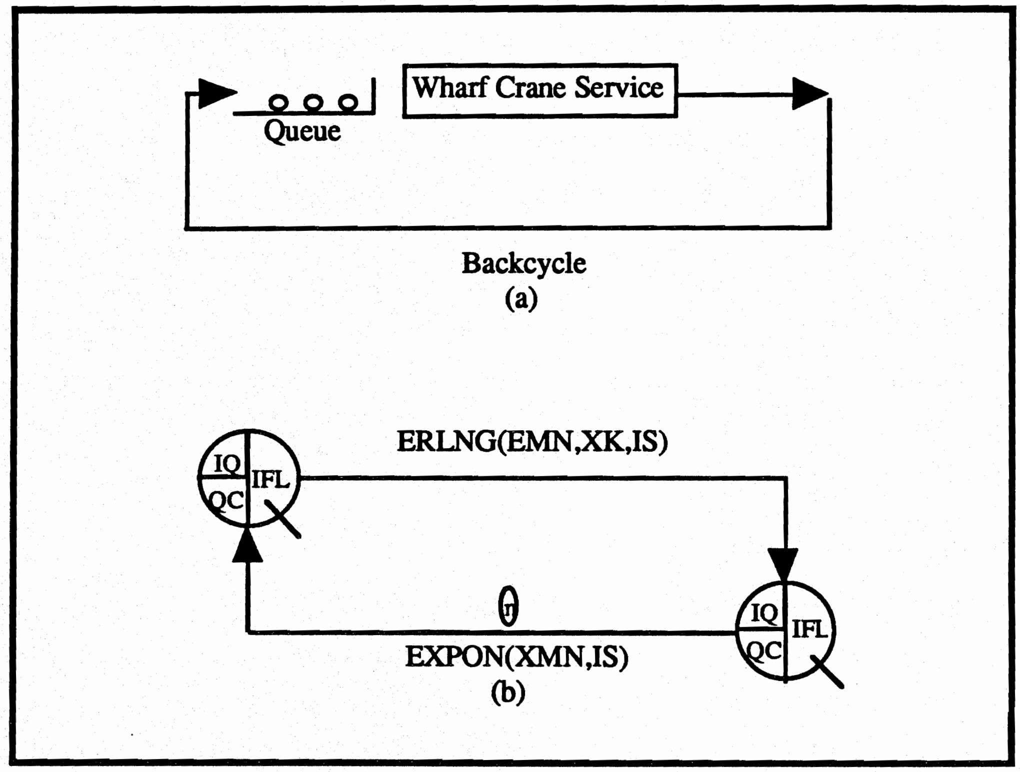


Figure 5.1 Cyclic queue and graphical SLAM equivalent for the general simulation model

The service provided by the wharf crane is represented by the arrow proceeding from the queue node in a clockwise direction. The service time distribution is identified above the arrow. In the example of Figure 5.1, the service phase is modeled as an Erlang distribution with parameters EMN, XK, and IS. It is translated as "a sample from an Erlang distribution which is the sum of XK exponential samples each with mean EMN using random number stream IS" [Ref 54]. Consequently, SLAM does not require that the parameter XK be an integer, as in analytical queuing models. The exponential distribution is described by the mean XMN and the random number stream IS.

Continuing clockwise around the circle, the second QUEUE node is placed between the wharf crane service activity and the backcycle activity. Its presence between two activities is a requirement of SLAM; however, the queue capacity has been set at zero. A zero queue capacity causes an entity to traverse immediately from one activity to the next. This queue node operates as a gate from the single server activity of the wharf crane to the self-service activity of the backcycle.

The last activity is the backcycle that connects the two queue nodes. In the example of Figure 5.1, the backcycle follows an exponential distribution. The parameter *n* that appears over the activity is the number of servers available in the activity. Thus, a self-service activity could be modeled by specifying as many servers in the activity as there are vehicles in the system. The backcycle time was modeled as a self-service process for two reasons. First, a large portion of the backcycle time is transit between stages where vehicles are allowed to pass each other (i.e. self-service). This is not a flawless assumption, however, since the backcycle includes the yard crane service that is actually a single server facility. The second reason is that if the backcycle were less than a self-service facility (say three or four servers), then the potential for queuing would exist before the backcycle stage. This is not the case here, since trucks immediately begin the backcycle when service is completed at the wharf crane.

Once the graphical model is built, it is translated into a Fortran based program. Before the simulation is executed, however, the user must specify several items—specifically, the duration of the simulations. Each model was executed for the amount of time that elapsed during the file's observation period. Thus, if a data file represented two hours of operations, the simulation would be run for 120 time units with no clearing of statistics, negating the start up period.

General Model Results

As mentioned, the general model was applied to all of the data files for which service time and backcycle time distributions were reported in Chapter 4. The primary statistic used to evaluate the quality of the model was the average time each vehicle waited in the queue, W_q. The same number of vehicles were placed in the model as reported in Table 4.2. From the simulation, SLAM reports several system characteristics, including the following:

1) The average number of vehicles waiting at queue node i, W_{qi}.
2) The maximum and minimum number of vehicles in the queue.

3) The average utilization of server i, h_i. At the wharf crane node, this is interpreted as the percent of the time that the crane was servicing a vehicle.
4) The maximum continuous idle time and busy time of each server.

The average wait time at the crane, W_{q1}, and the crane utilization h_1 of each model are summarized in Table 5.1. Also included in the table is each data file's field estimate of the waiting time in queue. The statistics illustrate the limitations of the general model, which consistently underestimates the average time in queue with only two exceptions. Feb12a.3 and Mar8a.2 are the only data files overestimated by the simulation; however, the overestimation is negligible. Feb12a.3 overestimates W_{q1} by over two and a half minutes (approximately 73 percent), whereas Mar8a.2 overestimates W_{q1} by only 28 seconds (approximately 9 percent). The remaining twelve models consistently underestimated W_{q1} in varying degrees. In fact, none of the remaining simulation models estimate W_{q1} within 10 percent of the field estimate.

Although the underestimation is easy to explain, it is not so easily corrected. The inaccuracy of the general models arises from the previously mentioned fact that the models do not account for operational delays at the wharf crane. The removal of a single hatch cover can easily take on the order of one vehicle backcycle time. This inherently suggests that all vehicles are able to queue at the crane before regular operations resume. The result is an increase in the average time a vehicle is in queue.

Hatch cover removal is not the only event that periodically interrupts operations and diminishes the accuracy of the model. The inclusion of both single moves and double moves in a data file also tends to inflate estimates of W_{q1}. The reason (see Chapter 4) is that the two moves follow different distributions; it is, thus, not appropriate to combine the two moves in a single simulation.

Another factor that inflates the field estimated time in queue is the movement of the crane from bay to bay. Although the time lost with this movement is much less than the time lost during the removal of hatch covers, it occurs much more frequently.

TABLE 5.1 SUMMARY OF SIMULATION MODEL RESULTS AND FIELD STATISTICS. THE PRIMARY STATISTIC USED AS A COMPARISON IS THE AVERAGE TIME IN QUEUE AT THE WHARF CRANE.

	Simulation Results			Field
File	Length(min)	η_1	W_{q1} (min)	W_{q1} (min)
Jan7p.1	150	0.619	1.826	2.483
Jan7p.2	80	0.632	0.744	2.450
Feb11a.1	90	0.887	1.460	2.183
Feb11a.2	90	0.325	0.327	0.633
Feb11p.1	200	0.499	0.664	1.333
Feb12a.1	no simulation performed			
Feb12a.2	no simulation performed			
Feb12a.3	45	0.976	3.895	3.800
Feb12p.1	110	0.911	2.861	4.583
Mar7p.1	50	0.422	0.126	0.633
Mar7p.2	90	0.820	1.072	1.800
Mar8a.1	90	0.746	1.271	2.067
Mar8a.2	30	0.883	5.472	5.150
Mar8p.1	170	0.874	1.821	4.333
Mar9p.1	300	0.922	3.087	4.533
Mar9p.2	300	0.818	1.924	2.670

A more accurate field estimate of W_{q1} could be obtained by excluding the waiting times of all ensuing vehicles affected by the delay. There are several problems with this proposal. First, as reported in Chapter 4, it was difficult to accurately measure all crane movements—which, in turn, makes it difficult to separate the waiting times of the affected vehicles. Second, it is problematic to determine how many ensuing vehicle waiting times are inflated by a crane delay. Most importantly, it is much more appropriate to improve the simulation model than it is to manipulate or to exclude any data from the field collected time-motion studies.

Despite its shortcomings, the model does have the ability to estimate the average time in queue for a system, if no delays were encountered during operations. This ability could be valuable to the port operator, that is, as a tool that provides an optimistic estimate of the number of vehicles required to achieve a certain performance level (such as a crane utilization rate of 85 percent). Nonetheless, a more detailed model that accounts for operational delays needs to be developed.

Detailed Model Development and Results

The general model was deemed inadequate, primarily because it does not account for delays and miscellaneous operations. In response, a detailed model was developed that accounts for operational delays such as single moves, double moves, hatch cover removal, and extended service times that represent mechanical adjustments or bay to bay crane movements. One disadvantage of the detailed model is that only the larger data files include all of the mentioned operational delays. The detailed model will be applied to two of the data files—Mar9p.1 and Mar9p.2. Both of the data files represent approximately five hours of operations and include all of the aforementioned operational interruptions.

Conceptually, the cyclic queue that is simulated in the detailed model is the same as the general model. However, more activities are included, and several points are introduced where the entity is directed to one of several activities depending on an assigned probability. Each of these activities could have significantly different durations, allowing delays and other operational interruptions to be included in the model. The formal arrangement of the SLAM network is illustrated in Figure 5.2.

The simplest way to describe the detailed model is to follow an entity (truck) through the network, beginning with the node labeled A in the far left of Figure 5.2. If node labels are assigned, they appear in small boxes beneath the node. Node A is called an ASSIGN node, and is used to assign a new value to the truck each time it cycles through the system. The attribute that is assigned is named TNOW, and it refers to the current time of the simulation. Each time the truck proceeds through this node, the current time is stored in its attribute file number one. The value of TNOW is used as a decision attribute further in the system. The arrow emanating from the node had been previously defined as an activity. The activity can be assigned any of numerous distributions. If no distribution is specified above the arrow (as is the case here) the activity has a duration of zero time units, meaning the entity travels immediately to the next node.

The next node is a special type of queue node called an AWAIT node. The AWAIT node is used to hold entities until a resource unit (called 'serve' in this example) becomes available. A resource unit is something that an entity carries through the system until it is released by another node in the network. At that time, the resource is available to be carried by the next vehicle. Because the wharf crane is a single service facility, only one resource exists in the system. An example will clarify this procedure.

Suppose that truck number one arrives at the AWAIT node. There are no trucks in service at the crane, meaning the resource unit is available. Truck number one carries the resource unit into the service activities. Meanwhile, truck number two arrives. Truck number two

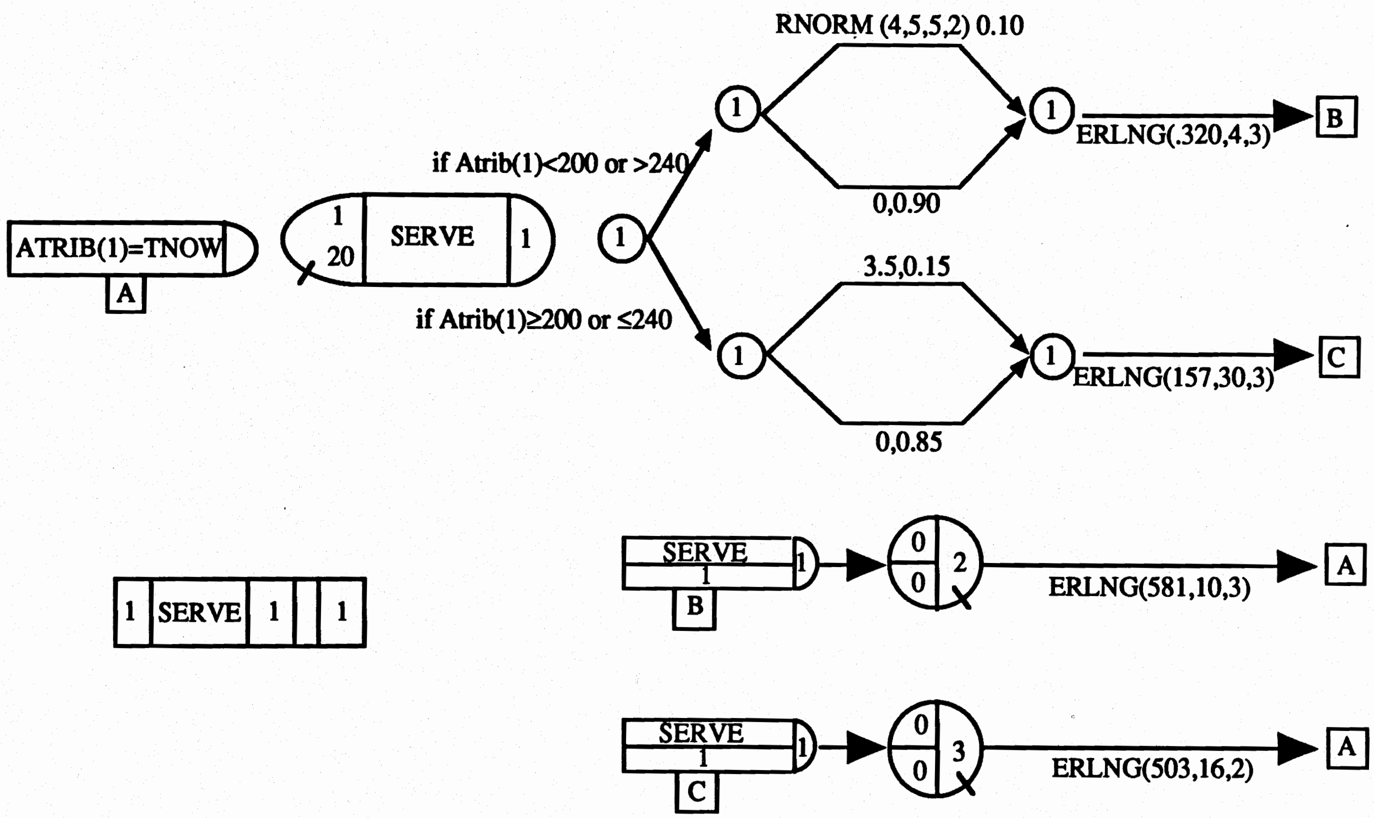


Figure 5.2 SLAM network of the delay model. The distributions shown above apply to the Mar9p.1 data file.

is forced to queue at the AWAIT node until truck number one completes service. When truck number one finishes service, the resource node is released and is available for truck number two. Obviously, it is important that the resource unit not be freed until the service activities are completed—otherwise, two vehicles could be in service simultaneously. The resource unit (to jump ahead momentarily) is released from one of two FREE nodes that are labeled B and C. Each of these nodes marks the completion of service at the crane. The transfer of the resource unit from one entity to the next is instantaneous, if an entity is waiting for the resource unit. The queue capacity of the AWAIT node has been set at twenty to assure that there is enough queuing space in the model.

The next node is identified by a simple circle with a number one. This is called a GOON node ("go on" node), which simply separates consecutive activities. The number one specifies that only one of the activities emanating from the node can be selected. The decision regarding which activity follows is made by the "if" statements that appear over the two emanating activities. The "if" statements refer to attribute 1, which was previously defined as TNOW and was assigned to the ASSIGN node. The top activity is selected if TNOW is less than 200 or greater than 240. Because the units are minutes, this parameter translates as follows: the truck taking the top activity if the truck arrives before 3 hours 20 minutes from the start of the data file or after 4 hours from the start of the data file. The times in the "if" statements are identical to the field data. For example, file Mar9p.1 reported that single moves were executed for all but 40 minutes of its duration. The ensuing top half of the network represents single moves, and the bottom half represents double moves.

Continuing through the network, we see that the next node (on the top half) is another GOON node that leads to two more activities. The top activity represents a delay that follows a normal distribution with a mean of 4.5 minutes and a standard deviation of 5 minutes. The probabilistic approach is employed in that the top activity is taken 10 percent of the time. The activity is included to capture delays owing to crane movements from bay to bay, carriage adjustments, or cable attachments. The bottom activity, on the other hand, has a duration of zero minutes, and 90 percent of the time the bottom activity is taken, representing normal operations in which no delay occurred.

Still in the top half of the network, the two activities join at another GOON node. The activity emanating from the GOON node is the service time for single moves, which is modeled as an E(4) distribution. The boxed B at the end of the activity signifies that the network continues at node B. Node B is the FREE node previously mentioned. At this node, the resource unit called "serve" is released from the current truck, allowing the next truck in queue to begin service.

Following the free node, there is a queue node whose presence, like the general model, is a requirement of SLAM. The queue capacity is zero so that entities are allowed to begin the backcycle stage without delay. The backcycle for single moves is specified as an eight server activity in order to create a self-service facility. Following the completion of the backcycle activity, the network continues at node A.

There are few differences between the lower half of the network and the upper half. The lower half represents double moves that are executed between 200 and 240 minutes. Double move delays are modeled as follows: occurring 25 percent of the time and with a constant distribution of 3.5 minutes. The service time for double moves is modeled as an E(30) distribution, while the backcycle is modeled as an E(16) distribution (both according to Equation 4.1).

The selection of the delay distributions was based on visual inspection of the delays reported in the data files. For example, only a few delays occurred during double moves—all approximately 3 minutes in duration. Thus, the delays were modeled as having a constant duration. The delays during single moves, on the other hand, were more frequent and randomly distributed resulting in the assignment of the normal distribution.

The delay activities provide two opportunities to calibrate the model. First, the probability that each branch will be taken can be varied in order to control the number of entities processed by the activity. Second, the distributions themselves can be varied. This option was rarely used because of the desire to use the observed field distribution.

The same simulation model was applied to both data files. The only differences between the two models were the service time distributions, the activity probabilities, and the elapsed time during which single or double moves were executed. The simulation models were executed for a total of 300 minutes each. Because the data files were begun with all vehicles in queue at the beginning of a day, the simulation models were also started with all vehicles in queue. The statistics were <u>not</u> cleared after a start up period, so that the start up period could be accurately simulated.

The delay model resulted in very accurate estimations of W_{q1} for both data files. Specifically, the Mar9p.1 simulation estimated W_{q1} as 4.596 minutes, whereas the field estimate was 4.530 minutes. The complete summary statistic report is presented in Figure 5.3, followed by the translated code in Figure 5.4. Further consideration of the summary report shows that the average queue length is 2.0 vehicles, with a maximum length of 5 vehicles. (The sixth vehicle immediately started service when the simulation began.) A total of 141 entities were processed, 13 of which encountered delays during single moves and 1 of which encountered a delay during a double move. A total of 130 single moves were executed, and a total of 11 double moves were executed (i.e. 22 twenty-foot containers moved). This compares to 120 total moves represented in the field data (108 single moves and 12 double moves). Crane utilization can be loosely interpreted as the resource utilization that is reported as 92 percent. Based on the field observations, this estimate may be slightly high. The reason the statistic is not an accurate estimation is that the resource utilization reports the percentage of time that the resource unit is being used, which includes the delays that are encountered within the service facility. The actual crane utilization, however, does not include operational delays during which the crane is momentarily idle.

The summary report for the Mar9p.2 simulation is shown in Figure 5.5. Note that the translated code associated with the network is not reported here because of its similarity to the code for the Mar9p.1 data file.

The average time in queue was also estimated very accurately for the Mar9p.2 data file. The simulation model estimated W_{q1} as 2.755 minutes compared with the field estimate of 2.667 minutes. The average queue from the simulation is 1.423 vehicles. The simulation processed a total of 170 entities, including 13 single moves that were delayed, 3 double moves that were delayed, 133 undelayed single moves, and 21 undelayed double moves. Because of work stoppages in the data file, there are only 133 trucks recorded from the field. The simulation suggested that the crane was busy 82 percent of the time.

In general, both applications of the detailed model provide very good results. The models are flexible in the sense that the service distributions and delays may be modified to model a wide range of unloading and loading processes. However, this flexibility can only be taken advantage of when the actual distributions are known. Specifically, the frequency and duration of delays caused by hatch cover removals, single moves, double moves, and bay to bay crane movements must be known before the model can be used as a predictive tool. The number of twenty-foot and forty-foot container moves, and, thus, the number of hatch cover removals and bay to bay movements could be predicted from work orders for each ship entering port. However, it has been shown that the activity distributions cannot be accurately predicted (see Chapter 4) without numerous time-motion studies forming a database of performance characteristics. The likelihood of having all of this information is lowered even more, considering its variability from ship to ship.

Simulation Project Mar9p.1 By Kiesling
Date 7/8/91 Run Number 1 of 1
Current Time .30000E+03
Statistical Arrays Cleared at Time .0000E+00

File Statistics

File Number	Label/ Type	Average Length	Standard Deviation	Maximum Length	Current Length	Average WaitTime
1	Await	2.007	1.623	5	3	4.596
2	Queue	.000	.000	0	0	.000
3	Queue	.000	.000	0	0	.000
4	Calendar	1.558	1.558	6	1	.908

Regular Activity Statistics

Activity Index/Label	Average Utilization	Standard Deviation	Maximum Util	Current Util	Entity Util
1	.2303	.4211	1	0	13
2	.0100	.0995	1	0	1
3	.5245	.4994	1	1	117
4	.1597	.3663	1	0	10

Service Activity Statistics

Act Num	Act Start	Label or Node	Ser Cap	Average Util	Std Dev	Cur Util	Average Block	Max Idl Tme/Ser	Max Bsy Tme/Ser	Ent Cnt
5		Queue	8	2.312	1.84	0	.00	8.00	6.00	117
6		Queue	2	.245	.60	0	.00	2.00	2.00	8

Resource Statistics

Resource Number	Resource Label	Current Capacity	Average Util	Standard Deviation	Maximum Util	Current Util
1	Serve	1	92	.264	1	1

Resource Number	Resource Label	Current Capacity	Average Availability	Minimum Available	Maximum Available
1	Serve	0	.0754	0	1

Figure 5.3 SLAM summary statistics for the simulation of the Mar9p.1 data file.

```
GEN,KIESLING,MAR9P.1,7/8/1991,1,Y,Y,Y/Y,Y,Y/1,72;
LIMITS,3,2,300;
INITIALIZE,,300,Y;
NETWORK;
        RESOURCE/1,SERVE,1;
;
A       ASSIGN,ATRIB(1)=TNOW,1;
        ACTIVITY;
        AWAIT(1/20),SERVE,,1;
        ACTIVITY;
        GOON,1;
        ACTIVITY,,ATRIB(1).LT.200.OR.ATRIB(1).GT.240;
        ACTIVITY,,ATRIB(1).GE.200.AND.ATRIB(1).LE.240,ZAAB;
        GOON,1;
        ACTIVITY/1,RNORM(3.5,5,3),0.075;
        ACTIVITY,,0.925;
        GOON,1;
        ACTIVITY/3,ERLNG(0.320,4,3);
        FREE,SERVE,1;
        ACTIVITY;
        QUEUE(2),,0,;
        ACTIVITY(8)/5,ERLNG(.581,10,3),,A;
ZAAB    GOON,1;
        ACTIVITY/2,3.0,.25;
        ACTIVITY,,.75;
        GOON,1;
        ACTIVITY/4,ERLNG(0.157,30,3);
        FREE,SERVE,1;
        ACTIVITY;
        QUEUE(3),,0,;
        ACTIVITY(2)/6,ERLNG(.503,16,2),,A;
        END;
ENTRY/1,0.0;
ENTRY/1,0.0;
ENTRY/1,0.0;
ENTRY/1,0.0;
ENTRY/1,0.0;
ENTRY/1,0.0;
FIN;
```

Figure 5.4 Translated code for the simulation of the Mar9p.1 data file. The translation is performed by SLAM before the execution of the model.

Simulation Project Mar9p.2
Date 7/9/91
Current Time .30000E+03
Statistical Arrays Cleared at Time .0000E+00

By Kiesling
Run Number 1 of 1

File Statistics

File Number	Label/ Type	Average Length	Standard Deviation	Maximum Length	Current Length	Average Wait Time
1	Await	10423	1.315	5	0	2.755
2	Queue	.000	.000	0	0	.000
3	Queue	.000	.000	0	0	.000
4	Calendar	4.136	1.611	6	4	.893

Regular Activity Statistics

Activity Index/Label	Average Utilization	Standard Deviation	Maximum Util	Current Util	Entity Util
1	.1163	.3206	1	0	13
2	.0225	.1483	1	0	3
3	.4443	.4969	1	1	133
4	.2402	.4272	1	0	21

Service Activity Statistics

Act Num	Act Start	Label or Node	Ser Cap	Average Util	Std Dev	Cur Util	Average Block	Max Idl Tme/Ser	Max Bsy Tme/Ser	Ent Cnt
5		Queue	8	3.024	2.16	0	.00	8.00	6.00	130
6		Queue	2	.289	.56	0	.00	2.00	2.00	19

Resource Statistics

Resource Number	Resource Label	Current Capacity	Average Util	Standard Deviation	Maximum Util	Current Util
1	Serve	1	82	.381	1	1

Resource Number	Resource Label	Current Capacity	Average Availability	Minimum Available	Maximum Available
1	Serve	0	.1767	0	1

Figure 5.5 SLAM summary statistics for the simulation of the Mar9p.2 data file.

Simulation models are often more valuable as comparative tools that consider changes to an existing system as opposed to a predictive tool that evaluates a new system. Such is the case in the wharf crane simulation model. Because of so many variables, the model can probably not be used to simulate a process that has already been completed. This was the approach taken in this section. The next section exploits the power of simulation by using the delay models to illustrate the benefits of a very simple change to the system.

Pooled Queue Model

Recall from Chapter 2 that a single gang is dedicated to serving each wharf crane and that there are as many as two cranes servicing the same ship simultaneously. The containers are retrieved from (or delivered to) only one of several yard cranes or top-pick loaders in the storage area. The vehicle drivers continue to service the same area in the storage yard unless told differently at the wharf crane. In effect, the trucks are merely acting as shuttles between the wharf crane and one of several points in the storage yard.

The operational improvement proposed in this section is applicable when two cranes simultaneously service a ship. This improvement involves combining two gangs into one larger gang that services both cranes. Essentially, one queue is formed in front of the cranes which releases trucks to the next available crane. The motivation behind the pooling of the queues is owing to idle periods when cranes are waiting for another truck to arrive. When an idle period occurs for one crane, it is rare that the other crane is also idle. Thus, it would benefit the idle crane if a truck from the other crane's queue were able to receive the service of the idle crane. The best arrangement for this modification would be to have at least one truck queued at the front crane while the remainder of the trucks queue at the back crane, which is illustrated in Figure 5.6. This arrangement assures that the increased move up time does not delay the crane operations.

The concept of forming one queue in front of multiple servers is not new in queuing theory. It has been successfully analyzed and has been shown to reduce average waiting times by as much as 50 percent. The psychological elements that may make this consolidation undesirable in some customer applications (see Larson, Ref 55) are not of concern at the port.

There are a few limitations to applying this arrangement at the wharf crane. Perhaps the most significant constraint is that both cranes have to be executing the same container moves to employ the procedure. In other words, one crane cannot be exporting containers while the other is importing containers. The exception, of course, is if a truck delivers a container to one crane and receives a container from the other crane. The second limitation is that the two cranes should be servicing the same container size to avoid confusion.

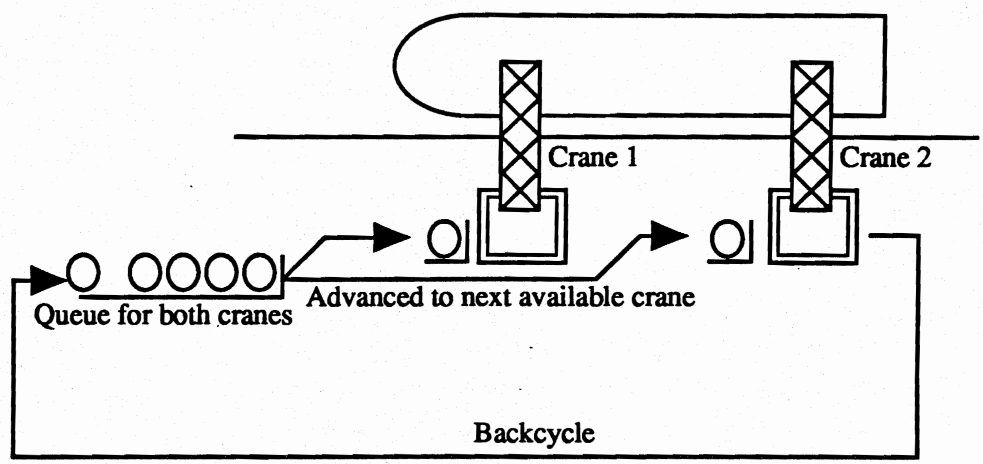


Figure 5.6 The recommended arrangement of providing a single queue for both cranes.

The simulation model was developed by placing the two delay models above one another, assigning them a common queue, and connecting them with a server selection node. The final network is illustrated in Figure 5.7. In the figure, everything to the right of the ASSIGN nodes (Atrib(1)=TNOW) is identifiable as one of the individual delay models.

There are three items worth mentioning about the development of the model. The AWAIT nodes, where entities wait for a resource to become available, have been slightly modified. There are now two different resource units—the first is called "one" and the other is called "two" in reference to the crane number. The AWAIT nodes correspond to files three and four, and each one is assigned a queue capacity of one unit. The double line on the node represents the phenomenon of blocking. If one vehicle is in the AWAIT node, the preceding activity is blocked and cannot be executed, which is not significant since the preceding activity is zero minutes in duration.

The two QUEUE nodes in front of the AWAIT nodes are where the majority of the entities wait. The presence of both AWAIT nodes and QUEUE nodes may seem redundant but their presence is a requirement of SLAM. The AWAIT node is necessary to provide a place to wait for a resource unit. The QUEUE node is present because the decision node (diamond) cannot feed

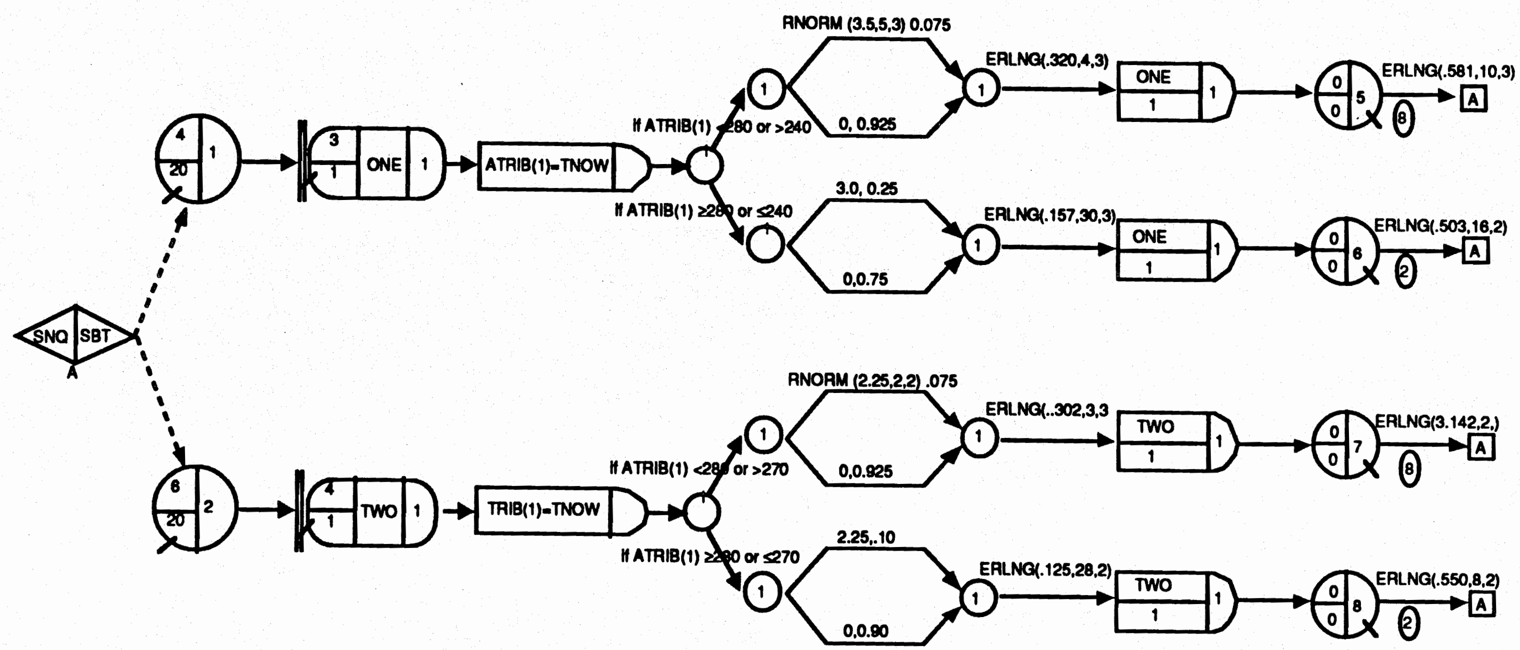


Figure 5.7 SLAM network for single queue delay model. The distributions represent Mar9p.1 and Mar9p.2 dta files.

directly into an AWAIT node without first going through a QUEUE node. The presence of all four nodes makes it difficult to interpret the waiting time in the queues, but is necessary for SLAM. The figure shows that four vehicles began in QUEUE file one, while six vehicles began in QUEUE file two.

The last new node that we will discuss is the SELECT node, represented by the diamond at the beginning of the network. The SELECT node provides the opportunity to send an arriving entity to the next server or queue according to a specific rule. In this model, the selection of the queue is based on the queue with the smallest number of entities (SNQ) at the current time.

The network is not a perfect simulation because of the requirements of SLAM which resulted in the awkward queue arrangement at the beginning of the network. However, the network provides a good estimation of the crane utilization and of the waiting times of trucks. More importantly, the number of vehicles in the system can be varied in order to determine the number of trucks that can be removed from the system while still attaining the same level of crane utilization as that of separated queues.

Recall that the crane utilization for model Mar9p.1 (crane 1) was estimated as being 92 percent by the simulation, and the crane utilization of model Mar9p.2 (crane 2) was 82 percent. Each of these models was executed with six vehicles in the system. To compare the results of the pooled queue model, the same number of vehicles was placed in each half of the network at the beginning of the run. The first model (with twelve trucks) estimated that crane number one was 99 percent utilized and that crane number two was 90 percent utilized. The sum of the average time in the queue for crane one was 4.118 minutes compared to 4.596 minutes in the aforementioned individual delay model. Similarly, the total average time in the queue for crane two was 1 .939 minutes compared to 2.755 minutes in the Mar9p.2 detail model. Obviously, there have already been marked improvements in the queue characteristics. These results are summarized in Figure 5.8.

The improved conditions also resulted in an increase in the number of containers moved. A total of 311 (141 + 170) containers were moved by the individual files, whereas the pooled queue model was able to process 381 containers. Recall that identical service rates, delays, and random number seeds were used in each of the files, implying that the pooled system can process more trucks and increase the utilization of the crane. Both improvements result in the ship being serviced more quickly in the port. The summary statistics for the model are included in Figure 5.8.

SIMULATION PROJECT SINGLE QUEUE MARCH 9 BY KIESLING
DATE 7/9/91 RUN NUMBER 1 OF 1

FILE STATISTICS

FILE NUMBER	LABEL/ TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITTIME
1	ZAAB QUEUE	.998	1.092	6	0	2.094
2	ZAAC QUEUE	.500	.783	6	0	.754
3	AWAIT	.972	.166	1	1	2.024
4	AWAIT	.790	.407	1	0	1.185
5	QUEUE	.000	.000	0	0	.000
6	QUEUE	.000	.000	0	0	.000
7	QUEUE	.000	.000	0	0	.000
8	CALENDAR	.000	.000	0	0	.000
9		8.630	2.576	14	12	.677

** REGULAR ACTIVITY STATISTICS**

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY UTIL
1	.2411	.4278	1	0	14
2	.6212	.4851	1	1	136
4	.0300	.1706	1	0	3
5	.1010	.3013	1	0	6
7	.1000	.3000	1	0	19
8	.5641	.4959	1	1	181
10	.0300	.1706	1	0	4
11	.2109	.4079	1	0	18

** SERVICE ACTIVITY STATISTICS**

ACT NUM	ACT START	LABEL OR NODE	SER CAP	AVERAGE UTIL	STD DEV	CUR UTIL	AVERAGE BLOCK	MAX IDL TME/SER	MAX BSY TME/SER	ENT CNT
0	ZAAB	QUEUE	1	.000	.00	0	.89	2.16	.00	
0	ZAAC	QUEUE	1	.000	.00	0	.59	7.25	.00	
3		QUEUE	8	2.541	1.98	3	.00	8.00	8.00	133
6		QUEUE	2	.155	.41	0	.00	2.00	2.00	6
9		QUEUE	8	3.785	2.52	7	.00	8.00	8.00	173
12		QUEUE	2	.251	.52	0	.00	2.00	2.00	18

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	ONE	1	.99	.082	1	1
2	TWO	1	.90	.293	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE AVAILABILITY	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	ONE	0	.0068	0	1
1	TWO	0	.0951	0	1

Figure 5.8 SLAM II summary statistics for the pooled queue simulation model.

To illustrate further the potential of the pooled queue, the number of trucks in the system was incrementally reduced to determine how many trucks are required to obtain the same crane utilizations as the separate files. The first step was to run the model with only 10 trucks in the system, with all other parameters remaining unchanged. The results indicate that crane number one was 99 percent utilized while crane number two was utilized 78 percent of the time. The fact that the utilization of crane number two was drastically reduced indicates that the arrangement of the queues at the beginning of the model does not optimally describe the system. Whatever the cause, the system could not be improved because of SLAM requirements. Despite this limitation, a comparison of the average utilizations indicates that the system is still working better with ten trucks in the pooled queue system than with twelve trucks in the independent delay models. In addition to the crane utilization, the simulation suggests that the trucks wait an average total of 4.721 minutes, compared with 7.351 minutes in the separate delay models.

A nine vehicle system estimates that crane number one is utilized 98 percent of the time and crane number two is utilized 69 percent of the time. The total average wait time has been reduced to approximately 4 minutes. The simulation was not executed for eight or fewer vehicles. However, the removal of three vehicles is sufficient to illustrate the potential savings attained by pooling queues, that is, if conditions permit pooling for a significant period of time.

Simulation Model Summary

The simulation section of this chapter illuminated several important items. First, a general model was proposed that could quickly and easily be used to estimate crane utilizations and waiting times for different scenarios. The model was not successful because of its inability to account for delays encountered in the field, which meant that the average time in queue was consistently underestimated. As a result, a detailed model was developed that accounted for operational delays. The results more accurately replicated the field estimates of W_q, although more information is needed to calibrate the detailed model. Nonetheless, it shows that the model can be used to accurately model the cyclic system employed at the port.

Lastly, the detailed models were used to simulate a hypothetical situation in which the two gangs are pooled into one serving both cranes. The pooled queue simulation showed that several trucks could be dropped from the system without decreasing overall crane utilization or increasing vehicle waiting times. The benefit is that the trucks do not wait as long for service and, thus, save on fuel and labor. Another benefit of the pooled queue system is that more containers can potentially be moved per hour. The limitation of the pooled system is that conditions may not allow the pooled queue to be sustained for a long period of time. The point should be made, however, that limited improvements could be attained even with partial implementation of the pooled process. In other words, if one crane is waiting for a truck, there is no reason why a truck from the other crane's queue should not be serviced.

Because simulation models are primarily used for analyzing case studies and do not serve well as an optimization tool, it is important to explore and to assess the ways in which the system can be mathematically modeled. The formal analytical queuing models presented next in this report are valuable tools in modeling the system, but they have several limitations. The benefits and limitations of each of the models are presented in the following two sections.

CYCLIC QUEUES

The analysis of cyclic queues has received much less attention in the literature than single server queues, or even network queues. One reason is because non-exponential service times in any stage of the cyclic queue significantly complicate the analysis. (Also, there is a lack of data available to describe the processes of the cyclic queue.) However, the assumption of exponential service times in each stage of the cyclic queue may not always be appropriate, which is shown in Chapter 4.

This section explores the analysis of cyclic queues based, primarily, on exponential and Erlang service stages. The greatest advantage of cyclic queue analysis is that each stage in the cycle can be considered in the model, including those not represented by the field data (i.e., yard crane service times and transit times which have been combined in the data collection process to create the backcycle time). These stages may include the transit stages and the yard service stage.

Defining and Simplifying the Cyclic Queue

The conceptual cyclic queue considered in this section has already been presented in Chapter 2 (see Figure 2.3). The mathematical representation is discussed in this section.

The cyclic queue is a special type of queuing network. In queuing networks, customers typically enter at one end and depart from the other. It is called a closed network if vehicles are not allowed to enter or to leave the system from within, and an open network if vehicles are allowed to balk or to arrive in stages other than the first or last. A cyclic queue, on the other hand, is a network queue that closes in on itself, providing no theoretical beginning or end. Thus, in a cyclic system of M stages, a vehicle completing service at stage M-1 will proceed to station M, whereas a vehicle completing service at stage M will proceed to station 1. Since there are separate gangs that work each crane, no vehicles exit or enter the system, making it a closed cyclic queue.

Cyclic queues can have as many or as few stages as desired. However, the analysis requirements increase dramatically when the cyclic queue in question incorporates many stages, since the number of possible system states increases rapidly as stages are added to the cycle. In fact, the number of possible states in a cyclic queue, c, is combinatorial and is defined by Equation 5.1. The state of a cyclic system is defined by the number of customers in each system stage. Therefore, each state of a four stage system (M=4) is represented as $P(n_1, n_2, n_3, n_4)$ where n_i is the number of trucks in the i^{th} stage.

$$c = \frac{(K+M-1)!}{((K+M-1)-K)!K!} = \frac{(K+M-1)!}{(M-1)!K!} \tag{5.1}$$

where:

K = the number of cyclic customers in the system, and
M = the number of stages in the system.

There are four stages to consider at the container port, including two transit stages (to and from the wharf crane). Although four stages are not too cumbersome, it would be convenient to reduce the number of stages in the system. Maher and Cabrera [Ref 56] provide a powerful, simplifying condition that can bring about such a reduction. They specifically consider the transit stages of a cyclic queue and the effects of various transit service distributions on the overall system performance. They proved that the production of a cyclic queue is dependent on the total mean (all stages combined) transit times and that the production of a cyclic queue is <u>not</u> dependent on individual-stage mean transit times. In other words, all transit stages do not need to be modeled in specific order in the network model. Instead, they can be grouped together and modeled as one single transit stage without affecting the performance of the model. The disadvantage of combining transit stages is that it may be desirable to maintain the sequencing introduced by the serial processing of customers. There are no foreseeable advantages to preserving the order of transit times in these models so the reduction will be explored. The basis for the Maher and Cabrera proof is summarized by first defining the following:

$$T = \sum_{j=1}^{M} \beta_j^{-1} = \text{ the mean total transit time} \tag{5.2}$$

$$\beta_j^{-1} = \text{ vehicle transit time at stage j, j = 1,2...M} \tag{5.3}$$

$$\alpha_j^{-1} = \text{ vehicle service time at stage j, j, = 1,2...M} \tag{5.4}$$

$$p_i = \alpha_j^{-1} / \sum_{j=1}^{M} \alpha_j^{-1} = \text{ proportion of the total average service} \tag{5.5}$$

$$X = \sum_{j=1}^{M} \beta_j^{-1} / \sum_{j=1}^{M} \alpha_j^{-1} \quad \text{time taken by vehicle i} \tag{5.6}$$

Maher and Cabrera present the explicit expression below Equation 5.7—this is based on the work of Koenigsberg in 1958—for the average production rate of a multi-stage cyclic queuing system in which the mean service times may all be different. The quantity $F_N^{(k)}$ is the ratio of the maximum average production rate to the actual average production rate. This illustrates that the output of the system does not depend on the individual mean transit times, but on X, the ratio of mean total transit time to the mean total service time.

$$p_k F_N^{(k)} = \frac{\displaystyle\sum_{u=0}^{N} \frac{X^{-u}}{(N-u)!} \sum_{i=1}^{M} \frac{p_i^{u+m-2}}{\prod_{j \neq i} (p_i - p_j)}}{\displaystyle\sum_{u=0}^{N} \frac{X^{-u}}{(N-u)!} \sum_{i=1}^{M} \frac{p_i^{u+m-1}}{\prod_{j \neq i} (p_i - p_j)}} \tag{5.7}$$

Expressions (5.2) through (5.7) are valid for a cyclic queue with M stages that provide service according to a wide range of distributions, including the Erlang and uniform distributions. This is particularly valuable since it has been shown that exponential service stages are seldom appropriate. Bear in mind that when N exponentially distributed service stages are combined, the resulting random variable follows an Erlang (N) distribution.

The case of uniform transit times (or high-parameter Erlang distributions) can be modeled with the aforementioned procedure, although it becomes extremely labor intensive, based on Equation 5.1. The procedure suggests that all uniform transit stages can be combined into one transit stage, regardless of the magnitude. The combined stage is then modified by breaking the combined transit stage into many "substages" of exponential service. Each exponential substage is assigned identical mean values whose magnitude is determined by dividing the combined uniform transit time by the number of substages. Suppose the combined uniform transit time in a 4 stage cyclic queue is 25 minutes. We could replace the uniform transit stage with 10 exponential service stages, each having a mean of 2.5 minutes, and model the modified 13 stage queue as described in this report. Posner and Bernholtz [Ref 57] argue that these procedures are applicable for general distributions as well. The concept of Erlang stages is further clarified by Carmichael [Ref 58] who writes that "effectively, the transit times are being modeled as Erlang distributions; each sub-phase is according to an exponential distribution and together they form an Erlang distribution. For many stages, the Erlang distribution approaches a constant distribution." The problem with this procedure should be obvious. For a cyclic queue with only six customers, increasing the number of stages from 4 to 13, as described above, pushes the number of possible states from 84 to 18,564.

With this background on cyclic queues and with the explanation of how to reduce the number of stages in the cyclic queue, the actual procedure for analyzing the cyclic queue can be presented. Carmichael has completed a large number of papers and books on modeling the cyclic queues that are prevalent in the construction and mining industries. The construction queues analyzed by Carmichael have many parallels to the container port queues presented in the remainder of this section.

General Cyclic Queue Modeling Principles

The cyclic queue models that Carmichael presents are limited by the assumption of exponential service times in each stage and in steady-state operations. An advantage of this procedure is the ease with which the procedure can determine the probability of the system existing in any state. Other pertinent assumptions are that entities transfer between stages instantaneously and that the system is a closed cycle.

The transition diagram is used to develop the balance equations for a system in steady-state. From the balance equations, a single recursive expression can be obtained for the probability of the system being in any specific state. This expression is often in terms of the steady-state probability that no customers are in the system, P_0. For the cyclic queue, the transition diagram must specify $P(n_1, n_2, \ldots n_M)$ instead of just $P(n)$. An example transition diagram of a three stage cyclic queue is provided in Figure 5.9. Each node represents one possible state in the form (n_1, n_2, n_3).

The following steady-state expression can be developed from the balance equations that stem out of Figure 5.9:

$$P(n_1, n_2, n_3) = \frac{\mu_1^{K-n_1}}{\mu_2^{n_2}\mu_3^{n_3}} P(K,0,0) \tag{5.8}$$

The term P(K,0,0) is the probability that all K customers of the cyclic queue are in stage one, with zero customers in all other stages. When more stages are considered in the cyclic system, there are inherently more states possible in the transition diagram and, thus, more balance equations. From all of these equations, the recursive expression for steady-state probabilities of a system with M phases can be obtained, which is illustrated by Equation 5.9:

$$P(n_1, n_2, \ldots, n_M) = \frac{\mu_1^{K-n_1}}{\mu_2^{n_2}\mu_3^{n_3}\ldots\mu_M^{n_M}} P(K,0,\ldots,0) \tag{5.9}$$

The quantity P(K,0,...,0) can be calculated by considering that the summation over all states of the state probabilities must equal 1. The summation leads to the following expression:

$$P(K,0,\ldots,0) = \left[\sum_{n=1}^{K}\left(\frac{\mu_1}{\mu_1}\right)^{n_2}\left(\frac{\mu_1}{\mu_2}\right)^{n_2}\cdots\left(\frac{\mu_1}{\mu_M}\right)^{n_M}\right]^{-1} \tag{5.10}$$

There are two variations to Equation 5.9 that are worth noting at this point. The first variation is the situation where $m_i = m$ for $i = 1, 2, \ldots M$. This is known as the balanced machine problem. For balanced machines, Equation 5.9 is simplified as follows:

$$P(n_1, n_2, \ldots n_M) = \frac{\mu^{K-n_1}}{\mu^{K-n_1}} P(K,0,\ldots,0) = P(K,0,\ldots,0) \tag{5.11}$$

Also, recall that Equation 5.9 is applicable only for single server stages. At the port, the transit phases are being modeled as self-service stages. The second variation to mention, therefore, is the allowance for one or more servers in a specific stage, which would be applicable to the port situation. When a stage has more than one server, in parallel, the probability of a customer completing service is no longer m_i but the quantity (n_i x m_i) for ($n_i \leq r_i$), and (r_ix m_i) for ($n_i > r_i$) where r_i is the number of parallel servers in stage i. The self-service case is one in which n_i can never exceed r_i, removing the quantity (r_i xm_i) from consideration. For self-service in stage i, Equation 5.9 is modified to Equation 5.12. Note that the quantity r_i does not appear because Equation 5.12 represents the probability of one specific state in which r_i is greater than or equal to n_i. This modification is illustrated in examples for three stage and four stage cyclic queues later in this section.

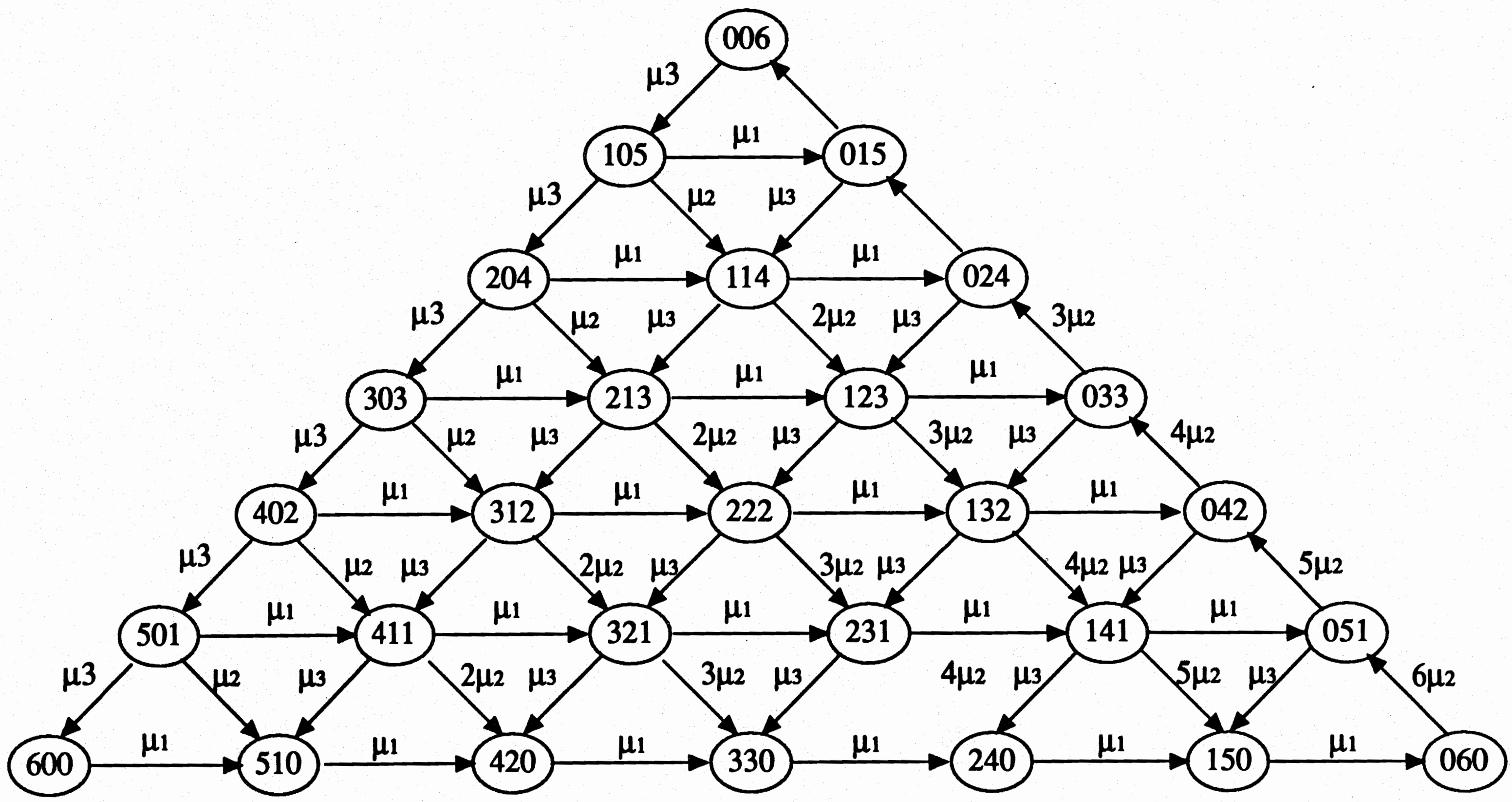


Figure 5.9 Rate diagram for a three stage, six vehicle cyclic queue. There is a total of 28 possible states.

$$P(n_1, n_2, \ldots n_i, \ldots, n_M) = \frac{\mu_1^{K-n_1}}{\mu_2^{n_2}\mu_3^{n_3} \ldots n_i! \mu_i^{n_i} \ldots \mu_M^{n_M}} P(K,0,\ldots,0) \tag{5.12}$$

After the calculation of the steady-state probabilities from Equation 5.9, several important system characteristics can be determined from classic queuing relationships. Specifically, the average time in queue, average queue lengths, and crane utilization statistics can be calculated. The crane utilization is the stage (or phase) utilization, given that the crane service is represented by one phase. The basic principles underlying these derivations are Little's relationships for general queuing systems. Specifically, the following is defined:

η_i = utilization of stage i, then

P[stage i is idle] $= 1 - \eta_i = \sum_{n_i=0}^{K} P(n_1, n_2, \ldots, n_{i-1}, 0, n_{i+1}, \ldots, n_M)$, and

P[stage i is busy] = η_i = 1-P[stage i is idle] (5.13)

Obviously the output, Δ_i, of stage i can be estimated by multiplying the utilization of the stage by the service rate, m_i. Because the output from each phase has the same mean as the input into the phase, the productivity of the system is limited by the phase with the lowest mean service rate. Also recall that the order of the stages is not important in determining performance characteristics. The performance characteristics of individual stages are summarized as follows:

L_i = ave number of trucks in stage i = $\sum_{n_i=0}^{K} n_i P(n_1, n_2, \ldots n_i, \ldots n_M)$

L_{qi} = ave number of trucks in queue i

$$= \sum_{n_i=0}^{K} (n_i - 1) P(n_1, n_2, \ldots, n_i, \ldots, n_M) = L_i - \eta_i \tag{5.14}$$

Then, from Little's relationships:

W_{qi} = ave time in queue i = L_{qi} / Δ_i

W_i = ave time in stage i = $W_{qi} + 1/m_i$ (5.15)

Finally, the average cycle time (for one unit to complete M stages) is determined by the following relationship:

$$\text{Ave total cycle time} = \sum_{i=1}^{M} (W_{qi} + 1/\mu_i) \qquad (5.16)$$

Equations (5.13) to (5.16) provide valuable information in the analysis of system performance. The characteristics can be used to identify bottlenecks in the system and to quantify the percentage of time stages of the system that are idle. The aforementioned procedures are illustrated by applying them to a four stage cyclic queue and to a reduced three stage cyclic queue.

Analysis of Four Stage Cyclic Queue

The concepts presented thus far in the section will be applied first to the four stage cyclic queue represented in Figure 5.10. The system assumes that all service stages are exponentially distributed and that there is no blocking between stages. The transitions between stages are instantaneous. The transit stages are modeled as self-service stages, and crane service stages are modeled with only one server. Finally, there are six trucks present in the system.

The original data file considered was Jan7p.1. Recall, however, that none of the data files captured yard service times or transit times. Therefore, to model the data file as a four stage cyclic queue, assumptions have to be made about the transit and yard service times. Because the field data provides no basis for this breakdown, it may prove difficult to properly calibrate the analytical model. It follows that the average time in queue and stage utilization may also be inaccurately represented by the analytical model.

It was assumed that the transit times were independent and identically distributed to and from the wharf crane with equal means. In actuality, the transit time may be slightly longer when a truck is loaded with a container. However, the assumption is that as many containers will be moved to the ship as from the ship; the assumption implies that there are as many loaded truck trips to the ship as there are from the ship. Since the results of this procedure are for steady-state operations, it was decided that the average service times in each stage would be equal over a long period of time. It is difficult to use the backcycle time as a basis for assigning service times in the three stages, since the backcycle time includes the time in queue at the wharf crane, whereas the actual service time used in the model should exclude the waiting time. Figure 5.10 shows the service rates of each stage in the cycle. Recall that the service time is inversely proportional to the service rate.

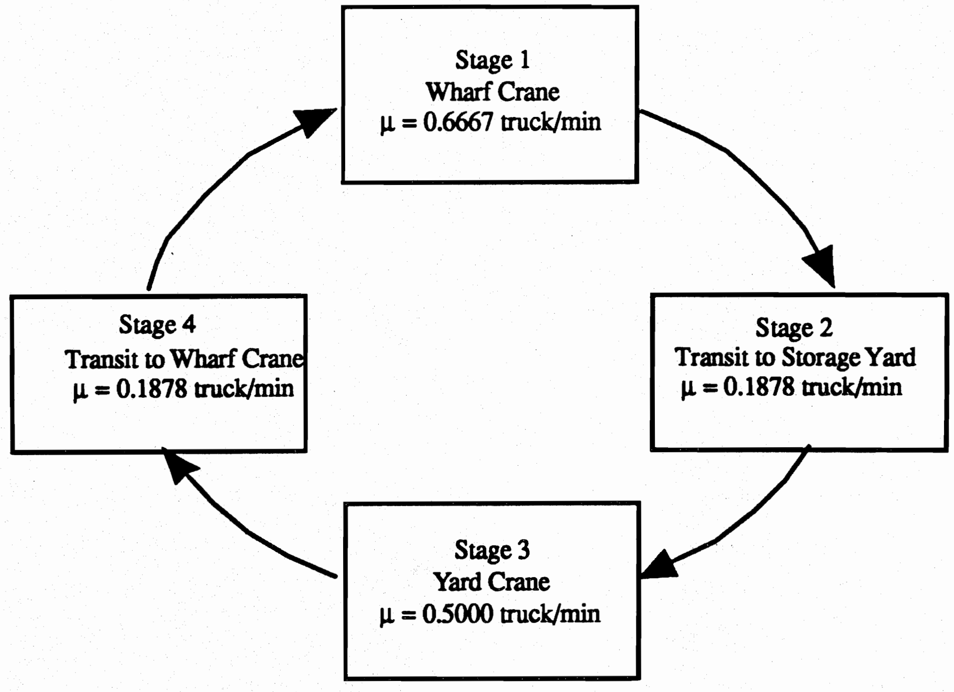


Figure 5.10 Four stage cyclic queue example.

The steady-state probabilities for the four stage cyclic queue can be taken from Equation 5.12. Because the second and fourth stages are self-service, there are two factorial expressions in the denominator.

$$P(n_1,n_2,n_3,n_4) = \frac{\mu_1^{K-n_1}}{n_2!\,\mu_2^{n_2}\mu_3^{n_3}n_4!\,\mu_4^{n_4}} P(6,0,0,0) \qquad (5.17)$$

A spreadsheet model was once again employed to determine the steady-state probabilities. The results of the spreadsheet calculations are presented in the following two-page table. Table 5.2 includes the probability that each state can occur. For K=6 and M=4, there are a total of 84 possible states. The state (n_1,n_2,n_3,n_4) i represented by the four columns of the spreadsheet is labeled as indicated.

The determination of state probabilities is based on the fact that the sum of all state probabilities must equal one. If the sum of the coefficients is also known, it is easy to calculate the individual state probabilities. The coefficient referred to is the quantity that is multiplied by P(6,0,0,0) in the state probability expression.

The first step in the procedure is to calculate the coefficient of each system state, shown in the sixth column of Table 5.2. After the individual coefficients are summed, the state probability (column 7) is calculated by dividing the individual coefficient by the sum. Once these calculations have been made, the performance characteristics can be easily determined with the techniques presented previously. Specifically:

$$\eta_1 = 1 - P(0, n_2, n_3, n_4) = 0.519$$
$$\eta_2 = 1 - P(n_1, 0, n_3, n_4) = 0.872$$
$$\eta_3 = 1 - P(n_1, n_2, 0, n_4) = 0.692$$
$$\eta_4 = 1 - P(n_1, n_2, n_3, 0) = 0.872$$

The estimates of the crane utilization (stages 1 and 3) are likely underestimated owing to the way the transit times and yard service time were estimated. (The error in the estimations was discussed previously.) The crane utilizations can be interpreted as the percentage of time that the crane was in use. There was at least one truck in stage two or stage four 87 percent of the time (i.e., in transit between the yard crane to the wharf crane). The determination of stage utilization leads to estimating the potential output of each stage Δ_i:

$$\Delta_i = \eta_i * \mu_i$$

Δ_1 =0.346 trucks/minute Δ_2 =0.164 trucks/minute

Δ_3 =0.346 trucks/minute Δ_4 =0.164 trucks/minute

The average number of trucks in queue (L_{qi}) and the average number of trucks in the stage (L_i) have been determined for stages 1 and 3. The calculations are included in Table 5.2 and are based on Equation 5.14. Equation 5.15 provides the basis for estimating the average waiting time in queue W_{qi} and the average time in each stage W_{qi}. The results of all calculations are presented below:

L_1 = 0.765 trucks W_1 = 2.538 minutes/truck

L_{q1} = 0.359 trucks W_{q1} = 1.038 minutes/truck

L_3 = 1.557 trucks W_3 = 4.153 minutes/truck

L_{q3} = 0.745 trucks W_{q3} = 2.153 minutes/truck

TABLE 5.2 STEADY-STATE PROBABILITIES FOR FOUR STAGE CYCLE QUEUE

	u1	u2	u3	u4						
	0.6667	0.1878	0.5000	0.1878						
	State (n1, n2, n3, n4)						Ave trucks	Ave trucks	Ave trucks	Ave trucks
Entry	n1	n2	n3	n4	Coeff.	P (state)	in stage 1	in queue 1	in stage 3	in queue 3
1	6	0	0	0	1.0000	0.0006	0.0035	0.0029	0.0000	
2	5	1	0	0	3.5501	0.0021	0.0104	0.0083	0.0000	
3	5	0	1	0	1.3334	0.0008	0.0039	0.0031	0.0008	0.0000
4	5	0	0	1	3.5501	0.0021	0.0104	0.0083	0.0000	
5	4	2	0	0	6.3014	0.0037	0.0147	0.0110	0.0000	
6	4	0	2	0	1.7780	0.0010	0.0042	0.0031	0.0021	0.0010
7	4	0	0	2	6.3014	0.0037	0.0147	0.0110	0.0000	
8	4	1	1	0	4.7736	0.0028	0.0111	0.0083	0.0028	0.0000
9	4	1	0	1	12.6029	0.0074	0.0295	0.0221	0.0000	
10	4	0	1	1	4.7736	0.0028	0.0111	0.0083	0.0028	0.0000
11	3	3	0	0	7.4568	0.0044	0.0131	0.0087	0.0000	
12	0	0	3	0	2.3707	0.0014	0.0042	0.0028	0.0042	0.0028
13	0	0	0	3	7.4568	0.0044	0.0131	0.0087	0.0000	
14	2	2	1	0	8.4023	0.0049	0.0147	0.0098	0.0049	0.0000
15	2	2	0	1	22.3704	0.0131	0.0392	0.0261	0.0000	
16	1	1	2	0	6.3118	0.0037	0.0111	0.0074	0.0074	0.0037
17	0	0	2	1	6.3118	0.0037	0.0111	0.0074	0.0074	0.0037
18	1	1	0	2	22.3704	0.0131	0.0392	0.0261	0.0000	
19	0	0	1	2	8.4023	0.0049	0.0147	0.0098	0.0049	0.0000
20	1	1	1	1	16.8047	0.0098	0.0295	0.0196	0.0098	0.0000
21	4	4	0	0	6.6180	0.0039	0.0077	0.0039	0.0000	
22	0	0	4	0	3.1611	0.0018	0.0037	0.0018	0.0074	0.0055
23	0	0	0	4	6.6180	0.0039	0.0077	0.0039	0.0000	
24	3	3	1	0	9.9429	0.0058	0.0116	00.058	0.0158	0.0000
25	3	3	0	1	26.4721	0.0155	0.0309	0.0155	0.0000	
26	1	1	3	0	8.4162	0.0049	0.0098	0.0049	0.0148	0.0098
27	0	0	3	1	8.4162	0.0049	0.0098	0.0049	0.0148	0.0098
28	1	1	0	3	26.4721	0.0155	0.0309	0.0155	0.0000	
29	0	0	1	3	9.9429	0.0058	0.0116	0.0058	0.0058	0.0000
30	2	2	1	1	29.8288	0.0174	0.0349	0.0174	0.0174	0.0000
31	1	1	2	1	22.4074	0.0131	0.0362	0.0131	0.0262	0.0131
32	1	1	1	2	29.8288	0.0174	0.0349	0.0174	0.0174	0.0000
33	2	2	2	2	11.2037	0.0065	0.0065	0.0065	0.0000	0.0065
34	2	2	0	2	39.7081	0.0232	0.0232	0.0232	0.1160	
35	2	0	2	2	11.2037	0.0065	0.0065	0.0065	0.0000	0.0065
36	1	5	0	0	4.6989	0.0027	0.0027	0.0000	0.0027	
37	1	0	5	0	4.2150	0.0025	0.0025	0.0000	0.0000	0.0098
38	1	0	0	5	4.6989	0.0027	0.0027	0.0000	0.0110	
39	1	4	1	0	8.8245	0.0052	0.0052	0.0000	0.0206	0.0000
40	1	4	0	1	23.4943	0.0137	0.0137	0.0000	0.0000	

TABLE 5.2 CONTINUED

	u1	u2	u3	u4						
	0.6667	0.1878	0.5000	0.1878						
	State (n1, n2, n3, n4)						Ave trucks	Ave trucks	Ave trucks	Ave trucks
Entry	n1	n2	n3	n4	Coef	P (state)	in stage 1	in queue 1	in stage 3	in queue 3
41	1	1	4	0	11.2222	0.0066	0.0066	0.0000	0.0066	0.0197
42	1	0	4	1	11.2222	0.0066	0.0066	0.0000	0.0131	0.0197
43	1	1	0	4	23.4943	0.0137	0.0137	0.0000	0.0000	
44	1	0	1	4	8.8245	0.0052	0.0052	0.0000	0.0155	0.0000
45	1	3	2	0	13.2579	0.0077	0.0077	0.0000	0.0232	0.0077
46	1	3	0	2	46.9887	0.0275	0.0275	0.0000	0.0000	
47	1	2	3	0	14.9390	0.0087	0.0087	0.0000	0.0175	0.0175
48	1	0	3	2	14.9390	0.0087	0.0087	0.0000	0.0087	0.0175
49	1	2	0	3	46.9887	0.0275	0.0275	0.0000	0.0824	
50	1	0	2	3	13.2579	0.0077	0.0077	0.0000	0.0077	0.0077
51	1	3	1	1	35.2979	0.0206	0.0206	0.0000	0.0412	0.0000
52	1	1	3	1	29.8780	0.0175	0.0175	0.0000	0.0175	0.0349
53	1	1	1	3	35.2979	0.0206	0.0206	0.0000	0.0412	0.0000
54	1	2	2	1	39.7737	0.0232	0.0000	0.0000	0.0000	0.0232
55	1	2	1	2	52.9468	0.0309	0.0000	0.0000	0.1856	0.0000
56	1	1	2	2	39.7737	0.0232	0.0000	0.0000	0.0000	0.0232
57	0	6	0	0	2.7802	0.0016	0.0000		0.0016	
58	0	0	6	0	5.6203	0.0033	0.0000		0.0000	0.0164
59	0	0	0	6	2.7802	0.0016	0.0000		0.0081	
60	0	5	1	0	6.2655	0.0037	0.0000		0.0183	0.0000
61	0	5	0	1	16.6812	0.0097	0.0000		0.0000	
62	0	1	5	0	14.9636	0.0087	0.0000		0.0087	0.0350
63	0	0	5	1	14.9636	0.0087	0.0000		0.0087	0.0350
64	0	1	0	5	16.6812	0.0097	0.0000		0.0390	
65	0	0	1	5	6.2655	0.0037	0.0000		0.0037	0.0000
66	0	4	1	1	31.3273	0.0183	0.0000		0.0366	0.0000
67	0	1	4	1	39.8393	0.0233	0.0000		0.0233	0.0698
68	0	1	1	4	31.3273	0.0183	0.0000		0.0549	0.0000
69	0	3	2	1	47.0662	0.0275	0.0000		0.0825	0.0275
70	0	3	1	2	62.6547	0.0366	0.0000		0.0366	0.0000
71	0	2	3	1	53.0342	0.0310	0.0000		0.0620	0.0620
72	0	1	3	2	53.0342	0.0310	0.0000		0.0620	0.0620
73	0	2	1	3	62.6547	0.0366	0.0000		0.0732	0.0000
74	0	1	2	3	47.0662	0.0275	0.0000		0.0000	0.0275
75	0	2	2	2	70.5993	0.0412	0.0000		0.1650	0.0412
76	0	4	2	0	11.7665	0.0069	0.0000		0.0275	0.0069
77	0	4	0	2	41.7031	0.0244	0.0000		0.0000	
78	0	2	4	0	19.9196	0.0116	0.0000		0.0233	0.0349
79	0	0	4	2	19.9196	0.0166	0.0000		0.0349	0.0349
80	0	2	0	4	41.7031	0.0244	0.0000		0.0000	
81	0	0	2	4	11.7665	0.0069	0.0000		0.0206	0.0069
82	0	3	3	0	17.6781	0.0130	0.0000		0.0000	0.0207
83	0	3	0	3	55.6041	0.0325	0.0000		0.0000	
84	0	0	3	3	17.6781	0.0103	0.0000		0.0000	0.0207
				Total	1711.76	1.0000	0.7645		1.5574	0.7448

The Jan7p.1 field data corresponds to an average time in queue of 2.483 minutes. Similarly, the simulation model estimated that the average time in queue was 1.826 minutes. Recall that the simulation was a two stage model that combined both transit stages and the yard crane service time into one stage, which is shown in Figure 5.1. Both stages were specified as Erlang(2) distributions in the simulation model. The analytical model results are significantly higher than a similar simulation model because of the assumptions that require the backcycle process to be broken into two transit times and one yard crane service time. Based on the time-motion studies, it is impossible to determine how best to describe the three stages (two transit and one yard service) given the knowledge of only one feature (backcycle). It is possible that the assumptions of equal transit stages are not appropriate, or that the breaking of the backcycle time into transit and yard crane service times was not accurate. Yet another reason for the discrepancy could be that the service time is more accurately described by the E(2) distribution than by the exponential distribution, whereas the K-S test failed for exponential backcycle times (see Table 4.3 and Table 4.5 for these results).

The last result is the probability distribution of how many trucks are present in stage 1. Stage 1 is chosen because it corresponds to the wharf crane, the critical element of the system. This provides additional information that is valuable when comparing results of alternative approximation models, including those presented in Section 3 of this chapter.

$P_0 = P(0,n_2,n_3,n_4) = 0.481$ $\quad$ $P_4 = P(4,n_2,n_3,n_4) = 0.021$

$P_1 = P(1,n_2,n_3,n_4) = 0.283$ $\quad$ $P_5 = P(5,n_2,n_3,n_4) = 0.005$

$P_2 = P(2,n_2,n_3,n_4) = 0.146$ $\quad$ $P_6 = P(6,n_2,n_3,n_4) = 0.001$

$P_3 = P(3,n_2,n_3,n_4) = 0.063$

This completes the calculation of service characteristics for the four stage cyclic queue. To illustrate the procedure of combining stages, the transit stages of this network have been combined. The results of the model are presented next.

Analysis of Three Stage Cyclic Queue

The reduction of the four stage cyclic queue into a three stage cyclic queue is very simple. In this example, the two transit stages are combined into one. The resulting service rate is 0.0939 trucks/minute, and is represented in stage 2 of the network. Thus, stage 1 is the wharf crane service (0.667 trucks/minute) and stage 3 is the yard crane service (0.500 trucks/minute). Because stage two is the only self-service stage, the steady-state probability equation becomes:

$$P(n_1, n_2, n_3) = \frac{\mu_1^{K-n_1}}{n_2!\,\mu_2^{n_2}\mu_3^{n_3}} P(K,0,0) \tag{5.18}$$

With this exception, and the fact that there are only 28 states possible, the analysis procedure is identical to that of the four stage cyclic queue. Because of their similarities, only the results are presented below:

$\eta_1 = 0.5190$ $\Delta_1 = 0.346$ trucks/minute

$\eta_2 = 0.989$ $\Delta_2 = 0.093$ trucks/minute

$\eta_3 = 0.692$ $\Delta_3 = 0.346$ trucks/minute

$L_1 = 0.878$ trucks $L_3 = 1.437$ trucks

$L_{q1} = 0.359$ trucks $L_{q3} = 0.745$ trucks

$W_1 = 2.538$ minutes/truck $W_3 = 4.154$ minutes/truck

$W_{q1} = 1.038$ minutes/truck $W_{q3} = 2.153$ minutes/truck

$P_0 = P(0,n_2,n_3,n_4) = 0.481$ $P_4 = P(4,n_2,n_3,n_4) = 0.021$

$P_1 = P(1,n_2,n_3,n_4) = 0.283$ $P_5 = P(5,n_2,n_3,n_4) = 0.005$

$P_2 = P(2,n_2,n_3,n_4) = 0.146$ $P_6 = P(6,n_2,n_3,n_4) = 0.001$

$P_3 = P(3,n_2,n_3,n_4) = 0.063$

The near identical results of the four stage and three stage models illustrate the validity of reducing the number of stages in the network. To determine the accuracy of the modeling technique itself, simulation models were run for both the four stage and three stage queues. Steady-state operations were assured by running the simulations for a total of 1,500 minutes and clearing the statistics at 500 minutes. The simulation models were very similar to the general simulation models presented earlier, but with three or four stages instead of only two. Because of their similarities, the development of the models will not be discussed in this report. The results provided by the simulation models are presented in Table 5.3.

The results of the four stage simulation model compare very well with the cyclic queue results. The largest discrepancy is in the estimate of L_{q1} and W_{q1}, which are underestimated by the simulation by approximately 11 percent, that is, compared with the cyclic queue results. All other discrepancies were less than 10 percent. The errors of the three cycle simulation model estimates (compared with the cyclic queue results) are consistently greater than that of the four stage simulation model. It is not possible to say which models are more accurate, but the fact remains that the two mathematical models produced very consistent results.

TABLE 5.3. RESULTS OF THREE STAGE AND FOUR STAGE SIMULATION MODELS OF THE CYCLIC QUEUE EXAMPLE

Three Stage Simulation Results	Four Stage Simulation Results
L_{q1} = 0.279 trucks	L_{q1} = 0.322 trucks
L_{q3} = 0.872 trucks	L_{q3} = 0.797 trucks
W_{q1} = 0.806 minutes/truck	W_{q1} = 0.937 minutes/truck
W_{q3} = 2.507 minutes/truck	W_{q3} = 2.290 minutes/truck
$\eta_1 = 0.511$	$\eta_1 = 0.495$
$\eta_2 = 0.707$	$\eta_2 = 0.715$

Cyclic Queue Summary

The cyclic queue section of this chapter explored a technique for analyzing closed cyclic queues. The queue could have as many stages as desired, but the service at each stage must follow an exponential distribution. Furthermore, the cyclic queue models apply only to steady-state results.

Several variations to the closed cyclic queue were also presented. First, it was shown that self-service stages can be included in the analysis process with only slight modifications. Second, a simplifying technique of combining transit stages was explored. The combination of k stages can significantly simplify the analysis of a cyclic queue, but it should be recognized that the new stage actually follows an Erlang (k) distribution.

The aforementioned techniques were applied to a hypothetical four stage cyclic queue. The four stage queue was then reduced to a three stage queue and analyzed again. The results were nearly identical, indicating that the techniques of stage reduction are indeed valid. When the results were compared with the simulation models, there were slight discrepancies. The cause of the discrepancies is unknown. However, the simulation results are not consistent between four stage and three stage cycles, indicating that the theoretical models are more consistent and possibly more accurate.

The cyclic queue analysis procedure is very powerful when analyzing queues that follow exponential service times. But it has been shown that such an assumption is not always accurate. As a result, other modeling options must be explored which allow non-exponential service (and interarrival) distributions. In keeping with that goal, Section 3 considers several single server models that are used to approximate the actual system.

SINGLE-SERVER MODELS

This section considers several alternative modeling techniques that can be used to analyze the wharf crane queue. The cyclic analysis in the previous section was limited by the assumptions of exponential distributions in every stage which includes transit times, yard crane service times, and wharf crane service times. It has been shown that this is not appropriate at all times. As a result, several other modeling options are explored that do not require the same limiting assumptions as the cyclic analysis.

Three modeling approaches are presented in this section: the machine repair model, the finite capacity model, and a finite source model. Non-exponential service times can be assumed for the first and third alternatives, but exponential service times must be assumed in the finite capacity model. However, to provide results that can be compared with those of Section 2, exponential distributions were assumed for alternatives one and two.

Advantages of an accurate mathematical queuing model include the ability to use the models for optimization studies. Another advantage is the ease of analyzing the same model with different distributions. There are two primary disadvantages to the mathematical models. The first is that closed form solutions do not normally exist when non-exponential distributions are assumed. This is not too limiting, since it has been shown that most backcycle times and interarrival times can be accurately approximated with the exponential distribution. The second disadvantage is that the models provide only steady-state results. In other words, the theoretical models do not account for operational interruptions.

Machine Repair Problem (M/M/2/FCFS/6/6)

The first alternative modeling approach that is presented is the machine repair problem. This model has received a significant amount of attention in queuing literature and is relatively simple to apply. The machine repair problem states that a repair facility (with R repair people) services a finite pool of machines (K) which break down periodically. The length of time a machine remains in operating condition is usually assumed to be exponentially distributed. A machine, at any particular time, is either operating or awaiting repair. When a machine breaks down, it is immediately sent to the repair facility where a wide range of distributions can be assigned to model the repair time. There are no restrictions on the queue lengths in the system.

The parallels between the port queue and the machine repair problem may be obvious. The service facility is still the wharf crane, and there is only one repair person, or server. The service at the wharf crane is similar to the time needed to repair a machine. The backcycle time of the truck is equivalent to the length of time that a machine is in good condition. The total number of machines is the same as the total number of trucks, which has been set at six in the following examples. Thus, the port system is a two stage machine repair problem where the first stage is service at the wharf crane, and the second stage is the backcycle process. The system state is now defined as the number of broken machines (j) which is equivalent to the number of trucks in service and in queue at a specific time. Winston [Ref 59] provides the information needed for the machine repair problem. To be consistent with the Winston text, the notation has slightly changed so that the probability of state j is represented by p_j instead of P_j. Through the use of Equation 5.19, the probability of each state occurring can be determined. The process involves expressing p_j (j = 0, 1,...,K) in terms of p_0, and using the fact that the sum of all stage probabilities equals one. The determination of p_j then leads directly to the estimation of all performance characteristics.

$$\pi_j = \binom{K}{j}\rho^j\pi_0 \qquad (j = 0, 1,...,R)$$

$$= \frac{\binom{K}{j}\rho^j j!\,\pi_0}{R!R^{j-R}} \qquad (j = R+1, R+2,...,K) \qquad (5.19)$$

where:

$\rho = \lambda / \mu$ and,

l = rate of machine breakdowns (trucks/minute)

To explore the accuracy of the approximation, the port queue example of Section 2 was analyzed again. The average backcycle and service rates were 0.600 trucks/minute and 0.079 trucks/minute, respectively. The calculations are straightforward, and with the exception of Equation 5.19, they are not included in this text. The results of the calculations are presented below:

crane utilization = $\eta_1 = 1 - \pi_0 = 0.716$

output of wharf crane = $\Delta_1 = \eta_1\mu_1 = 0.429$ trucks/minute

L_1 = 1.564 trucks $\qquad$ W_1 = 3.637 minutes/truck

L_{q1} = 0.849 trucks $\qquad$ W_{q1} = 1.974 minutes/truck

If we refer back to Table 5.1, we find that the field estimate for the average time in queue for the Jan7p.1 data file is 2.483 minutes. Once again, the estimate by the model is less than the field measurement because the model does not account for operational interruptions. However, the general simulation model (that does not consider delays) estimates W_{q1} as 1.826 minutes and L_{q1} as 0.633 trucks. This suggests that the machine repair approach provides a reasonable model when operational interruptions are not considered.

Finite Capacity Queue (M/M/1/FCFS/6/∞)

The second alternative to consider is the finite capacity model, which has been equated in the queuing literature to telephone systems in which callers who receive busy signals are lost to the system. If successful, the greatest benefit of such a system is that it is a very simple, single server queue that utilizes the arrival distribution instead of the backcycle distribution.

Recall that the machine repair approximation did not require exponential distributions (although the example did assume them) in either the service or interarrival process. The finite capacity model does require exponential assumptions for the following reason. The only way a cyclic queue can be broken apart is if the input (birth) process and the output (death) process are identical between stages—an occurrence that is only possible with the exponential distribution. Burke [Ref 60] proved this by showing that the output of a stage with Poisson arrivals and exponential service times is also Poisson distributed. The breaking of the cyclic queue into an open-ended queue is also documented by Gordon and Newell [Ref 61] who state that a closed cyclic system with K customers is "stochastically equivalent to open systems in which the number of customers cannot exceed N."

The breakdown of a cyclic queue can be illustrated by considering the port queue itself. Because the primary focus of this report is on the wharf crane, it is natural to break the cyclic queue, which is shown in Figure 5.11. The reduced queue becomes a simple single-server queue that has exponential interarrival times and service times.

The concept behind the finite capacity queue is that a predetermined number of vehicles are allowed to be in service or in queue. Any additional arrivals to the system are canceled. As mentioned, the arrival process must be defined in order to use this technique. Up to this point, the Jan7p.1 data file was being modeled as an example. The interarrival rate for this data file has a mean of $\lambda = 0.385$ truck/min and follows an exponential distribution. Winston again provides the necessary information for analyzing a finite capacity queue. Specifically, the steady-state probabilities are defined by the following:

$$\pi_j = \rho^j \pi_0 \qquad (j = 1, 2, \ldots c)$$

$$\pi_j = 0 \qquad (j = c+1, c+2, \ldots)$$

where:

$$\pi_0 = \frac{1-\rho}{1-\rho^{c+1}} \tag{5.20}$$

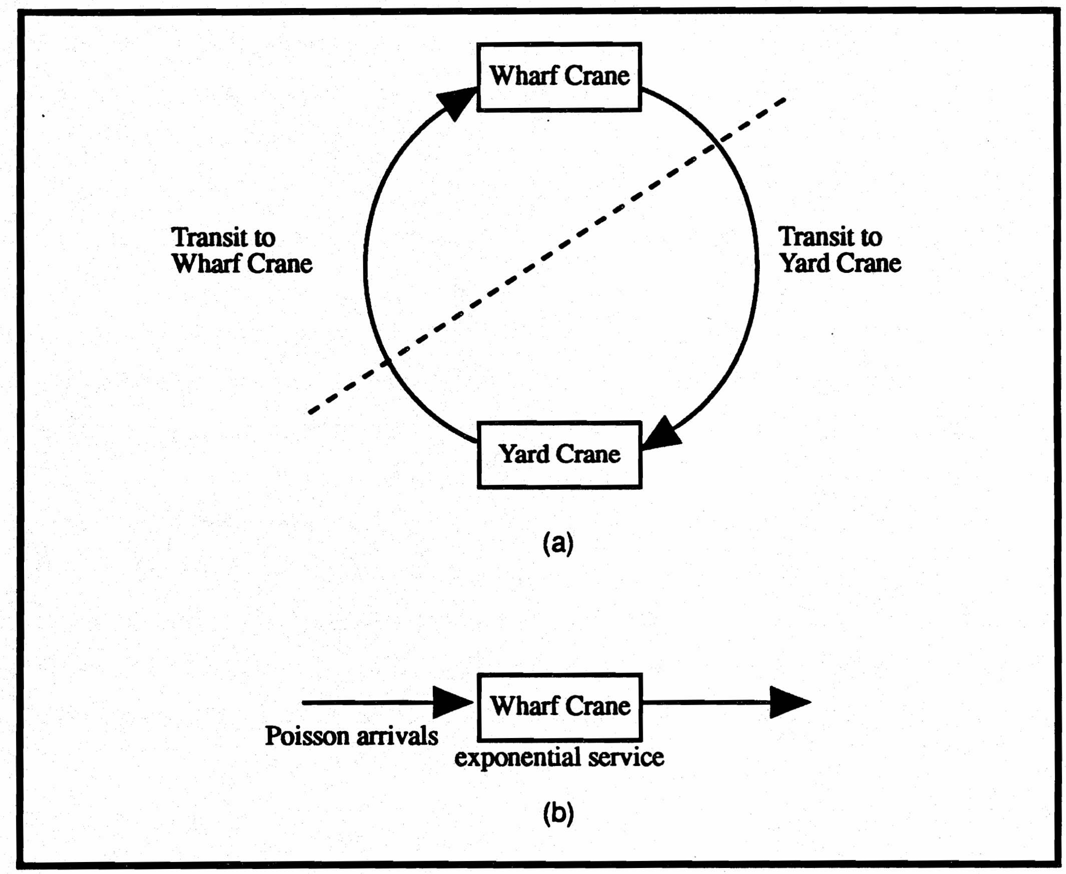


Figure 5.11 The break line of the cycle queue (a). The open ended queue that results is shown in (b).

Once again, the performance characteristics are derived from the steady-state probabilities in a straightforward manner. The results of the finite capacity approach are presented below.

crane utilization = $\eta_1 = 1 - \pi_0 = 0.631$

output of wharf crane = $\Delta_1 = \eta_1\mu_1 = 0.378$ trucks/minute

L_1 = 1.551 trucks	W_1 = 4.100 minutes/truck
L_{q1} = 0.920 trucks	W_{q1} = 2.432 minutes/truck

The technique does not approximate the system as well as the machine repair analogy. The field estimate of W_q is 2.483 minutes. Recall, however, that this estimate includes operational delays. Thus, we can assume the results above are somewhat inflated. This assumption is proven correct when we consider the results of the general simulation model which estimates W_q and L_q as 1.826 minutes and 0.633 trucks, respectively. The overestimation is likely owing to the traffic intensity. It is expected that as the intensity increases, the estimates worsen since a high traffic intensity results in many trucks being canceled from the system, making the model more and more unrealistic. Thus, this estimating technique (finite capacity approach) is acceptable only for very light traffic intensities (perhaps r<0.5).

Erlang Service Distributions (M/E2/1/FCFS/6/6)

The last modeling approach presented in this chapter expands the first two techniques by allowing Erlang distributions to describe the service process at the crane. The model is a single server one, but the backcycle times are used in the analysis instead of the interarrival times. Since the Erlang distribution is being modeled in this procedure, the development of the steady-state probability expression is not as straightforward as other exponential models. Because of this and because the transition diagram is an integral part of the solution to the problem, the transition diagram will be developed and presented in this text. Carmichael [Ref 62] applies the same procedure to a cyclic queue that exists in earthmoving operations.

The Mar8p.1 data file was selected for this procedure which is described by E(2) service times (m=0.7143 trucks/minute) and exponential backcycle times (l=0.1261 trucks/minute). The development of the transition diagram introduces a slightly different notation for the system state. The system state is now identified by the number of wharf crane service phases that require completion. For example, if there is one truck in the second phase of service and one truck in queue, the state of the system is three. The state zero indicates that the crane is idle. There are a total of 13 states for this system, and the corresponding transition diagram is illustrated in Figure 5.12.

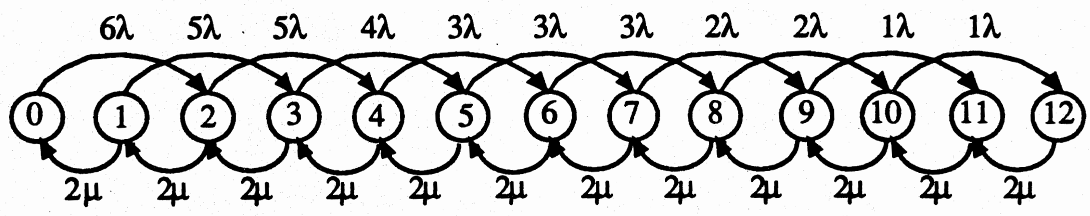


Figure 5.12 The state transition diagram for exponential backcycle times and Erlang(2) service times.

The arrival of vehicles at the truck is state dependent and is illustrated by the arrival rates appearing at the top of the transition diagram. Note that the probability of a service completion is always 2m, since the service time follows an E(2) distribution. The balance equations of the system can be written by equating the flow in and flow out for each node of the state transition diagram producing the following equations:

$6l\ P_0 = 2mP_1$
$(2m + 5l)\ P_1 = 2mP_2$
$(2m + 5l)\ P_2 = 6lP_0 + 2m\ P_3$
$(2m + 4l)\ P_3 = 5lP_1 + 2m\ P_4$
$(2m + 4l)\ P_4 = 5lP_2 + 2m\ P_5$
$(2m + 3l)\ P_5 = 4lP_3 + 2m\ P_6$
$(2m + 3l)\ P_6 = 4lP_4 + 2m\ P_7$

$(2m + 2l)\ P_7 = 3lP_5 + 2m\ P_8$
$(2m + 2l)\ P_8 = 3lP_6 + 2m\ P_9$
$(2m + l)\ P_9 = 2lP_7 + 2m\ P_{10}$
$(2m + l)\ P_{10} = 2lP_8 + 2m\ P_{11}$
$2m\ P_{11} = lP_9 + 2m\ P_{12}$
$2m\ P_{12} = lP_{10}$

$$\sum_{m=0}^{K1} P_m = 1$$

The probability of each state can be calculated by using the following procedure. First, estimate the value of P_0. Then, based on this estimate and prior knowledge of l and m, the remainder of the state probabilities can be calculated. Note, however, that the state probabilities must then be corrected by summing the probabilities, and then by scaling them according to how different the sum is from 1. The probability of j vehicles being in the system can now be calculated, which is shown below. The actual results of the procedure are reported below.

$p_0 = P_0 = 0.2241$ | $p_4 = P_7 + P_8 = 0.0653$

$p_1 = P_1 + P_2 = 0.2898$ | $p_5 = P_9 + P_{10} = 0.0169$

$p_2 = P_3 + P_4 = 0.2485$ | $p_6 = P_{11} + P_{12} = 0.0020$

$p_3 = P_5 + P_6 = 0.1535$ | (total = 1.0001)

These results can now be used in the same way as the procedures previously presented, in order to obtain the desired queue characteristics. Specifically, the results of the M/E_2/1 model are reported below:

crane utilization = $\eta_1 = 1 - \pi_0 = 0.7759$

output of wharf crane = $\Delta_1 = \eta_1\mu_1 = 0.5542$ trucks/minute

L_1 = 1.605 trucks W_1 = 2.896 minutes/truck

L_{q1} = 0.829 trucks W_{q1} = 1.496 minutes/truck

Recall that the field estimate of W_{q1} was 4.333 minutes/truck. As with the other theoretical models, this model underestimates the time in queue because of the impossibility of accounting for other operational delays. This is illustrated by reconsidering the Mar9p.1 data file. If all queue waiting times, possibly inflated by operational delays, were removed from the calculation of W_{q1}, the estimated average would decrease from 4.333 minutes/truck to approximately 1.3 minutes/truck. The problem is the difficulty in determining which queue waiting items have or have not been affected by an operational delay (i.e., which reflect steady-state operations).

In summary, the technique is valid for analyzing Erlang distributed service times. The disadvantage of this model is the same as that of the other theoretical models—it produces only steady-state results that do not account for operational delays. Thus, it will be difficult to use this type of model as a predictive tool. Instead, it should only be used to estimate the queue characteristics resulting from steady-state operations.

Single-Server Model Summary

The mathematical models presented in this section met with limited success for one primary reason: each of the models is unable to account for operational delays. This was the weakness of the cyclic queue model as well. Consequently, the models should only be used to produce steady-state estimates.

The machine repair analogy is the most powerful model of all the models that have been considered. If, however, the machine repair problem does not lend itself to modeling Erlang distributions, the third technique of analyzing finite source queues with Erlang distributions is also very simple and powerful to use. On the other hand, it is suggested that the finite capacity model should only be used for very light traffic, since it appears that the more trucks that are "lost" from the system, the more inaccurate the estimations become.

SUMMARY

This chapter explored several alternatives for modeling port operations—specifically, the queue that forms at the wharf crane. The chapter was divided into three sections representing simulation models, a cyclic queue analysis, and several mathematical models.

First, a very simple simulation model was developed, one that, as a stated goal, could be accurately and easily applied to all data files. However, the results fell short of that goal because the general model did not account for operational delays at the wharf crane. Therefore, a more detailed model was developed that did account for occasional delays, as well as single and double moves. The more detailed model produced results that were more accurate, but they required more effort to calibrate. Then two detailed models were used to consider the effects of pooling the queue at the wharf crane so that a single gang could service two cranes. Although this pooled queue arrangement cannot always be implemented, it was shown that significant improvements in the system's performance are possible. Specifically, the pooled gang probably could be reduced from 12 trucks to 10 trucks or fewer, without reducing the level of service. As an alternative, the waiting time in queue could be reduced from over 7 minutes to approximately 6 minutes (sum of both cranes), with the same number of trucks.

The second section of the chapter explored a technique for manually analyzing the cyclic queue. The advantage of this technique is that each stage can be modeled separately, if the correct information is available, including the modeling of self-service transit stages. A disadvantage of the technique is its inability to model non-exponential distributions and operational delays. Additional techniques were presented that allowed certain stages to be combined, significantly simplifying the analysis.

In the last section of the chapter, three alternative approaches for modeling the wharf crane queue were presented. Modeling analogies were drawn to the machine repair problem, finite capacity model, and a finite source model. The only model requiring exponential assumptions is the finite capacity model. The results using the first two models were compared with the cyclic queue analysis. The machine repair problem approach was significantly better than the finite capacity model. The finite capacity model will provide acceptable results only for very light traffic intensities (say, $r<0.50$). The third alternative that was presented allowed the assumption of non-exponential service times, while manually deriving the balance equations. The technique was applied to the Mar8p.1 data file, but the technique underestimated the field estimate of time in queue. Once again, the reason for the inaccuracy was that the model cannot account for operational delays. In fact, all mathematical models report only steady-state results, a serious limitation. The models are not completely invalid, however, since the steady-state results that were produced could be interpreted as the crane's maximum productivity, if there were no delays. Therefore, the models could be used to provide an optimistic estimate of the number of vehicles that would be needed to maintain a certain level of service.

CHAPTER 6. SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

This chapter summarizes the study findings and makes recommendations for further research on the wharf crane queuing phenomenon. The first section summarizes each major element of the research—the prediction of crane productivity, data collection, data analysis and results, and all wharf crane queuing models. The second section of the chapter proposes several ideas for further research on wharf crane operations.

SUMMARY OF RESEARCH

The overall report presents the analysis of numerous data sets that describe different elements of wharf crane operations. The data were collected from historical crane performance records and extensive field observations.

Historical records from The Port of Houston were made available for the 1989 calendar year. The records included general descriptions of each ship being serviced, in addition to detailed accounts of how many (and what type of) containers were moved to or from the ship while it was berthed. This information was used to develop an econometric model that attempted to predict the net productivity of the wharf crane, a prediction based on ship characteristics and on the distribution of the expected number of container moves between the storage yard and the wharf crane. The resulting model was not strong enough to be used as a forecasting tool, but several variables having a statistically significant influence on the net productivity of the wharf crane were identified. It was shown that the number of outbound container moves, the number of inbound container moves, the type of ship being serviced, the number of ships being serviced simultaneously, and the stevedoring company contracted to service the ship all have a significant influence on crane productivity. The model is site specific for The Port of Houston, Barbours Cut Terminal. However, the same variables would probably have significant effects at other national container ports as well. The linear model was not intended to include all significant variables, but it does include information that should be readily available when ships enter port.

The goal of the remainder of the research was to determine whether exponential distributions adequately describe the interarrival, service, and backcycle processes at the container port. Data were manually collected at The Port of Houston's Barbours Cut Terminal and The Port of New Orleans' France Road Terminal, as well as at two privately operated shipping lines. The data were collected in the form of time-motion studies, recording the specific times a vehicle arrives in queue, begins service, and completes service. The result was a tally of interarrival, service, and backcycle times for a total of over 30 hours of operations. The data was then analyzed using Kolmogorov-Smirnoff tests to determine which theoretical distribution best described the field data.

The results of the Kolmogorov-Smirnoff testing procedure revealed several important trends. First, the interarrival process appears to be accurately modeled with the exponential distribution. Second, it seems that the service process at the wharf gantry crane does not often follow an exponential distribution. The distribution best describing the service process varies from the exponential distribution to the Erlang distribution with a significantly high shape parameter. The specification of the service time distribution is complicated by the unpredictable nature of the distribution. It was also shown that the exponential distribution is not always the appropriate way to describe the backcycle process. These findings are potentially very valuable to the person modeling wharf crane operations because the queuing models and simulation models are driven by these distribution specifications. Most importantly, it is demonstrated that a common assumption should not be made, namely, that the exponential distribution is a service time distribution at the wharf crane—a very common assumption in many queuing applications.

The results of the data collection and analysis were used as a foundation for exploring numerous simulation and mathematical models of wharf crane operations. The collection of time-motion data provided an excellent resource which enabled researchers to compare the results of each model to the field data. The first models developed were simulation models that attempted to provide accurate estimations of the average time in queue for the trucks in the gang. These models proved inappropriate because they did not consider operational delays. The average time in queue estimates were significantly underestimated by the simulation models. Subsequently, more detailed models were created to account for operational delays owing to double moves, hatch cover removals, crane movements, and crane maintenance. The average time in queue was accurately estimated by the detailed models; however, more effort—a very significant amount—was required to calibrate the models.

The detailed models were also used to illustrate the potential benefit of pooling queues from two cranes that are simultaneously servicing the same ship. The pooling of queues can allow as many as three vehicles to be dropped from the system, without decreasing the level of service provided to the wharf cranes. Other benefits that could be derived from pooling queues include an increase in net crane productivity and a significant decrease in the average time in queue at the crane. One disadvantage of the pooled arrangement is that it probably cannot be implemented full time.

The mathematical models that were explored in the report included application of the machine repair problem, finite source queues, finite capacity queues, and cyclic queue analysis techniques. This exploration suggests that the cyclic queue techniques provided the most accurate results; however, they are limited to exponentially based service times at each stage of the queue. The greatest advantage of the technique is its ability to simultaneously model both single server and self-service stages. Methods of simplifying cyclic queues by combining transit stages were also presented.

When using single server queuing models, researchers do not have to make exponential distribution assumptions in order to describe the service or arrival processes. The most accurate results seem to be provided by the machine repair analogy (based on its estimate of the average time in queue and steady-state probabilities), that is, when compared with the cyclic queue model. The finite capacity model seems appropriate only for light traffic conditions.

RECOMMENDATIONS FOR FURTHER RESEARCH

The two most significant contributions of this research effort are as follows: the identification of variables that have statistically significant effects on crane productivity and verification that the exponential distribution does not necessarily provide an accurate description of the service and backcycle processes. Models stemming from these findings can be very valuable, potentially, to port managers since the models provide the tools to predict the number of vehicles needed in a gang or to analyze the effects of various operating strategies on crane productivity.

It was mentioned that the econometric model of wharf crane productivity is not powerful enough to be used as a predictive tool. With expanded data sets, this could be overcome. Specifically, data should be collected from many different container ports. Models would probably be site specific, so the data could not be placed in the original model. Nonetheless, it would be helpful to determine whether the same variables affect crane productivity at all ports. Also, the econometric model could be significantly improved if weather factors and port congestion factors could be integrated into the model. Weather information could perhaps be obtained from the U.S. Weather Service; field measurements may also be required. The effects of port congestion are not as readily defined. Thus, developing ways to quantify and to reduce port congestion caused by the trucks servicing a ship is of the utmost importance.

There are numerous opportunities to continue time-motion studies in the container port. First, a procedure should be developed to safely capture descriptive data of the storage yard operations. This may be possible by using the procedures described in this report or through the use of video equipment. The collection of such data would be valuable to queuing analyses, because it would allow studies of yard crane operations and transit time distributions. These studies, in turn, would lead to the development of more accurate and readily usable models of each stage of the cyclic queue at the container port.

The container port, while conceptually simple, is a very complex system. To operate smoothly, the port must coordinate numerous subsystems that interact directly with one another. Perhaps the interaction of the subsystems provides the most fertile area for further research in container port operations. The research undertaken for this report was an initial effort to explore the operations of the wharf crane—the interface between the ocean side and the land side of the container port. These interactions can be explored in more depth only if data collection efforts are expanded to include a wider variety of ship types, container ports, and container storage techniques. However, the collection of data for simultaneous port operations is critical to improving the procedure.

The importance of container port research is rapidly growing. More general cargo is being transported by containers each year as global competition increases. As a result, container ports are becoming busier and more congested. To provide adequate space for the increased traffic, ports have only two options—they must either expand facilities or improve the efficiency of operations. Because many container ports are becoming land constrained, improving operational efficiency is often the only feasible option. Modeling tools, such as those described in this report, will play a critical role in the improvement of the internal operations of the container port.

APPENDIX A. FIELD DATA

Figure A.1 - Field data for Jan7p.1 data file.

• Crane #3 servicing "FALSTRIA"										
• January 7, 1991									Backcycle	
						elapsed	Inter.	Service	Time, all	time
Event	Truck	HH:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
		13:46:08	0	0	0					
2	952	13:46:09	0	1	1	0:00:01	0:00:00		0:01:08	0:00:00
3	952	13:46:47	0	0	0	0:00:39	0:00:00	0:00:38	0:01:32	
2	53	13:49:46	0	1	1	0:03:38	0:03:37		0:02:12	0:00:00
3	53	13:50:11	0	0	0	0:04:03	0:00:00	0:00:25	0:04:08	
2	50	13:53:03	0	1	1	0:06:55	0:03:17		0:04:27	0:00:00
3	50	13:54:13	0	0	0	0:08:05	0:00:00	0:01:10	0:04:45	
4	0	13:56:37	0	0	0	0:10:29	0:00:00		0:05:25	
5	0	13:59:48	0	0	0	0:13:40	0:00:00		0:05:38	
2	105	14:00:01	0	1	1	0:13:53	0:06:58		0:06:09	0:00:00
3	105	14:00:21	0	0	0	0:14:13	0:00:00	0:00:20	0:06:24	
2	102	14:01:15	0	1	1	0:15:07	0:01:14		0:06:31	0:00:00
1	922	14:01:25	1	1	2	0:15:17	0:00:10		0:06:45	
3	102	14:02:10	1	0	1	0:16:02	0:00:00	0:00:55	0:07:16	
2	922	14:02:45	0	1	1	0:16:37	0:00:00		0:07:23	0:01:20
1	921	14:03:34	1	1	2	0:17:26	0:02:10		0:07:30	
3	922	14:05:14	1	0	1	0:19:06	0:00:00	0:02:29	0:07:31	
2	921	14:05:43	0	1	1	0:19:35	0:00:00		0:07:36	0:02:09
1	952	14:08:26	1	1	2	0:22:18	0:04:51		0:07:37	
1	922	14:09:21	2	1	3	0:23:13	0:00:56		0:08:02	
3	921	14:11:25	2	0	2	0:25:17	0:00:00	0:05:41	0:08:03	
2	953	14:11:46	1	1	2	0:25:38	0:00:00		0:09:05	
1	950	14:12:25	2	1	3	0:26:17	0:03:04		0:09:25	
3	953	14:13:35	2	0	2	0:27:27	0:00:00	0:02:10	0:09:36	
2	952	14:14:03	1	1	2	0:27:55	0:00:00		0:09:49	0:05:38
1	105	14:15:18	2	1	3	0:29:10	0:02:53		0:09:52	
3	952	14:16:33	2	0	2	0:30:25	0:00:00	0:02:58	0:09:53	
2	922	14:16:57	1	1	2	0:30:49	0:00:00		0:09:56	0:07:36
1	953	14:18:03	2	1	3	0:31:55	0:02:45		0:10:04	
2	950	14:18:10	1	2	3	0:32:02	0:00:00		0:10:23	0:05:45
1	102	14:18:41	2	2	4	0:32:33	0:00:39		0:10:39	
3	950	14:19:19	2	1	3	0:33:11	0:00:00	0:02:47	0:10:39	
2	105	14:20:08	1	2	3	0:34:00	0:00:00		0:11:12	0:04:50
3	105	14:21:24	1	1	2	0:35:16	0:00:00	0:02:05	0:14:21	
1	952	14:21:58	2	1	3	0:35:50	0:03:17		0:14:57	
2	102	14:22:12	1	2	3	0:36:04	0:00:00		0:15:05	0:03:31
3	102	14:23:20	1	1	2	0:37:12	0:00:00	0:01:56	0:15:48	
1	950	14:24:05	2	1	3	0:37:57	0:02:07		0:16:03	
3	922	14:25:36	2	0	2	0:39:28	0:00:00	0:02:16	0:16:25	
2	952	14:26:06	1	1	2	0:39:58	0:00:00		0:16:31	0:04:08
3	952	14:27:37	1	0	1	0:41:29	0:00:00	0:02:01	0:16:53	
2	953	14:28:07	0	1	1	0:41:59	0:00:00		0:16:59	0:10:04
1	921	14:29:08	1	1	2	0:43:00	0:05:04		0:18:22	
3	953	14:30:43	1	0	1	0:44:35	0:00:00	0:02:36	0:21:39	
2	921	14:31:13	0	1	1	0:45:05	0:00:00		0:23:48	0:02:05
1	111	14:32:40	1	1	2	0:46:32	0:03:32		0:24:30	
3	921	14:33:00	1	0	1	0:46:52	0:00:00	0:01:47	0:24:51	
2	950	14:33:22	0	1	1	0:47:14	0:00:00		0:28:52	0:09:18
3	950	14:35:22	0	0	0	0:49:14	0:00:00	0:02:00	0:29:17	

Figure A.1 - Field data for Jan7p.1 data file (continued).

• Crane #3 servicing "FALSTRIA"									
• January 7, 1991								Backcycle	
						elapsed	Inter.	Service	Time, all	time
Event	Truck	HH:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
2	111	14:35:52	0	1	1	0:49:44	0:03:12		0:35:03	0:03:12
3	111	14:37:48	0	0	0	0:51:40	0:00:00	0:01:55	0:46:34	
6	0	14:39:31	0	0	0	0:53:23	0:00:00			
7	1	14:40:09	0	0	0	0:54:01	0:00:00			
2	921	14:42:53	0	1	1	0:56:45	0:07:00			0:00:00
1	922	14:43:58	1	1	2	0:57:50	0:01:06			
3	921	14:44:25	1	0	1	0:58:17	0:00:00	0:01:32		
2	922	14:44:37	0	1	1	0:58:29	0:00:00			0:00:39
3	922	14:44:59	0	0	0	0:58:51	0:00:00	0:00:22		
6	1	14:45:16	0	0	0	0:59:08	0:00:00			
2	952	14:45:34	0	1	1	0:59:26	0:01:35			0:00:00
7	1	14:45:36	0	1	1	0:59:28	0:00:00			
1	105	14:46:16	1	1	2	1:00:08	0:00:42			
1	950	14:46:34	2	1	3	1:00:26	0:00:19			
1	953	14:46:47	3	1	4	1:00:39	0:00:12			
3	952	14:47:55	3	0	3	1:01:47	0:00:00	0:02:22		
2	105	14:48:13	2	1	3	1:02:05	0:00:00			0:01:57
3	105	14:48:59	2	0	2	1:02:51	0:00:00	0:01:03		
2	950	14:49:53	1	1	2	1:03:45	0:00:00			0:03:19
3	950	14:50:27	1	0	1	1:04:19	0:00:00	0:01:28		
3	857	14:52:35	1	1	2	1:06:27	0:00:00			
			1	1	2	1:06:27	0:00:00			
3	857	14:54:35	1	1	2	1:08:27	0:00:00			
1	921	14:54:48	2	1	3	1:08:40	0:08:01			
3	857	14:56:06	2	1	3	1:09:58	0:00:00			
3	953	14:58:21	2	1	3	1:12:13	0:00:00			
3	953	14:59:36	2	0	2	1:13:28	0:00:00			
2	921	15:00:20	1	1	2	1:14:12	0:00:00			0:05:32
1	953	15:00:44	2	1	3	1:14:36	0:05:55			
1	922	15:01:53	3	1	4	1:15:45	0:01:09			
3	921	15:03:17	3	0	3	1:17:09	0:00:00	0:03:41		
2	953	15:03:29	2	1	3	1:17:21	0:00:00			0:02:46
3	953	15:04:27	2	0	2	1:18:19	0:00:00	0:01:10		
1	105	15:04:46	3	0	3	1:18:38	0:02:54			
2	922	15:05:25	2	1	3	1:19:17	0:00:00			0:03:32
3	922	15:05:45	2	0	2	1:19:37	0:00:00	0:01:18		
2	105	15:06:00	1	1	2	1:19:52	0:00:00			0:01:14
3	105	15:06:48	1	0	1	1:20:40	0:00:00	0:01:03		
2	950	15:07:21	0	1	1	1:21:13	0:00:00			
3	950	15:08:00	0	0	0	1:21:52	0:00:00	0:00:39		
6	1	15:08:24	0	0	0	1:22:16	0:00:00			
8	1	15:08:39	0	0	0	1:22:31	0:00:00			
2	102	15:09:54	0	1	1	1:23:46	0:05:08			0:00:00
8	2	15:10:46	0	1	1	1:24:38	0:00:00			
1	952	15:11:43	1	1	2	1:25:35	0:01:49			
3	102	15:13:08	1	0	1	1:27:00	0:00:00	0:03:14		
1	921	15:13:13	2	0	2	1:27:05	0:01:29			
2	952	15:13:51	1	1	2	1:27:43	0:00:00			0:02:08
1	953	15:14:31	2	1	3	1:28:23	0:01:19			

Figure A.1 - Field data for Jan7p.1 data file (continued).

• Crane #3 servicing "FALSTRIA"									
• January 7, 1991									
						elapsed	Inter.	Service	Backcycle Time, all	time
Event	Truck	HH:MMSS	Queue	Service	System	time	times	time	Vehicles	in queue
3	952	15:14:33	2	0	2	1:28:25	0:00:00	0:01:25		
2	921	15:14:45	1	1	2	1:28:37	0:00:00			0:01:32
3	921	15:15:41	1	0	1	1:29:33	0:00:00	0:01:08		
2	953	15:16:00	0	1	1	1:29:52	0:00:00			0:01:29
1	105	15:16:37	1	1	2	1:30:29	0:02:05			
3	953	15:16:49	1	0	1	1:30:41	0:00:00	0:00:49		
2	922	15:17:15	0	1	1	1:31:07	0:00:00			
1	950	15:17:52	1	1	2	1:31:44	0:01:15			
3	922	15:19:10	1	1	2	1:33:02	0:00:00			
3	922	15:20:21	1	0	1	1:34:13	0:00:00	0:03:06		
2	105	15:20:34	0	1	1	1:34:26	0:00:00			0:03:58
1	102	15:20:44	1	1	2	1:34:36	0:02:53			
1	952	15:22:04	2	1	3	1:35:56	0:01:20			
3	105	15:27:08	2	0	2	1:41:00	0:00:00	0:06:33		
2	950	15:27:29	1	1	2	1:41:21	0:00:00			0:09:38
1	922	15:27:51	2	1	3	1:41:43	0:05:47			
3	950	15:28:12	2	0	2	1:42:04	0:00:00	0:01:04		
2	102	15:28:34	1	1	2	1:42:26	0:00:00			0:07:50
3	102	15:30:07	1	0	1	1:43:59	0:00:00	0:01:55		
2	952	15:30:30	0	1	1	1:44:22	0:00:00			0:08:26
1	953	15:31:11	1	1	2	1:45:03	0:03:20			
3	952	15:31:50	1	0	1	1:45:42	0:00:00	0:01:20		
2	922	15:32:08	0	1	1	1:46:00	0:00:00			0:04:17
3	922	15:33:05	0	0	0	1:46:57	0:00:00	0:00:57		
2	953	15:33:23	0	1	1	1:47:15	0:02:12			0:02:12
3	953	15:34:11	0	0	0	1:48:03	0:00:00	0:00:49		
6		15:35:14	0	0	0	1:49:06	0:00:00			
7		15:36:40	0	0	0	1:50:32	0:00:00			
2	105	15:36:44	0	1	1	1:50:36	0:03:22			0:00:00
3	105	15:37:08	0	0	0	1:51:00	0:00:00	0:00:24		
2	950	15:37:37	0	1	1	1:51:29	0:00:53			0:00:00
3	950	15:38:07	0	0	0	1:51:59	0:00:00	0:00:30		
2	952	15:39:06	0	1	1	1:52:58	0:01:28			0:00:00
3	952	15:39:27	0	0	0	1:53:19	0:00:00	0:00:21		
2	921	15:40:11	0	1	1	1:54:03	0:01:06			0:00:00
3	921	15:40:45	0	0	0	1:54:37	0:00:00	0:00:34		
2	953	15:41:49	0	1	1	1:55:41	0:01:38			0:00:00
3	953	15:42:07	0	0	0	1:55:59	0:00:00	0:00:18		
6	1	15:43:00	0	0	0	1:56:52	0:00:00			
2	105	15:43:39	0	1	1	1:57:31	0:01:50			0:00:00
3	105	15:44:01	0	0	0	1:57:53	0:00:00	0:00:23		
2	950	15:44:16	0	1	1	1:58:08	0:00:38			0:00:00
3	950	15:45:11	0	0	0	1:59:03	0:00:00	0:00:55		
6	1	15:46:08	0	0	0	2:00:00	0:00:00			
7	1	15:48:03	0	0	0	2:01:55	0:00:00			
2	921	15:48:09	0	1	1	2:02:01	0:03:52			0:00:00
1	953	15:48:31	1	1	2	2:02:23	0:00:23			
3	921	15:48:36	1	0	1	2:02:28	0:00:00	0:00:27		
2	953	15:48:48	0	1	1	2:02:40	0:00:00			0:00:17

Figure A.1 - Field data for Jan7p.1 data file (continued).

• Crane #3 servicing "FALSTRIA"										
• January 7, 1991									Backcycle	
						elapsed	Inter.	Service	Time, all	time
Event	Truck	HH:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
3	953	15:49:42	0	0	0	2:03:34	0:00:00	0:00:54		
6	1	15:50:52	0	0	0	2:04:44	0:00:00			
6	1	15:52:02	0	0	0	2:05:54	0:00:00			
1	105	15:53:06	1	0	1	2:06:58	0:04:35			
1	950	15:53:13	2	0	2	2:07:05	0:00:07			
2	105	15:55:05	1	1	2	2:08:57	0:00:00			0:01:59
3	105	15:55:31	1	0	1	2:09:23	0:00:00	0:05:49		
2	950	15:55:49	0	1	1	2:09:41	0:00:00			0:02:36
3	950	15:56:42	0	0	0	2:10:34	0:00:00	0:00:52		
6	15	15:57:55	0	0	0	2:11:47	0:00:00			
6	1	15:59:20	0	0	0	2:13:12	0:00:00			
7	1	16:02:14	0	0	0	2:16:06	0:00:00			
2	922	16:02:22	0	1	1	2:16:14	0:09:09			0:00:00
3	922	16:02:39	0	0	0	2:16:31	0:00:00	0:00:17		
6	1	16:03:48	0	0	0	2:17:40	0:00:00			
2	953	16:04:47	0	1	1	2:18:39	0:02:25			0:00:00
1	102	16:05:10	1	1	2	2:19:02	0:00:23			
3	953	16:05:13	1	0	1	2:19:05	0:00:00	0:00:26		
2	102	16:05:28	0	1	1	2:19:20	0:00:00			0:00:18
1	921	16:05:34	1	1	2	2:19:26	0:00:25			
3	102	16:06:05	1	0	1	2:19:57	0:00:00	0:00:37		
1	105	16:06:10	2	0	2	2:20:02	0:00:36			
2	921	16:06:22	1	1	2	2:20:14	0:00:00			0:00:48
1	950	16:07:21	2	1	3	2:21:13	0:01:11			
3	921	16:07:42	2	0	2	2:21:34	0:00:00	0:01:36		
2	105	16:07:55	1	1	2	2:21:47	0:00:00			0:01:45
1	952	16:08:18	2	1	3	2:22:10	0:00:57			
3	105	16:10:08	2	0	2	2:24:00	0:00:00	0:02:26		
2	950	16:10:27	1	1	2	2:24:19	0:00:00			0:03:06
1	953	16:10:51	2	1	3	2:24:43	0:02:33			
3	950	16:11:10	2	0	2	2:25:02	0:00:00	0:01:02		
2	952	16:11:31	1	1	2	2:25:23	0:00:00			0:03:12
3	952	16:12:46	1	0	1	2:26:38	0:00:00	0:01:36		
2	953	16:13:11	0	1	1	2:27:03	0:00:00			0:02:19
3	953	16:14:15	0	1	1	2:28:07	0:00:00			
3	953	16:15:16	0	0	0	2:29:08	0:00:00	0:02:05		
1	921	16:15:45	1	0	1	2:29:37	0:04:53			
2	921	16:16:30	0	1	1	2:30:22	0:00:00			
1	952	16:19:32	1	1	2	2:33:24	0:03:47			
3	921	16:19:35	1	0	1	2:33:27	0:00:00	0:03:05		
2	952	16:19:43	0	1	1	2:33:35	0:00:00			
3	952	16:20:23	0	1	1	2:34:15	0:00:00			
3	952	16:21:37	0	0	0	2:35:29	0:00:00	0:01:54		

Figure A.2 - Field data for Jan7p.2 data file.

• Crane #4										
• January 7, 1991										
						Elapsed	Inter	Service	Backcycle Time, all	time
Event	Truck	H:MM:SS	System	Queue	Service	Time	Time	time	Vehicles	in queue
		13:43:57	0	0	0					
1	753	13:43:58	1	1	0	0:00:01	0:00:01		0:05:21	
2	753	13:44:11	1	0	1	0:00:13	0:00:00		0:05:35	0:00:13
1	1096	13:44:25	2	1	1	0:00:14	0:00:27		0:05:40	
3	753	13:44:54	1	1	0	0:00:29	0:00:00	0:00:43	0:08:03	
2	1096	13:45:17	1	0	1	0:00:23	0:00:00		0:08:21	0:00:52
3	1096	13:46:09	0	0	0	0:00:51	0:00:00	0:00:51	0:08:38	
2	1098	13:46:25	1	0	1	0:00:17	0:02:00		0:08:40	0:00:00
3	1098	13:47:06	0	0	0	0:00:41	0:00:00	0:00:41	0:08:47	
2	1094	13:49:09	1	0	1	0:02:03	0:02:44		0:09:15	0:00:00
3	1094	13:49:30	0	0	0	0:00:20	0:00:00	0:00:20	0:10:00	
2	1095	13:55:09	1	0	1	0:05:39	0:06:00		0:10:58	0:00:00
3	1095	13:55:23	0	0	0	0:00:14	0:00:00	0:00:14	0:11:06	
2	753	13:56:40	1	0	1	0:01:17	0:01:31		0:11:13	0:00:00
3	753	13:57:11	0	0	0	0:00:31	0:00:00	0:00:31	0:11:37	
2	1098	13:57:39	1	0	1	0:00:27	0:00:58		0:11:37	0:00:00
3	1098	13:58:29	0	0	0	0:00:50	0:00:00	0:00:50	0:11:39	
2	752	14:00:11	1	0	1	0:01:42	0:02:32		0:12:29	0:00:00
3	752	14:00:51	0	0	0	0:00:41	0:00:00	0:00:41	0:12:30	
2	1094	14:02:16	1	0	1	0:01:24	0:02:05		0:13:06	0:00:00
3	1094	14:02:37	0	0	0	0:00:21	0:00:00	0:00:21	0:13:16	
2	1096	14:03:00	1	0	1	0:00:24	0:00:45		0:13:25	0:00:00
1	1095	14:03:49	2	1	1	0:00:48	0:00:48		0:13:43	
3	1096	14:04:11	1	1	0	0:00:22	0:00:00	0:01:11	0:14:52	
2	1095	14:04:31	1	0	1	0:00:20	0:00:00		0:16:56	0:00:42
1	753	14:04:43	2	1	1	0:00:12	0:00:54		0:17:09	
1	-1	14:04:59	3	2	1	0:00:16	0:00:16		0:17:43	
3	1095	14:05:15	2	2	0	0:00:16	0:00:00	0:00:44		
2	753	14:05:28	2	1	1	0:00:13	0:00:00			0:00:45
1	1098	14:06:25	3	2	1	0:00:57	0:01:26			
3	753	14:06:42	2	2	0	0:00:17	0:00:00	0:01:28		
2	-1	14:07:03	2	1	1	0:00:21	0:00:00			0:02:04
3	-1	14:07:56	1	1	0	0:00:53	0:00:00			
2	1098	14:08:17	1	0	1	0:00:21	0:00:00			0:01:52
1	752	14:08:33	2	1	1	0:00:16	0:02:08			
3	1098	14:08:55	1	1	0	0:00:21	0:00:00	0:00:59		
2	752	14:09:18	1	0	1	0:00:24	0:00:00			0:00:45
3	752	14:10:08	0	0	0	0:00:50	0:00:00	0:00:50		
2	1094	14:10:53	1	0	1	0:00:45	0:02:20			0:00:00
3	1094	14:11:34	0	0	0	0:00:40	0:00:00	0:00:40		
2	1096	14:15:30	1	0	1	0:03:56	0:04:37			0:00:00
1	1095	14:16:08	2	1	1	0:00:38	0:00:38			
1	753	14:19:10	3	2	1	0:03:02	0:03:02			
1	-1	14:19:51	4	3	1	0:00:40	0:00:40			
1	1098	14:19:56	5	4	1	0:00:05	0:00:05			
3	1096	14:20:56	4	4	0	0:01:00	0:00:00	0:05:26		
1	752	14:21:26	5	5	0	0:00:30	0:01:30			
1	1094	14:22:30	6	6	0	0:01:04	0:01:04			
2	1095	14:25:18	6	5	1	0:02:48	0:00:00			0:09:10

Figure A.2 - Field data for Jan7p.2 data file (continued).

• Crane #4										
• January 7, 1991									Backcycle	
						Elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	System	Queue	Service	Time	Time	time	Vehicles	in queue
3	1095	14:26:00	5	5	0	0:00:42	0:00:00	0:05:04		
2	753	14:26:18	5	4	1	0:00:18	0:00:00			0:07:08
1	1096	14:26:28	6	5	1	0:00:10	0:03:58			
3	753	14:27:30	5	5	0	0:01:02	0:00:00	0:01:30		
2	-1	14:27:58	5	4	1	0:00:28	0:00:00			0:08:07
3	-1	14:28:56	4	4	0	0:00:58	0:00:00			
2	1098	14:29:10	4	3	1	0:00:14	0:00:00			0:09:14
3	1098	14:30:02	3	3	0	0:00:51	0:00:00	0:01:06		
2	752	14:30:21	3	2	1	0:00:20	0:00:00			0:08:55
1	1095	14:33:40	4	3	1	0:03:19	0:07:12			
3	752	14:34:12	3	3	0	0:00:32	0:00:00	0:04:10		
2	1094	14:34:40	3	2	1	0:00:28	0:00:00			0:12:09
1	1098	14:34:45	4	3	1	0:00:06	0:01:06			
3	1094	14:35:38	3	3	0	0:00:52	0:00:00	0:01:26		
2	1096	14:35:48	3	2	1	0:00:11	0:00:00			0:09:20
3	1096	14:37:13	2	2	0	0:01:24	0:00:00	0:01:35		
2	1095	14:37:38	2	1	1	0:00:25	0:00:00			0:03:58
1	207	14:38:06	3	2	1	0:00:28	0:03:20			
3	1095	14:38:23	2	2	0	0:00:17	0:00:00	0:01:10		
2	1098	14:38:50	2	1	1	0:00:27	0:00:00			0:04:05
1	753	14:39:43	3	2	1	0:00:53	0:01:37			
3	1098	14:39:48	2	2	0	0:00:05	0:00:00	0:01:25		
2	207	14:40:04	2	1	1	0:00:16	0:00:00			0:01:58
1	752	14:41:16	3	2	1	0:01:12	0:01:32			
3	207	14:41:44	2	2	0	0:00:29	0:00:00	0:01:56		
2	753	14:42:11	2	1	1	0:00:26	0:00:00			0:02:27
3	753	14:43:25	1	1	0	0:01:14	0:00:00	0:01:41		
2	752	14:43:41	1	0	1	0:00:16	0:00:00			0:02:26
1	1094	14:43:55	2	1	1	0:00:14	0:02:39			
1	1098	14:44:11	3	2	1	0:00:16	0:00:16			
3	752	14:44:39	2	2	0	0:00:29	0:00:00	0:00:58		
2	1094	14:44:57	2	1	1	0:00:17	0:00:00			0:01:02
1	207	14:45:44	3	2	1	0:00:47	0:01:33			
3	1094	14:46:12	2	2	0	0:00:28	0:00:00	0:01:32		
2	1098	14:46:26	2	1	1	0:00:15	0:00:00			0:02:16
1	1096	14:46:54	3	2	1	0:00:28	0:01:11			
3	1098	14:47:22	2	2	0	0:00:28	0:00:00	0:01:11		
1	1095	14:47:38	3	3	0	0:00:16	0:00:44			
2	207	14:47:47	3	2	1	0:00:09	0:00:00			0:02:04
3	207	14:48:21	2	2	0	0:00:33	0:00:00	0:00:59		
2	1096	14:48:32	2	1	1	0:00:11	0:00:00			0:01:38
3	1096	14:49:51	1	1	0	0:01:19	0:00:00	0:01:30		
2	1095	14:50:17	1	0	1	0:00:27	0:00:00			0:02:39
3	1095	14:51:40	0	0	0	0:01:23	0:00:00	0:01:23		
2	753	14:55:27	1	0	1	0:03:47	0:07:49			0:00:00
3	753	14:55:50	0	0	0	0:00:23	0:00:00	0:00:23		
2	752	14:57:52	1	0	1	0:02:02	0:02:25			0:00:00
3	752	14:58:15	0	0	0	0:00:23	0:00:00	0:00:23		
2	1094	14:59:49	1	0	1	0:01:34	0:01:57			0:00:00

Figure A.2 - Field data for Jan7p.2 data file (continued).

• Crane #4										
• January 7, 1991									Backcycle	
						Elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	System	Queue	Service	Time	Time	time	Vehicles	in queue
3	1094	15:00:04	0	0	0	0:00:15	0:00:00	0:00:15		
2	1098	15:03:22	1	0	1	0:03:18	0:03:33			0:00:00
3	1098	15:04:20	0	0	0	0:00:58	0:00:00	0:00:58		
2	207	15:04:56	1	0	1	0:00:36	0:01:34			0:00:00
3	207	15:05:24	0	0	0	0:00:28	0:00:00	0:00:28		

Figure A.3 - Field data for Feb11a.1 data file.

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Inter	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles
			0	0	0				
2	919	8:51:07	0	1	1	0:00:00	0:00:00		0:03:00
1	8315	8:52:08	1	1	2	0:01:00	0:01:00		0:03:20
1	1104	8:52:32	2	1	3	0:00:25	0:00:25		0:03:32
3	919	8:52:42	2	0	2	0:00:10	0:00:00	0:01:35	0:03:39
2	1102	8:53:13	1	1	2	0:00:31	0:00:00		0:03:45
1	1106	8:53:37	2	1	3	0:00:24	0:01:04		0:03:50
3	1102	8:54:13	2	0	2	0:00:37	0:00:00	0:01:31	0:03:51
2	1104	8:54:23	1	1	2	0:00:10	0:00:00		0:04:00
3	1104	8:55:38	1	0	1	0:01:15	0:00:00	0:01:24	0:04:03
2	1106	8:56:16	0	1	1	0:00:38	0:00:00		0:04:09
1	3568	8:56:23	1	1	2	0:00:08	0:02:47		0:04:11
1	919	8:57:03	2	1	3	0:00:40	0:00:40		0:04:11
3	1106	8:57:12	2	0	2	0:00:09	0:00:00	0:00:57	0:04:12
2	3568	8:57:30	1	1	2	0:00:18	0:00:00		0:04:17
1	8315	8:57:38	2	1	3	0:00:07	0:00:34		0:04:17
1	1104	8:58:38	3	1	4	0:01:00	0:01:00		0:04:21
3	3568	8:58:57	3	0	3	0:00:19	0:00:00	0:01:44	0:04:26
2	919	8:59:11	2	1	3	0:00:15	0:00:00		0:04:30
3	919	9:00:31	2	0	2	0:01:20	0:00:00	0:01:35	0:04:31
2	8315	9:00:47	1	1	2	0:00:16	0:00:00		0:04:40
1	1106	9:01:02	2	1	3	0:00:15	0:02:25		0:04:57
3	8315	9:01:31	2	0	2	0:00:29	0:00:00	0:01:00	0:04:57
2	1104	9:02:02	1	1	2	0:00:32	0:00:00		0:06:05
1	8315	9:02:43	2	1	3	0:00:41	0:01:41		0:06:29
3	1104	9:02:52	2	0	2	0:00:09	0:00:00	0:01:21	0:06:34
2	1106	9:03:05	1	1	2	0:00:13	0:00:00		0:06:36
3	1106	9:04:06	1	0	1	0:01:01	0:00:00	0:01:14	0:06:40
2	919	9:05:45	0	1	1	0:01:39	0:00:00		0:06:52
3	919	9:06:13	0	0	0	0:00:27	0:00:00	0:00:27	0:06:54
2	1104	9:06:37	0	1	1	0:00:25	0:03:54		0:07:01
3	1104	9:07:47	0	0	0	0:01:09	0:00:00	0:01:09	0:07:21
999	1106	9:08:10	0	0	0	0:00:23	0:00:00		0:07:36
2	8315	9:08:19	0	1	1	0:00:10	0:01:42		0:07:44
1	3568	9:08:54	1	1	2	0:00:35	0:00:35		0:10:53
1	1106	9:09:03	2	1	3	0:00:09	0:00:09		
2	3568	9:09:03	1	2	3	0:00:00	0:00:00		
3	3568	9:10:13	1	1	2	0:01:10	0:00:00		
1	1104	9:11:38	2	1	3	0:01:25	0:02:35		
3	8315	9:12:25	2	0	2	0:00:47	0:00:00	0:02:12	
2	1106	9:12:47	1	1	2	0:00:22	0:00:00		
1	919	9:13:34	2	1	3	0:00:47	0:01:56		
3	1106	9:14:26	2	0	2	0:00:52	0:00:00	0:02:01	
2	1104	9:14:45	1	1	2	0:00:19	0:00:00		
3	1104	9:16:47	1	0	1	0:02:02	0:00:00	0:02:21	
2	919	9:17:13	0	1	1	0:00:26	0:00:00		
1	1106	9:18:05	1	1	2	0:00:52	0:04:31		
3	919	9:18:10	1	0	1	0:00:05	0:00:00	0:00:56	
2	1106	9:18:22	0	1	1	0:00:12	0:00:00		

Figure A.3 - Field data for Feb11a.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Inter	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles
1	1103	9:19:38	1	1	2	0:01:16	0:01:33		
3	1106	9:19:47	1	0	1	0:00:08	0:00:00	0:01:25	
2	1103	9:19:59	0	1	1	0:00:12	0:00:00		
1	1104	9:20:47	1	1	2	0:00:48	0:01:09		
3	1103	9:21:49	1	0	1	0:01:02	0:00:00	0:01:50	
2	1104	9:22:03	0	1	1	0:00:14	0:00:00		
1	919	9:22:22	1	1	2	0:00:19	0:01:35		
1	1106	9:23:06	2	1	3	0:00:44	0:00:44		
3	1104	9:24:03	2	0	2	0:00:57	0:00:00	0:02:01	
2	919	9:24:23	1	1	2	0:00:19	0:00:00		
3	919	9:25:56	1	0	1	0:01:33	0:00:00	0:01:53	
1	1103	9:26:00	2	0	2	0:00:04	0:02:53		
2	1106	9:26:18	1	1	2	0:00:18	0:00:00		
3	1106	9:27:59	1	0	1	0:01:41	0:00:00	0:02:03	
2	1103	9:28:29	0	1	1	0:00:29	0:00:00		
1	1104	9:30:09	1	1	2	0:01:40	0:04:09		
3	1103	9:30:20	1	0	1	0:00:11	0:00:00	0:01:51	
2	1104	9:30:32	0	1	1	0:00:13	0:00:00		
1	804	9:30:45	1	1	2	0:00:13	0:00:37		
3	1104	9:32:16	1	0	1	0:01:30	0:00:00	0:01:43	
2	804	9:32:45	0	1	1	0:00:29	0:00:00		
3	804	9:33:54	0	0	0	0:01:09	0:00:00	0:01:09	
6.1	111	9:35:22	0	0	0	0:01:28	0:00:00		
2	1106	9:35:36	0	1	1	0:00:13	0:04:50		
7.1	111	9:35:44	0	1	1	0:00:09	0:00:00		
3	1106	9:35:59	0	0	0	0:00:15	0:00:00	0:00:24	
2	919	9:36:49	0	1	1	0:00:50	0:01:14		
1	1103	9:38:04	1	1	2	0:01:14	0:01:14		
3	919	9:38:30	1	0	1	0:00:27	0:00:00	0:01:41	
2	1103	9:38:50	0	1	1	0:00:19	0:00:00		
1	1104	9:39:09	1	1	2	0:00:20	0:01:06		
3	1103	9:40:18	1	0	1	0:01:09	0:00:00	0:01:29	
1	804	9:40:23	2	0	2	0:00:05	0:01:14		
2	1104	9:40:31	1	1	2	0:00:07	0:00:00		
3	1104	9:42:01	1	0	1	0:01:30	0:00:00	0:01:42	
2	804	9:42:25	0	1	1	0:00:24	0:00:00		
1	1106	9:42:33	1	1	2	0:00:08	0:02:10		
3	804	9:43:55	1	0	1	0:01:22	0:00:00	0:01:31	
2	1106	9:44:05	0	1	1	0:00:10	0:00:00		
4	111	9:44:18	0	1	1	0:00:13	0:00:00		
5	111	9:45:02	0	1	1	0:00:44	0:00:00		
1	919	9:45:06	1	1	2	0:00:04	0:02:33		
6	111	9:46:07	1	1	2	0:01:01	0:00:00		
7	111	9:46:31	1	1	2	0:00:24	0:00:00		
1	1103	9:47:11	2	1	3	0:00:40	0:02:05		
3	1106	9:48:06	2	0	2	0:00:55	0:00:00	0:04:01	
2	919	9:48:23	1	1	2	0:00:17	0:00:00		
1	1104	9:49:02	2	1	3	0:00:39	0:01:52		
3	919	9:49:50	2	0	2	0:00:47	0:00:00	0:01:44	

Figure A.3 - Field data for Feb11a.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Inter	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles
2	1103	9:50:10	1	1	2	0:00:20	0:00:00		
1	804	9:50:35	2	1	3	0:00:26	0:01:33		
3	1103	9:51:48	2	0	2	0:01:13	0:00:00	0:01:58	
2	1104	9:52:01	1	1	2	0:00:13	0:00:00		
1	1106	9:52:32	2	1	3	0:00:32	0:01:57		
3	1104	9:53:21	2	0	2	0:00:48	0:00:00	0:01:33	
2	804	9:53:49	1	1	2	0:00:29	0:00:00		
1	919	9:54:46	2	1	3	0:00:57	0:02:14		
3	804	9:55:08	2	0	2	0:00:22	0:00:00	0:01:47	
2	1106	9:55:37	1	1	2	0:00:29	0:00:00		
1	1103	9:55:59	2	1	3	0:00:21	0:01:13		
3	1106	9:56:48	2	0	2	0:00:49	0:00:00	0:01:40	
2	919	9:57:03	1	1	2	0:00:15	0:00:00		
1	1104	9:57:51	2	1	3	0:00:49	0:01:52		
3	919	9:58:32	2	0	2	0:00:41	0:00:00	0:01:44	
2	1103	9:59:05	1	1	2	0:00:33	0:00:00		
1	804	9:59:38	2	1	3	0:00:34	0:01:47		
3	1103	10:00:18	2	0	2	0:00:40	0:00:00	0:01:46	
2	1104	10:00:30	1	1	2	0:00:12	0:00:00		
1	1106	10:00:51	2	1	3	0:00:21	0:01:12		
3	1104	10:01:55	2	0	2	0:01:05	0:00:00	0:01:37	
2	804	10:02:07	1	1	2	0:00:11	0:00:00		
1	919	10:02:49	2	1	3	0:00:43	0:01:58		
3	804	10:03:47	2	0	2	0:00:58	0:00:00	0:01:52	
2.1	1106	10:04:00	2	0	2	0:00:13	0:00:00		
2	1106	10:04:08	1	1	2	0:00:08	0:00:00		
1	1103	10:04:28	2	1	3	0:00:20	0:01:39		
1	1104	10:05:28	3	1	4	0:01:00	0:01:00		
3	1106	10:07:11	3	0	3	0:01:43	0:00:00	0:03:23	
2.1	919	10:07:20	3	0	3	0:00:09	0:00:00		
2	919	10:07:38	2	1	3	0:00:18	0:00:00		
1	804	10:08:27	3	1	4	0:00:50	0:03:00		
3	919	10:09:30	3	0	3	0:01:03	0:00:00	0:02:20	
2.1	1103	10:09:41	3	0	3	0:00:11	0:00:00		
2	1103	10:09:53	2	1	3	0:00:12	0:00:00		
1	1106	10:11:27	3	1	4	0:01:35	0:03:00		
4	111	10:11:49	3	1	4	0:00:22	0:00:00		
5	111	10:12:03	3	1	4	0:00:14	0:00:00		
3	1103	10:13:14	3	0	3	0:01:12	0:00:00	0:03:44	
999	1104	10:13:42	3	0	3	0:00:28	0:00:00		

Figure A.4 - Field data for Feb11a.2 data file.

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #4 servicing "BONN EXPRESS"										
2	• February 11, 1991									Backcycle	
3							elapsed	Inter	Service	Time, all	time
4	Event	Truck	H:MM:SS	Queue	Service	System	time	Time	Time	Vehicles	in queue
5				0	1	1					
6	3	1108	10:28:17	0	0	0	0:00:00	0:00:00		0:03:03	
7	6.1	111	10:29:04	0	0	0	0:00:47	0:00:00		0:03:32	
8	7.1	111	10:32:27	0	0	0	0:03:23	0:00:00		0:03:43	
9	8	2354	10:32:38	0	0	0	0:00:12	0:00:00		0:03:50	
10	2	222	10:34:34	0	1	1	0:01:56	0:06:17		0:04:15	0:00:00
11	3	222	10:35:04	0	0	0	0:00:30	0:00:00	0:00:30	0:04:27	
12	6.1	111	10:36:20	0	0	0	0:01:15	0:00:00		0:04:31	
13	2	222	10:36:45	0	1	1	0:00:25	0:02:11		0:04:39	0:00:00
14	3	222	10:37:23	0	0	0	0:00:38	0:00:00	0:00:38	0:04:42	
15	6.1	11	10:37:51	0	0	0	0:00:28	0:00:00		0:04:47	
16	2	8563	10:40:23	0	1	1	0:02:32	0:03:38		0:04:55	0:00:00
17	7.1	111	10:40:27	0	1	1	0:00:04	0:00:00		0:04:57	
18	3	8563	10:40:56	0	0	0	0:00:29	0:00:00	0:00:33	0:05:09	
19	6.1	111	10:42:03	0	0	0	0:01:07	0:00:00		0:05:36	
20	7.1	111	10:42:26	0	0	0	0:00:23	0:00:00		0:06:17	
21	2	952	10:42:52	0	1	1	0:00:26	0:02:29		0:07:24	0:00:00
22	3	952	10:44:00	0	0	0	0:01:08	0:00:00	0:01:08	0:09:19	
23	2	865	10:44:13	0	1	1	0:00:13	0:01:20		0:17:37	0:00:00
24	1	1109	10:44:24	1	1	2	0:00:11	0:00:11		0:24:31	
25	3	865	10:45:16	1	0	1	0:00:53	0:00:00	0:01:04	0:33:32	
26	2	1109	10:45:29	0	1	1	0:00:12	0:00:00		0:40:01	0:00:00
27	3	1109	10:46:40	0	0	0	0:01:11	0:00:00	0:01:11		
28	6.1	111	10:47:35	0	0	0	0:00:55	0:00:00			
29	7.1	111	10:48:48	0	0	0	0:01:13	0:00:00			
30	2	225	10:49:04	0	1	1	0:00:15	0:04:40			0:00:00
31	3	225	10:50:10	0	0	0	0:01:06	0:00:00	0:01:06		
32	6.1	111	10:50:45	0	0	0	0:00:35	0:00:00			
33	7.1	111	10:51:10	0	0	0	0:00:25	0:00:00			
34	2	1867	10:51:19	0	1	1	0:00:09	0:02:15			0:00:00
35	3	1867	10:52:51	0	0	0	0:01:31	0:00:00	0:01:31		
36	2	923	10:53:43	0	1	1	0:00:53	0:02:24			0:00:00
37	1	227	10:54:29	1	1	2	0:00:46	0:00:46			
38	3	923	10:57:17	1	0	1	0:02:48	0:00:00	0:03:34		
39	8	227	10:58:32	1	0	1	0:01:14	0:00:00			
40	2	227	10:59:04	0	1	1	0:00:33	0:00:00			0:04:35
41	1	4483	11:00:33	1	1	2	0:01:29	0:06:04			
42	3	227	11:00:39	1	0	1	0:00:06	0:00:00	0:01:35		
43	2	4483	11:00:44	0	1	1	0:00:05	0:00:00			0:00:11
44	2	226	11:00:58	0	2	2	0:00:14	0:00:25			0:00:00
45	1	952	11:01:37	1	2	3	0:00:39	0:00:39			
46	3	226	11:01:44	1	1	2	0:00:07	0:00:00	0:00:46		
47	3	4483	11:01:50	1	0	1	0:00:06	0:00:00	0:01:06		
48	2	952	11:03:47	0	1	1	0:01:57	0:00:00			0:02:11
49	3	952	11:05:14	0	0	0	0:01:27	0:00:00	0:01:27		
50	2	1108	11:08:17	0	1	1	0:03:03	0:06:41			0:00:00
51	3	1108	11:08:39	0	0	0	0:00:21	0:00:00	0:00:21		
52	6.1	111	11:10:04	0	0	0	0:01:25	0:00:00			

Figure A.4 - Field data for Feb11a.2 data file (continued).

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #4 servicing "BONN EXPRESS"										
2	• February 11, 1991									Backcycle	
3							elapsed	Inter	Service	Time, all	time
4	Event	Truck	H:MMSS	Queue	Service	System	time	Time	Time	Vehicles	in queue
53	2	125	11:10:39	0	1	1	0:00:35	0:02:22			0:00:00
54	7.1	111	11:11:25	0	1	1	0:00:46	0:00:00			
55	2	952	11:12:39	0	2	2	0:01:14	0:02:00			0:00:00
56	3	952	11:12:59	0	1	1	0:00:20	0:00:00	0:00:20		
57	3	125	11:13:53	0	0	0	0:00:55	0:00:00	0:03:14		
58	1	101	11:14:51	1	0	1	0:00:58	0:02:13			
59	1	1108	11:14:56	2	0	2	0:00:04	0:00:04			
60	999	101	11:15:24	2	0	2	0:00:29	0:00:00			
61	2	101	11:15:46	1	1	2	0:00:22	0:00:00			0:00:55
62	3	101	11:16:58	1	0	1	0:01:12	0:00:00	0:03:05		
63	2	1108	11:17:26	0	1	1	0:00:27	0:00:00			0:02:30
64	1	952	11:17:41	1	1	2	0:00:15	0:02:45			
65	3	1108	11:17:51	1	0	1	0:00:10	0:00:00	0:00:25		
66	2	952	11:18:15	0	1	1	0:00:24	0:00:00			0:00:34
67	3	952	11:19:03	0	0	0	0:00:48	0:00:00	0:00:48		
68	6.1	111	11:19:56	0	0	0	0:00:53	0:00:00			
69	2	1109	11:20:12	0	1	1	0:00:16	0:02:31			0:00:00
70	7.1	111	11:20:16	0	1	1	0:00:04	0:00:00			
71	3	1109	11:20:37	0	0	0	0:00:21	0:00:00	0:00:26		
72	2	1108	11:20:54	0	1	1	0:00:16	0:00:42			0:00:00
73	1	923	11:21:49	1	1	2	0:00:55	0:00:55			
74	3	1108	11:21:53	1	0	1	0:00:04	0:00:00	0:00:59		
75	2	923	11:22:03	0	1	1	0:00:10	0:00:00			0:00:14
76	3	923	11:23:08	0	0	0	0:01:04	0:00:00	0:01:04		
77	2	952	11:23:30	0	1	1	0:00:23	0:01:41			0:00:00
78	1	7451	11:25:19	1	1	2	0:01:49	0:01:49			
79	1	1109	11:25:33	2	1	3	0:00:14	0:00:14			
80	1	1108	11:27:29	3	1	4	0:01:57	0:01:57			
81	2	7451	11:29:10	2	2	4	0:01:41	0:00:00			0:03:51
82	3	7451	11:29:48	2	1	3	0:00:38	0:00:00	0:00:38		
83	3	952	11:30:56	2	0	2	0:01:08	0:00:00			
84	2	1109	11:31:24	1	1	2	0:00:28	0:00:00			0:05:51
85	3	1109	11:31:58	1	0	1	0:00:34	0:00:00	0:01:02		
86	2	923	11:32:15	0	1	1	0:00:17	0:00:00			
87	1	1108	11:32:39	1	1	2	0:00:23	0:05:09			
88	3	923	11:33:39	1	0	1	0:01:00	0:00:00	0:01:23		
89	2	1108	11:33:49	0	1	1	0:00:10	0:00:00			0:01:10
90	1	952	11:34:39	1	1	2	0:00:50	0:02:00			
91	3	1108	11:34:48	1	0	1	0:00:09	0:00:00	0:00:59		
92	2	952	11:35:02	0	1	1	0:00:14	0:00:00			0:00:24
93	3	952	11:36:09	0	0	0	0:01:07	0:00:00	0:01:07		
94	2	8160	11:36:43	0	1	1	0:00:34	0:02:04			0:00:00
95	3	8160	11:37:37	0	0	0	0:00:54	0:00:00	0:00:54		
96	2	923	11:37:54	0	1	1	0:00:16	0:01:11			0:00:00
97	1	1108	11:39:19	1	1	2	0:01:25	0:01:25			
98	3	923	11:39:24	1	0	1	0:00:04	0:00:00	0:01:30		
99	2	1108	11:39:30	0	1	1	0:00:07	0:00:00			0:00:11
100	1	952	11:40:48	1	1	2	0:01:18	0:01:29			

Figure A.4 - Field data for Feb11a.2 data file (continued).

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #4 servicing "BONN EXPRESS"										
2	• February 11, 1991										
3							elapsed	Inter	Service	Backcycle Time, all	time
4	Event	Truck	H:MMSS	Queue	Service	System	time	Time	Time	Vehicles	in queue
101	3	1108	11:41:00	1	0	1	0:00:12	0:00:00	0:01:30		
102	2	952	11:41:04	0	1	1	0:00:04	0:00:00			0:00:16
103	1	1109	11:41:17	1	1	2	0:00:12	0:00:28			
104	3	952	11:41:39	1	0	1	0:00:22	0:00:00	0:00:34		
105	2	1109	11:41:48	0	1	1	0:00:10	0:00:00			0:00:32
106	3	1109	11:42:42	0	0	0	0:00:54	0:00:00	0:00:54		
107	2	923	11:43:13	0	1	1	0:00:31	0:01:57			0:00:00
108	3	923	11:44:06	0	0	0	0:00:53	0:00:00	0:00:53		
109	2	1108	11:44:33	0	1	1	0:00:26	0:01:19			0:00:00
110	3	1108	11:45:51	0	0	0	0:01:19	0:00:00	0:01:19		
111	2	952	11:46:25	0	1	1	0:00:34	0:01:53			0:00:00
112	3	952	11:47:00	0	0	0	0:00:35	0:00:00	0:00:35		
113	2	1109	11:47:39	0	1	1	0:00:39	0:01:14			0:00:00
114	3	1109	11:48:12	0	0	0	0:00:32	0:00:00	0:00:32		
115	6.1	111	11:49:07	0	0	0	0:00:56	0:00:00			
116	7.1	111	11:50:13	0	0	0	0:01:06	0:00:00			
117	2	7635	11:50:24	0	1	1	0:00:11	0:02:45			0:00:00
118	3	7635	11:51:58	0	0	0	0:01:34	0:00:00	0:01:34		
119	6	111	11:52:14	0	0	0	0:00:16	0:00:00			

Figure A.5 - Field data for Feb11p.1 data file.

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Interarr	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
			1	1	2				
999	2578	13:51:57	1	1	2	0:00:00	0:00:00		0:02:25
999	-1	13:52:07	1	1	2	0:00:09	0:00:00		0:04:35
999	205	13:52:14	1	1	2	0:00:07	0:00:00		0:04:42
999	804	13:52:25	1	1	2	0:00:11	0:00:00		0:04:55
999	2578	13:53:44	1	1	2	0:01:19	0:00:00		0:05:01
999	2578	13:55:22	1	1	2	0:01:39	0:00:00		0:05:15
999	804	13:55:40	1	1	2	0:00:18	0:00:00		0:05:24
999	1104	13:56:23	1	1	2	0:00:43	0:00:00		0:05:26
2	1103	13:57:26	1	1	2	0:01:03	0:00:00		0:05:32
3	1103	13:58:27	1	0	1	0:01:02	0:00:00	0:01:02	0:05:56
2	1106	13:58:51	0	1	1	0:00:23	0:00:00		0:06:06
3.1	1106	14:00:02	0	0	0	0:01:11	0:00:00	0:01:11	0:06:18
6.1	111	14:01:01	0	0	0	0:00:59	0:00:00		0:06:20
7.1	111	14:02:34	0	0	0	0:01:33	0:00:00		0:06:26
2	804	14:02:39	0	1	1	0:00:05	0:10:41		0:06:42
3	804	14:02:56	0	0	0	0:00:17	0:00:00	0:00:17	0:06:43
2	804	14:03:39	0	1	1	0:00:43	0:01:00		0:06:46
6.1	111	14:04:02	0	1	1	0:00:23	0:00:00		0:06:53
12	1103	14:04:49	0	1	1	0:00:47	0:00:00		0:06:54
3.2	804	14:04:56	0	0	0	0:00:07	0:00:00	0:01:18	0:06:56
2	1103	14:05:20	0	1	1	0:00:24	0:01:42		0:07:08
3.1	1103	14:06:03	0	0	0	0:00:43	0:00:00	0:00:43	0:09:08
2	1106	14:06:40	0	1	1	0:00:37	0:01:20		0:09:14
3.1	1106	14:07:52	0	0	0	0:01:11	0:00:00	0:01:11	0:09:21
2	919	14:08:55	0	1	1	0:01:04	0:02:15		0:09:21
3.1	919	14:09:18	0	0	0	0:00:22	0:00:00	0:00:22	0:09:36
6.1	111	14:10:38	0	0	0	0:01:20	0:00:00		0:09:45
2	1104	14:10:53	0	1	1	0:00:15	0:01:58		0:09:53
7.1	111	14:10:57	0	1	1	0:00:04	0:00:00		0:10:02
3.1	1104	14:11:16	0	0	0	0:00:19	0:00:00	0:00:23	0:10:11
6.1	111	14:13:05	0	0	0	0:01:49	0:00:00		0:10:13
7.1	111	14:14:09	0	0	0	0:01:03	0:00:00		0:10:21
2	804	14:14:14	0	1	1	0:00:05	0:03:21		0:10:29
1	1103	14:14:34	1	1	2	0:00:20	0:00:20		0:10:36
3.1	804	14:14:38	1	0	1	0:00:04	0:00:00	0:00:24	0:10:47
2	1103	14:14:58	0	1	1	0:00:21	0:00:00		0:10:47
3.1	1103	14:15:38	0	1	1	0:00:39	0:00:00		0:11:19
1	1106	14:16:25	1	1	2	0:00:48	0:01:51		0:11:20
3.2	1103	14:16:51	1	0	1	0:00:25	0:00:00	0:01:52	0:11:34
2	1106	14:17:04	0	1	1	0:00:14	0:00:00		0:11:36
3.1	1106	14:17:52	0	1	1	0:00:48	0:00:00		0:11:40
1	919	14:18:16	1	1	2	0:00:24	0:01:50		0:11:58
3.2	1106	14:19:23	1	0	1	0:01:07	0:00:00	0:02:19	0:12:07
2	919	14:19:50	0	1	1	0:00:27	0:00:00		0:12:31
1	1104	14:20:01	1	1	2	0:00:10	0:01:45		0:12:41
3.1	919	14:20:39	1	1	2	0:00:39	0:00:00		0:12:49
3.2	919	14:21:39	1	0	1	0:01:00	0:00:00	0:01:49	0:12:57
2	1104	14:21:48	0	1	1	0:00:09	0:00:00		0:13:02

Figure A.5 - Field data for Feb11p.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Interarr	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
3.1	1104	14:22:40	0	1	1	0:00:52	0:00:00		0:13:04
3.2	1104	14:23:54	0	0	0	0:01:13	0:00:00	0:02:05	0:13:46
1	1103	14:23:55	1	0	1	0:00:01	0:03:54		0:13:58
2	1103	14:24:08	0	1	1	0:00:13	0:00:00		0:14:45
3.1	1103	14:25:03	0	1	1	0:00:56	0:00:00		0:20:04
1	804	14:25:33	1	1	2	0:00:29	0:01:38		0:20:19
3.2	1103	14:26:27	1	0	1	0:00:54	0:00:00	0:02:20	0:20:52
2	804	14:27:17	0	1	1	0:00:49	0:00:00		0:21:12
3.1	804	14:27:55	0	1	1	0:00:38	0:00:00		0:23:32
1	1106	14:28:05	1	1	2	0:00:10	0:02:32		0:26:13
3.2	804	14:28:55	1	0	1	0:00:50	0:00:00	0:01:38	0:26:26
2	1106	14:29:25	0	1	1	0:00:30	0:00:00		0:32:51
3.1	1106	14:29:53	0	1	1	0:00:28	0:00:00		0:38:37
1	1104	14:30:02	1	1	2	0:00:09	0:01:57		0:43:14
3.2	1106	14:30:55	1	0	1	0:00:53	0:00:00	0:01:30	
2	1104	14:31:04	0	1	1	0:00:09	0:00:00		
3.1	1104	14:31:56	0	1	1	0:00:52	0:00:00		
1	919	14:33:01	1	1	2	0:01:04	0:02:58		
3.2	1104	14:33:13	1	0	1	0:00:13	0:00:00	0:02:09	
2	919	14:33:27	0	1	1	0:00:14	0:00:00		
3.1	919	14:34:45	0	1	1	0:01:18	0:00:00		
4	111	14:35:02	0	1	1	0:00:17	0:00:00		
5	111	14:35:10	0	1	1	0:00:08	0:00:00		
1	1103	14:35:31	1	1	2	0:00:21	0:02:30		
3.2	919	14:36:32	1	0	1	0:01:01	0:00:00	0:03:05	
2	1103	14:36:51	0	1	1	0:00:19	0:00:00		
1	804	14:37:30	1	1	2	0:00:40	0:01:59		
3.1	1103	14:37:52	1	1	2	0:00:21	0:00:00		
1	1106	14:38:52	2	1	3	0:01:00	0:01:21		
3.2	1103	14:39:06	2	0	2	0:00:14	0:00:00	0:02:16	
2	804	14:39:22	1	1	2	0:00:16	0:00:00		
3.1	804	14:40:04	1	1	2	0:00:42	0:00:00		
3.2	804	14:40:59	1	0	1	0:00:55	0:00:00	0:01:53	
2	1106	14:41:20	0	1	1	0:00:22	0:00:00		
3.1	1106	14:42:16	0	1	1	0:00:56	0:00:00		
1	1104	14:42:43	1	1	2	0:00:28	0:03:52		
1	919	14:43:13	2	1	3	0:00:30	0:00:30		
3.2	1106	14:43:32	2	0	2	0:00:19	0:00:00	0:02:12	
2	1104	14:43:49	1	1	2	0:00:17	0:00:00		
3.1	1104	14:44:36	1	1	2	0:00:46	0:00:00		
3.2	1104	14:45:57	1	0	1	0:01:21	0:00:00	0:02:24	
2	919	14:46:15	0	1	1	0:00:18	0:00:00		
3.1	919	14:47:14	0	0	0	0:01:00	0:00:00	0:01:00	
6.1	111	14:48:17	0	0	0	0:01:02	0:00:00		
7.1	111	14:48:24	0	0	0	0:00:07	0:00:00		
2	1103	14:48:28	0	1	1	0:00:04	0:05:15		
3.1	1103	14:48:46	0	0	0	0:00:18	0:00:00	0:00:18	
2	804	14:49:04	0	1	1	0:00:18	0:00:36		
3.1	804	14:49:48	0	0	0	0:00:44	0:00:00	0:00:44	

Figure A.5 - Field data for Feb11p.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Interarr	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
6.1	111	14:50:54	0	0	0	0:01:06	0:00:00		
7.1	111	14:51:14	0	0	0	0:00:20	0:00:00		
2	1106	14:51:23	0	1	1	0:00:08	0:02:19		
3.1	1106	14:51:36	0	0	0	0:00:13	0:00:00	0:00:13	
6.1	111	14:52:47	0	0	0	0:01:11	0:00:00		
7.1	111	14:53:57	0	0	0	0:01:11	0:00:00		
2	1104	14:54:03	0	1	1	0:00:06	0:02:40		
3.1	1104	14:54:19	0	0	0	0:00:16	0:00:00	0:00:16	
6.1	111	14:55:37	0	0	0	0:01:18	0:00:00		
7.1	111	14:55:56	0	0	0	0:00:19	0:00:00		
2	919	14:56:02	0	1	1	0:00:06	0:01:59		
3.1	919	14:56:23	0	0	0	0:00:22	0:00:00	0:00:22	
6.1	111	14:57:39	0	0	0	0:01:15	0:00:00		
7.1	111	15:01:26	0	0	0	0:03:47	0:00:00		
2	1103	15:01:30	0	1	1	0:00:05	0:05:29		
3.1	1103	15:01:53	0	0	0	0:00:23	0:00:00	0:00:23	
1	804	15:02:09	1	0	1	0:00:15	0:00:38		
2	804	15:02:19	0	1	1	0:00:11	0:00:00		
1	1106	15:03:29	1	1	2	0:01:10	0:01:21		
3.1	804	15:03:39	1	0	1	0:00:10	0:00:00	0:01:20	
2	1106	15:03:48	0	1	1	0:00:09	0:00:00		
1	1104	15:04:14	1	1	2	0:00:25	0:00:44		
3.1	1106	15:05:09	1	0	1	0:00:55	0:00:00	0:01:20	
2	1104	15:05:28	0	1	1	0:00:19	0:00:00		
1	919	15:05:38	1	1	2	0:00:10	0:01:24		
3.1	1104	15:06:52	1	0	1	0:01:14	0:00:00	0:01:24	
2	919	15:07:18	0	1	1	0:00:27	0:00:00		
1	1103	15:07:50	1	1	2	0:00:32	0:02:12		
3.1	919	15:08:43	1	1	2	0:00:53	0:00:00		
1	804	15:09:04	2	1	3	0:00:21	0:01:14		
3.2	919	15:09:51	2	0	2	0:00:47	0:00:00	0:02:33	
1	1106	15:09:55	3	0	3	0:00:04	0:00:51		
2	1103	15:10:36	2	1	3	0:00:40	0:00:00		
8	1106	15:13:08	1	1	2	0:02:32	0:00:00		
3.1	1103	15:13:46	1	1	2	0:00:38	0:00:00		
3.2	1103	15:16:41	1	0	1	0:02:55	0:00:00	0:06:50	
2	804	15:17:34	0	1	1	0:00:53	0:00:00		
1	1104	15:18:00	1	1	2	0:00:26	0:08:05		
1	120	15:19:27	2	1	3	0:01:27	0:01:27		
3.1	804	15:25:32	2	1	3	0:06:05	0:00:00		
3.2	804	15:27:06	2	0	2	0:01:34	0:00:00	0:09:32	
2	1104	15:27:22	1	1	2	0:00:16	0:00:00		
999	1104	15:27:29	1	1	2	0:00:07	0:00:00		
1	213	15:29:17	2	1	3	0:01:48	0:09:49		
2	213	15:30:37	1	2	3	0:01:21	0:00:00		
3.1	213	15:31:02	1	1	2	0:00:24	0:00:00	0:03:55	
1	5412	15:32:01	2	1	3	0:01:00	0:02:45		
3.1	1104	15:32:27	2	1	3	0:00:26	0:00:00		
1	804	15:32:36	3	1	4	0:00:09	0:00:35		

Figure A.5 - Field data for Feb11p.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Interarr	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
8	804	15:33:45	2	1	3	0:01:09	0:00:00		
3.2	1104	15:34:08	2	0	2	0:00:24	0:00:00	0:06:46	
2	5412	15:34:32	1	1	2	0:00:24	0:00:00		
3.1	5412	15:35:51	1	0	1	0:01:19	0:00:00	0:01:42	
6.1	111	15:37:49	1	0	1	0:01:59	0:00:00		
2	781	15:39:01	0	1	1	0:01:12	0:00:00		
7.1	111	15:39:08	0	1	1	0:00:07	0:00:00		
3	781	15:39:36	0	0	0	0:00:28	0:00:00	0:00:35	
6	111	15:39:55	0	0	0	0:00:19	0:00:00		
999	111	15:40:35	0	0	0	0:00:39	0:00:00		
999	111	15:40:48	0	0	0	0:00:13	0:00:00		
2	1106	15:42:46	0	1	1	0:01:58	0:10:10		
7	111	15:42:51	0	1	1	0:00:05	0:00:00		
1	804	15:43:23	1	1	2	0:00:32	0:00:37		
1	1104	15:44:13	2	1	3	0:00:49	0:00:49		
3	1106	15:44:26	2	0	2	0:00:14	0:00:00	0:01:41	
2	804	15:44:50	1	1	2	0:00:24	0:00:00		
3	804	15:46:22	1	0	1	0:01:32	0:00:00	0:01:55	
1	1103	15:46:27	2	0	2	0:00:05	0:02:14		
2	1104	15:46:43	1	1	2	0:00:16	0:00:00		
3	1104	15:48:04	1	0	1	0:01:22	0:00:00	0:01:42	
2	1103	15:48:38	0	1	1	0:00:34	0:00:00		
1	919	15:48:52	1	1	2	0:00:15	0:02:26		
1	1106	15:49:02	2	1	3	0:00:09	0:00:09		
3	1103	15:49:57	2	0	2	0:00:55	0:00:00	0:01:19	
2	919	15:50:24	1	1	2	0:00:28	0:00:00		
3	919	15:51:43	1	0	1	0:01:19	0:00:00	0:01:46	
2	1106	15:52:11	0	1	1	0:00:28	0:00:00		
1	804	15:52:18	1	1	2	0:00:07	0:03:16		
3	1106	15:53:01	1	0	1	0:00:43	0:00:00	0:00:50	
1	1104	15:53:05	2	0	2	0:00:04	0:00:47		
2	804	15:53:21	1	1	2	0:00:17	0:00:00		
3	804	15:54:31	1	0	1	0:01:09	0:00:00	0:01:30	
2	1104	15:54:54	0	1	1	0:00:24	0:00:00		
3	1104	15:56:24	0	0	0	0:01:30	0:00:00	0:01:30	
2	1103	15:56:38	0	1	1	0:00:14	0:03:33		
1	919	15:57:15	1	1	2	0:00:37	0:00:37		
3	1103	15:58:22	1	0	1	0:01:07	0:00:00	0:01:43	
2	919	15:58:50	0	1	1	0:00:29	0:00:00		
3	919	16:00:04	0	0	0	0:01:13	0:00:00	0:01:13	
6	111	16:01:52	0	0	0	0:01:48	0:00:00		
2	804	16:08:29	0	1	1	0:06:37	0:11:14		
7	111	16:08:35	0	1	1	0:00:06	0:00:00		
3	804	16:09:17	0	0	0	0:00:42	0:00:00	0:00:48	
6	111	16:11:04	0	0	0	0:01:47	0:00:00		
7	111	16:12:52	0	0	0	0:01:49	0:00:00		
2	1106	16:13:05	0	1	1	0:00:13	0:04:36		
3	1106	16:13:36	0	0	0	0:00:31	0:00:00	0:00:31	
6	111	16:15:47	0	0	0	0:02:11	0:00:00		

Figure A.5 - Field data for Feb11p.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									Backcycle
						elapsed	Interarr	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
7	111	16:17:28	0	0	0	0:01:41	0:00:00		
2	1104	16:17:36	0	1	1	0:00:08	0:04:31		
3	1104	16:18:10	0	0	0	0:00:35	0:00:00	0:00:35	
2	1103	16:18:41	0	1	1	0:00:31	0:01:05		
1	804	16:19:38	1	1	2	0:00:57	0:00:57		
3	1103	16:20:21	1	0	1	0:00:43	0:00:00	0:01:40	
2	804	16:20:52	0	1	1	0:00:31	0:00:00		
1	919	16:20:56	1	1	2	0:00:04	0:01:18		
3	804	16:22:14	1	0	1	0:01:18	0:00:00	0:01:22	
2	919	16:22:39	0	1	1	0:00:24	0:00:00		
3	919	16:23:21	0	0	0	0:00:43	0:00:00	0:00:43	
2	1106	16:24:05	0	1	1	0:00:43	0:03:09		
8	1106	16:24:15	0	0	0	0:00:10	0:00:00		
6	111	16:24:32	0	0	0	0:00:17	0:00:00		
1	1104	16:25:18	1	0	1	0:00:46	0:01:14		
7	111	16:27:17	1	0	1	0:01:58	0:00:00		
2	1103	16:27:28	1	1	2	0:00:11	0:00:00		
3	1103	16:27:55	1	0	1	0:00:27	0:00:00	0:04:33	
1	804	16:29:01	2	0	2	0:01:06	0:03:43		
999	555	16:29:27	2	0	2	0:00:26	0:00:00		
2	1106	16:30:17	1	1	2	0:00:50	0:00:00		
3	1106	16:31:14	1	0	1	0:00:57	0:00:00	0:03:19	
2	1104	16:31:57	0	1	1	0:00:43	0:00:00		
1	1103	16:32:36	1	1	2	0:00:39	0:03:36		
3	1104	16:33:08	1	0	1	0:00:31	0:00:00	0:01:10	
2	804	16:33:30	0	1	1	0:00:23	0:00:00		
3	804	16:34:34	0	0	0	0:01:04	0:00:00	0:01:04	
2	1103	16:35:02	0	1	1	0:00:28	0:02:25		
4	111	16:35:43	0	1	1	0:00:41	0:00:00		
5	111	16:35:56	0	1	1	0:00:14	0:00:00		
3	1103	16:37:20	0	0	0	0:01:24	0:00:00	0:02:18	
6	111	16:38:55	0	0	0	0:01:35	0:00:00		
7	111	16:39:20	0	0	0	0:00:25	0:00:00		
2	803	16:39:26	0	1	1	0:00:05	0:04:24		
3	803	16:39:58	0	0	0	0:00:32	0:00:00	0:00:32	
1	1104	16:40:02	1	0	1	0:00:04	0:00:36		
2	1104	16:40:52	0	1	1	0:00:50	0:00:00		
1	1106	16:41:07	1	1	2	0:00:15	0:01:05		
3	1104	16:42:44	1	0	1	0:01:37	0:00:00	0:01:52	
2	1106	16:43:06	0	1	1	0:00:22	0:00:00		
1	1103	16:43:26	1	1	2	0:00:20	0:02:19		
3	1106	16:44:29	1	0	1	0:01:03	0:00:00	0:01:23	
2	1103	16:44:56	0	1	1	0:00:27	0:00:00		
1	803	16:45:36	1	1	2	0:00:40	0:02:10		
3	1103	16:46:14	1	0	1	0:00:38	0:00:00	0:01:18	
2	803	16:46:42	0	1	1	0:00:28	0:00:00		
1	1104	16:47:38	1	1	2	0:00:56	0:02:03		
3	803	16:48:17	1	0	1	0:00:39	0:00:00	0:01:35	
2	1104	16:48:36	0	1	1	0:00:18	0:00:00		

Figure A.5 - Field data for Feb11p.1 data file (continued).

• Crane #3 servicing "BONN EXPRESS"									
• February 11, 1991									
						elapsed	Interarr	Service	Backcycle Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
1	1106	16:49:54	1	1	2	0:01:19	0:02:16		
3	1104	16:50:11	1	0	1	0:00:17	0:00:00	0:01:36	
2	1106	16:50:37	0	1	1	0:00:26	0:00:00		
1	1103	16:51:29	1	1	2	0:00:52	0:01:34		
3	1106	16:52:05	1	0	1	0:00:36	0:00:00	0:01:28	
2	1103	16:52:33	0	1	1	0:00:28	0:00:00		
3	1103	16:53:33	0	0	0	0:01:00	0:00:00	0:01:00	
2	803	16:53:52	0	1	1	0:00:19	0:02:23		
3	803	16:55:14	0	0	0	0:01:22	0:00:00	0:01:22	
2	1104	16:55:35	0	1	1	0:00:22	0:01:43		
3	1104	16:56:44	0	0	0	0:01:09	0:00:00	0:01:09	
6	111	16:57:59	0	0	0	0:01:15	0:00:00		
7	111	16:58:44	0	0	0	0:00:45	0:00:00		
2	1106	16:58:48	0	1	1	0:00:04	0:03:13		
3	1106	16:59:12	0	0	0	0:00:23	0:00:00	0:00:23	
2	1103	16:59:50	0	1	1	0:00:38	0:01:02		
1	804	17:01:00	1	1	2	0:01:10	0:01:10		
2	804	17:01:14	0	2	2	0:00:14	0:00:00		
3	1103	17:01:20	0	1	1	0:00:06	0:00:00	0:01:30	
3	804	17:02:36	0	0	0	0:01:17	0:00:00	0:01:22	
6	111	17:04:03	0	0	0	0:01:27	0:00:00		
7	111	17:05:06	0	0	0	0:01:03	0:00:00		
2	803	17:05:09	0	1	1	0:00:03	0:04:09		
3	803	17:05:29	0	0	0	0:00:21	0:00:00	0:00:21	
6	111	17:06:49	0	0	0	0:01:20	0:00:00		

Figure A.6 - Field data for Feb12a.1 data file.

• Crane #1 servicing "YU HE"										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	Time	Vehicles	in queue
			0	0	0					
2	1003	7:50:28	0	1	1	0:00:00	0:00:00		0:14:16	
2	1002	7:52:58	0	2	2	0:02:31	0:02:31		0:14:23	0:00:00
3	1003	7:53:02	0	1	1	0:00:04	0:00:00	0:02:35	0:14:42	
2	1106	7:53:32	0	2	2	0:00:30	0:00:34		0:16:29	0:00:00
3	1002	7:54:32	0	1	1	0:01:00	0:00:00	0:01:33	0:18:35	
6	111	7:55:07	0	1	1	0:00:35	0:00:00		0:21:10	
7	111	7:56:41	0	1	1	0:01:34	0:00:00			
6	111	7:57:52	0	1	1	0:01:11	0:00:00			
1	1105	7:58:14	1	1	2	0:00:22	0:04:42			
1	867	7:58:19	2	1	3	0:00:05	0:00:05			
1	948	7:59:07	3	1	4	0:00:49	0:00:49			
7	111	7:59:29	3	1	4	0:00:21	0:00:00			
1	917	8:00:30	4	1	5	0:01:02	0:01:23			
3	1106	8:00:44	4	0	4	0:00:14	0:00:00	0:07:12		
2	1105	8:00:57	3	1	4	0:00:13	0:00:00			0:02:43
6	111	8:01:24	3	1	4	0:00:28	0:00:00			
7	111	8:02:04	3	1	4	0:00:40	0:00:00			
1	1006	8:02:21	4	1	5	0:00:17	0:01:50			
6	111	8:02:53	4	1	5	0:00:33	0:00:00			
8	917	8:03:52	4	1	5	0:00:59	0:00:00			
3	1105	8:04:25	4	0	4	0:00:33	0:00:00	0:03:41		
2	867	8:04:44	3	1	4	0:00:20	0:00:00			0:06:26
3	867	8:05:19	3	0	3	0:00:35	0:00:00	0:00:55		
2	948	8:05:37	2	1	3	0:00:18	0:00:00			0:06:30
1	949	8:05:54	3	1	4	0:00:17	0:03:33			
8	1006	8:06:05	3	1	4	0:00:10	0:00:00			
3	948	8:06:34	3	0	3	0:00:30	0:00:00	0:01:15		
2	949	8:07:25	2	1	3	0:00:50	0:00:00			0:01:30
1	333	8:07:46	3	1	4	0:00:21	0:01:52			
1	444	8:07:54	4	1	5	0:00:08	0:00:08			
3	949	8:08:29	4	0	4	0:00:35	0:00:00	0:01:55		
2	333	8:09:09	3	1	4	0:00:40	0:00:00			0:01:23
3	333	8:09:48	3	0	3	0:00:40	0:00:00	0:01:19		
2	444	8:10:00	2	1	3	0:00:12	0:00:00			0:02:06
3	444	8:11:11	2	0	2	0:01:11	0:00:00	0:01:23		
6.1	111	8:12:10	2	0	2	0:00:58	0:00:00			
7.1	111	8:12:29	2	0	2	0:00:20	0:00:00			
999	222	8:12:45	2	0	2	0:00:16	0:00:00			
999	222	8:14:48	2	0	2	0:02:03	0:00:00			
6	111	8:15:18	2	0	2	0:00:30	0:00:00			
7	111	8:16:09	2	0	2	0:00:51	0:00:00			
2	1106	8:17:24	1	1	2	0:01:15	0:00:00			
1	867	8:17:43	2	1	3	0:00:20	0:09:49			
3	1106	8:18:59	2	0	2	0:01:16	0:00:00			
2	867	8:19:10	1	1	2	0:00:11	0:00:00			0:01:27
3	867	8:20:33	1	0	1	0:01:23	0:00:00	0:01:34		
2	948	8:20:34	0	1	1	0:00:01	0:00:00			
1	1105	8:21:15	1	1	2	0:00:41	0:03:32			

Figure A.6 - Field data for Feb12a.1 data file (continued).

• Crane #1 servicing "YU HE"										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	Time	Vehicles	in queue
4	111	8:22:22	1	1	2	0:01:07	0:00:00			
5	111	8:22:29	1	1	2	0:00:07	0:00:00			
3	948	8:24:44	1	0	1	0:02:15	0:00:00	unknown		
2	1105	8:25:10	0	1	1	0:00:26	0:00:00			0:03:55
1	1004	8:26:19	1	1	2	0:01:09	0:05:04			
3	1105	8:26:47	1	0	1	0:00:28	0:00:00	0:01:37		
2	1004	8:27:00	0	1	1	0:00:13	0:00:00			0:00:41
3	1004	8:28:24	0	0	0	0:01:24	0:00:00	0:01:24		
6.1	111	8:29:16	0	0	0	0:00:52	0:00:00			
7.1	111	8:29:36	0	0	0	0:00:20	0:00:00			
2	949	8:29:40	0	1	1	0:00:04	0:03:21			0:00:00
1	1001	8:29:44	1	1	2	0:00:04	0:00:04			
3	949	8:30:15	1	0	1	0:00:31	0:00:00	0:00:35		
2	1001	8:30:26	0	1	1	0:00:11	0:00:00			0:00:42
3	1001	8:31:22	0	0	0	0:00:56	0:00:00	0:00:56		
2	867	8:31:55	0	1	1	0:00:33	0:02:11			0:00:00
3	867	8:32:30	0	0	0	0:00:35	0:00:00	0:00:35		
6.1	111	8:33:34	0	0	0	0:01:04	0:00:00			
2	954	8:35:19	0	1	1	0:01:45	0:03:24			0:00:00
7.1	111	8:35:24	0	1	1	0:00:04	0:00:00			
999	1008	8:35:29	0	1	1	0:00:05	0:00:00			
999	1800	8:35:39	0	1	1	0:00:10	0:00:00			
3	954	8:35:54	0	0	0	0:00:15	0:00:00	0:00:35		
999	1008	8:36:12	0	0	0	0:00:18	0:00:00			
999	1800	8:36:17	0	0	0	0:00:05	0:00:00			
6.1	111	8:36:59	0	0	0	0:00:42	0:00:00			
7.1	111	8:37:29	0	0	0	0:00:30	0:00:00			
2	1106	8:37:34	0	1	1	0:00:05	0:02:15			0:00:00
999	1107	8:37:39	0	1	1	0:00:04	0:00:00			
3	1106	8:38:04	0	0	0	0:00:26	0:00:00	0:00:30		
999	1107	8:38:23	0	0	0	0:00:18	0:00:00			
6.1	111	8:39:00	0	0	0	0:00:38	0:00:00			
7.1	111	8:39:20	0	0	0	0:00:20	0:00:00			
2	948	8:39:26	0	1	1	0:00:05	0:01:51			0:00:00
3	948	8:39:47	0	0	0	0:00:21	0:00:00	0:00:21		
6.1	111	8:40:25	0	0	0	0:00:38	0:00:00			
7.1	111	8:40:45	0	0	0	0:00:20	0:00:00			
7.1	111	8:42:14	0	0	0	0:01:29	0:00:00			
2	1003	8:42:19	0	1	1	0:00:05	0:02:53			0:00:00
3	1003	8:42:56	0	0	0	0:00:37	0:00:00	0:00:37		
6.1	111	8:44:13	0	0	0	0:01:17	0:00:00			
2	949	8:46:44	0	1	1	0:02:31	0:04:25			0:00:00
7.1	111	8:46:47	0	1	1	0:00:03	0:00:00			
3	949	8:47:10	0	0	0	0:00:23	0:00:00	0:00:27		
1	867	8:47:49	1	0	1	0:00:39	0:01:05			
6.1	111	8:48:18	1	0	1	0:00:29	0:00:00			
7.1	111	8:48:24	1	0	1	0:00:06	0:00:00			
2	3132	8:48:25	0	1	1	0:00:01	0:00:00			
1	1105	8:48:42	1	1	2	0:00:17	0:00:53			

Figure A.6 - Field data for Feb12a.1 data file (continued).

• Crane #1 servicing "YU HE"										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MMSS	Queue	Service	System	time	times	Time	Vehicles	in queue
3	3132	8:49:00	1	0	1	0:00:18	0:00:00	unknown		
2	867	8:49:10	0	1	1	0:00:10	0:00:00			0:01:21
3	867	8:49:54	0	0	0	0:00:44	0:00:00	0:00:44		
2	1105	8:50:18	0	1	1	0:00:24	0:01:36			0:01:36
1	954	8:50:30	1	1	2	0:00:13	0:00:13			
3	1105	8:51:34	1	0	1	0:01:04	0:00:00	0:01:17		
2	954	8:52:07	0	1	1	0:00:33	0:00:00			0:01:37
1	1106	8:52:20	1	1	2	0:00:13	0:01:50			
3	954	8:53:02	1	0	1	0:00:42	0:00:00	0:00:55		
2	1106	8:53:13	0	1	1	0:00:11	0:00:00			0:00:53
999	1106	8:53:44	0	1	1	0:00:31	0:00:00			
3	1106	8:54:01	0	0	0	0:00:17	0:00:00	0:00:48		
2	948	8:54:09	0	1	1	0:00:08	0:01:49			0:00:00
3	948	8:55:32	0	0	0	0:01:22	0:00:00	0:01:22		
6.1	111	8:56:44	0	0	0	0:01:12	0:00:00			
7.1	111	8:59:40	0	0	0	0:02:56	0:00:00			
2	2798	8:59:45	0	1	1	0:00:05	0:05:36			0:00:00
3	2798	9:00:23	0	0	0	0:00:38	0:00:00	0:00:38		
6.1	111	9:01:24	0	0	0	0:01:00	0:00:00			
2	1001	9:05:26	0	1	1	0:04:02	0:05:41			0:00:00
7.1	111	9:05:44	0	1	1	0:00:18	0:00:00			
3	1001	9:06:14	0	0	0	0:00:31	0:00:00	0:00:48		

Figure A.7 - Field data for Feb12a.2 data file.

• Crane #1 servicing "YU HE"									
• February 12, 1991									Backcycle
						elapsed	Inter.	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
			0	0	0				
2	1105	9:23:23	0	1	1	0:00:00	0:00:00		0:06:42
3	1105	9:23:57	0	0	0	0:00:34	0:00:00	0:00:34	0:09:12
2	1106	9:25:09	0	1	1	0:01:13	0:01:47		0:09:36
3	1106	9:25:34	0	0	0	0:00:25	0:00:00	0:00:25	0:10:00
11	1105	9:25:51	0	0	0	0:00:17	0:00:00		0:10:02
6	111	9:26:19	0	0	0	0:00:28	0:00:00		0:10:16
11	1106	9:26:59	0	0	0	0:00:40	0:00:00		0:10:49
7.1	111	9:27:05	0	0	0	0:00:06	0:00:00		0:30:45
2	1009	9:27:11	0	1	1	0:00:06	0:02:02		0:32:29
3	1009	9:27:31	0	0	0	0:00:20	0:00:00	0:00:20	0:32:44
11	1009	9:28:09	0	0	0	0:00:38	0:00:00		0:33:22
7	111	9:30:06	0	0	0	0:01:58	0:00:00		
2	1105	9:30:11	0	1	1	0:00:05	0:03:00		
3	1105	9:30:42	0	0	0	0:00:31	0:00:00	0:00:31	
6	111	9:31:43	0	0	0	0:01:00	0:00:00		
7	111	9:32:09	0	0	0	0:00:26	0:00:00		
2	1106	9:32:16	0	1	1	0:00:07	0:02:04		
3	1106	9:33:04	0	0	0	0:00:49	0:00:00	0:00:49	
6	111	9:33:50	0	0	0	0:00:46	0:00:00		
11	1106	9:34:20	0	0	0	0:00:30	0:00:00		
7	111	9:34:30	0	0	0	0:00:10	0:00:00		
2	949	9:34:37	0	1	1	0:00:07	0:02:21		
3	949	9:35:07	0	0	0	0:00:30	0:00:00	0:00:30	
6	111	9:36:42	0	0	0	0:01:35	0:00:00		
11	949	9:36:49	0	0	0	0:00:07	0:00:00		
7	111	9:37:25	0	0	0	0:00:37	0:00:00		
2	1009	9:37:31	0	1	1	0:00:06	0:02:54		
3	1009	9:38:28	0	0	0	0:00:56	0:00:00	0:00:56	
11	1009	9:39:07	0	0	0	0:00:40	0:00:00		
2	867	9:39:17	0	1	1	0:00:10	0:01:46		
3	867	9:40:36	0	0	0	0:01:18	0:00:00	0:01:18	
11	867	9:41:02	0	0	0	0:00:26	0:00:00		
6	111	9:41:51	0	0	0	0:00:49	0:00:00		
7	111	9:41:57	0	0	0	0:00:06	0:00:00		
1	1106	9:42:16	1	0	1	0:00:19	0:02:59		
2	1106	9:43:06	0	1	1	0:00:50	0:00:00		
3	1106	9:44:48	0	0	0	0:01:42	0:00:00	0:01:42	
2	949	9:45:09	0	1	1	0:00:21	0:02:53		
3	949	9:46:11	0	0	0	0:01:02	0:00:00	0:01:02	
11	1106	9:46:30	0	0	0	0:00:19	0:00:00		
6	111	9:47:10	0	0	0	0:00:40	0:00:00		
11	949	9:48:56	0	0	0	0:01:46	0:00:00		
7	111	9:49:09	0	0	0	0:00:14	0:00:00		
2	1009	9:49:17	0	1	1	0:00:08	0:04:08		
3	1009	9:49:45	0	0	0	0:00:28	0:00:00	0:00:28	
11	1009	9:50:13	0	0	0	0:00:29	0:00:00		
6	111	9:50:36	0	0	0	0:00:23	0:00:00		
7	111	9:50:48	0	0	0	0:00:11	0:00:00		

Figure A.7 - Field data for Feb12a.2 data file (continued).

• Crane #1 servicing "YU HE"									
• February 12, 1991									Backcycle
						elapsed	Inter.	Service	Time, all
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles
2	867	9:50:51	0	1	1	0:00:04	0:01:34		
3	867	9:51:13	0	0	0	0:00:22	0:00:00	0:00:22	
11	867	9:51:47	0	0	0	0:00:34	0:00:00		
6	111	9:52:27	0	0	0	0:00:40	0:00:00		
7	111	9:54:14	0	0	0	0:01:48	0:00:00		
2	1106	9:54:24	0	1	1	0:00:09	0:03:33		
3	1106	9:54:46	0	0	0	0:00:22	0:00:00	0:00:22	
11	1106	9:56:03	0	0	0	0:01:17	0:00:00		
6	111	9:56:24	0	0	0	0:00:21	0:00:00		
7	111	10:14:51	0	0	0	0:18:26	0:00:00		
13	949	10:17:15	0	0	0	0:02:24	0:00:00		
6	111	10:17:30	0	0	0	0:00:16	0:00:00		
12	1009	10:17:39	0	0	0	0:00:09	0:00:00		
7	111	10:19:25	0	0	0	0:01:45	0:00:00		
2	949	10:19:33	0	1	1	0:00:09	0:25:09		
3	949	10:19:57	0	0	0	0:00:23	0:00:00	0:00:23	
13	1009	10:20:31	0	0	0	0:00:34	0:00:00		
12	867	10:21:02	0	0	0	0:00:31	0:00:00		
6	111	10:21:06	0	0	0	0:00:04	0:00:00		
11	949	10:21:47	0	0	0	0:00:40	0:00:00		
13	867	10:21:54	0	0	0	0:00:08	0:00:00		
7	111	10:22:11	0	0	0	0:00:16	0:00:00		
12	1106	10:22:15	0	0	0	0:00:05	0:00:00		
7	111	10:22:22	0	0	0	0:00:07	0:00:00		
2	1009	10:22:29	0	1	1	0:00:07	0:02:56		
3	1009	10:22:45	0	0	0	0:00:16	0:00:00	0:00:16	
13	1106	10:23:38	0	0	0	0:00:53	0:00:00		
2	867	10:23:43	0	1	1	0:00:05	0:01:14		
12	949	10:24:01	0	1	1	0:00:18	0:00:00		
6	111	10:24:31	0	1	1	0:00:30	0:00:00		
11	1009	10:25:21	0	1	1	0:00:50	0:00:00		
7	111	10:25:25	0	1	1	0:00:04	0:00:00		
1	1106	10:25:31	1	1	2	0:00:06	0:01:48		
6	111	10:26:17	1	1	2	0:00:46	0:00:00		
8	867	10:27:26	1	0	1	0:01:09	0:00:00		
18	949	10:28:08	1	0	1	0:00:42	0:00:00		
18	1009	10:28:13	1	0	1	0:00:05	0:00:00		
12	867	10:28:26	1	0	1	0:00:13	0:00:00		
8	1106	10:28:56	0	0	0	0:00:31	0:00:00		
13	867	10:29:18	0	0	0	0:00:22	0:00:00		
12	1106	10:30:10	0	0	0	0:00:51	0:00:00		
13	1106	10:31:17	0	0	0	0:01:07	0:00:00		

Figure A.8 - Field data for Feb12a.3 data file.

• Crane #6 servicing "NEWARK BAY" - SEA LAND										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
			0	0	0					
1	3525	11:07:26	1	0	1	0:00:00	0:00:00		0:04:28	
1	3527	11:08:46	2	0	2	0:01:20	0:01:20		0:04:55	
2	3532	11:09:22	2	1	3	0:00:36	0:00:00		0:05:01	0:00:00
3	3532	11:10:39	2	0	2	0:01:17	0:00:00		0:05:14	
2	3525	11:11:03	1	1	2	0:00:25	0:00:00		0:05:21	0:03:37
3	3525	11:11:56	1	0	1	0:00:53	0:00:00	0:01:17	0:05:34	
1	3526	11:12:05	2	0	2	0:00:09	0:03:19		0:05:42	
2	3527	11:12:15	1	1	2	0:00:10	0:00:00		0:05:48	0:03:29
1	3400	11:12:26	2	1	3	0:00:10	0:00:21		0:06:17	
3	3527	11:13:10	2	0	2	0:00:44	0:00:00	0:01:14	0:06:28	
2	3526	11:13:23	1	1	2	0:00:13	0:00:00		0:06:41	0:01:17
999	3531	11:13:32	1	1	2	0:00:10	0:00:00		0:06:53	
1	3529	11:15:00	2	1	3	0:01:28	0:02:35		0:08:02	
999	3531	11:15:20	2	1	3	0:00:19	0:00:00		0:08:27	
1	3532	11:15:52	3	1	4	0:00:32	0:00:52		0:08:30	
3	3526	11:16:04	3	0	3	0:00:12	0:00:00	0:02:55	0:08:33	
2	3400	11:16:24	2	1	3	0:00:20	0:00:00			0:03:59
1	3525	11:16:51	3	1	4	0:00:27	0:00:59			
1	3530	11:17:29	4	1	5	0:00:38	0:00:38			
3	3400	11:18:12	4	0	4	0:00:42	0:00:00	0:02:07		
2	3529	11:18:37	3	1	4	0:00:25	0:00:00			0:03:36
3	3529	11:19:42	3	0	3	0:01:05	0:00:00	0:01:30		
999	-1	11:19:53	3	0	3	0:00:11	0:00:00			
2	3532	11:19:56	2	1	3	0:00:03	0:00:00			0:04:04
1	3526	11:20:33	3	1	4	0:00:37	0:03:04			
3	3532	11:20:57	3	0	3	0:00:25	0:00:00	0:01:15		
2	3530	11:21:14	2	1	3	0:00:17	0:00:00			0:03:45
3	3530	11:22:12	2	0	2	0:00:57	0:00:00	0:01:14		
2	3525	11:22:27	1	1	2	0:00:15	0:00:00			0:05:36
3	3525	11:23:55	1	0	1	0:01:28	0:00:00	0:01:43		
2	3527	11:24:17	0	1	1	0:00:23	0:00:00			0:00:00
1	3531	11:25:32	1	1	2	0:01:15	0:04:59			
3	3527	11:25:44	1	0	1	0:00:12	0:00:00	0:03:33		
2	3526	11:26:03	0	1	1	0:00:19	0:00:00			
1	3400	11:26:13	1	1	2	0:00:10	0:00:41			
1	3532	11:27:15	2	1	3	0:01:02	0:01:02			
3	3526	11:27:24	2	0	2	0:00:10	0:00:00	xxxxxx		
1	3529	11:28:09	3	0	3	0:00:45	0:00:54			
2	3531	11:28:23	2	1	3	0:00:14	0:00:00			0:02:51
3	3531	11:28:50	2	0	2	0:00:27	0:00:00	0:01:25		
1	3530	11:29:05	3	0	3	0:00:15	0:00:56			
2	3400	11:29:09	2	1	3	0:00:04	0:00:00			0:02:55
1	3525	11:29:16	3	1	4	0:00:07	0:00:11			
3	3400	11:30:20	3	0	3	0:01:04	0:00:00	0:01:30		
2	3529	11:30:44	2	1	3	0:00:24	0:00:00			0:02:35
3	3529	11:32:00	2	0	2	0:01:16	0:00:00	0:01:40		
2	3532	11:32:19	1	1	2	0:00:19	0:00:00			0:05:04
1	3527	11:32:25	2	1	3	0:00:06	0:03:10			

Figure A.8 - Field data for Feb12a.3 data file (continued).

• Crane #6 servicing "NEWARK BAY" - SEA LAND										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
3	3532	11:33:17	2	0	2	0:00:52	0:00:00	0:01:17		
2	3530	11:33:41	1	1	2	0:00:24	0:00:00			0:04:36
1	3526	11:33:52	2	1	3	0:00:11	0:01:27			
3	3530	11:35:06	2	0	2	0:01:14	0:00:00	0:01:49		
1	3400	11:35:21	3	0	3	0:00:15	0:01:29			
2	3525	11:35:27	2	1	3	0:00:06	0:00:00			0:06:11
3	3525	11:36:57	2	0	2	0:01:30	0:00:00	0:01:51		
2	3527	11:37:11	1	1	2	0:00:14	0:00:00			0:04:46
1	3531	11:37:20	2	1	3	0:00:09	0:01:59			
3	3527	11:38:28	2	0	2	0:01:08	0:00:00	0:01:31		
2	3526	11:38:47	1	1	2	0:00:19	0:00:00			0:04:55
1	3532	11:39:05	2	1	3	0:00:18	0:01:45			
3	3526	11:40:06	2	0	2	0:01:01	0:00:00	0:01:38		
2	3531	11:40:25	1	1	2	0:00:19	0:00:00			0:03:05
1	3529	11:40:33	2	1	3	0:00:08	0:01:28			
1	3530	11:40:39	3	1	4	0:00:06	0:00:06			
3	3531	11:41:40	3	0	3	0:01:00	0:00:00	0:01:34		
2	3400	11:41:52	2	1	3	0:00:12	0:00:00			0:06:30
1	3525	11:42:39	3	1	4	0:00:48	0:02:00			
3	3400	11:43:08	3	0	3	0:00:29	0:00:00	0:01:28		
2	3529	11:43:31	2	1	3	0:00:23	0:00:00			0:02:58
3	3529	11:44:45	2	0	2	0:01:13	0:00:00	0:01:37		
2	3532	11:45:07	1	1	2	0:00:23	0:00:00			0:06:02
3	3532	11:45:54	1	0	1	0:00:47	0:00:00	0:01:10		
2	3530	11:46:16	0	1	1	0:00:22	0:00:00			0:05:36
3	3530	11:47:07	0	0	0	0:00:52	0:00:00	0:01:13		

Figure A.9 - Field data for Feb12p.1 data file.

• Crane #6 servicing "NEWARK BAY" - SEA LAND										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
			1	1	2					
1	3530	13:13:41	1	1	2	0:00:00	0:00:00		0:02:43	
1	3531	13:14:03	2	1	3	0:00:22	0:00:22		0:04:07	
3	3532	13:14:08	2	0	2	0:00:05	0:00:00		0:04:37	
2	3531	13:15:00	1	1	2	0:00:52	0:00:00		0:04:41	0:00:57
3	3531	13:15:28	1	0	1	0:00:27	0:00:00		0:04:55	
1	3526	13:15:34	2	0	2	0:00:06	0:01:30		0:04:59	
2	3530	13:16:10	1	1	2	0:00:36	0:00:00		0:05:08	
1	3012	13:16:25	2	1	3	0:00:15	0:00:51		0:05:13	
1	3527	13:16:39	3	1	4	0:00:14	0:00:14		0:05:32	
3	3530	13:16:59	3	0	3	0:00:19	0:00:00	0:01:31	0:05:35	
1	3529	13:17:04	4	0	4	0:00:05	0:00:25		0:05:37	
2	3012	13:17:24	3	1	4	0:00:21	0:00:00		0:05:39	0:00:59
3	3012	13:18:08	3	0	3	0:00:44	0:00:00	0:01:09	0:05:51	
2	3526	13:18:30	2	1	3	0:00:22	0:00:00		0:06:03	0:02:56
3	3526	13:19:06	2	0	2	0:00:36	0:00:00	0:00:58	0:06:06	
1	3400	13:19:12	3	0	3	0:00:06	0:02:09		0:06:12	
2	3527	13:19:23	2	1	3	0:00:11	0:00:00		0:06:14	0:02:44
1	3532	13:20:48	3	1	4	0:01:25	0:01:36		0:06:16	
3	3527	13:20:53	3	0	3	0:00:05	0:00:00	0:01:47	0:06:16	
2	3529	13:21:08	2	1	3	0:00:15	0:00:00		0:06:32	0:04:04
1	3531	13:21:33	3	1	4	0:00:25	0:00:45		0:06:36	
3	3529	13:22:33	3	0	3	0:01:00	0:00:00	0:01:40	0:06:39	
2	3400	13:22:47	2	1	3	0:00:14	0:00:00		0:06:40	0:03:35
3	3400	13:24:07	2	0	2	0:01:20	0:00:00	0:01:33	0:06:43	
2	3532	13:24:24	1	1	2	0:00:17	0:00:00		0:06:43	0:03:36
999	3012	13:24:33	1	1	2	0:00:09	0:00:00		0:06:58	
1	3530	13:25:26	2	1	3	0:00:54	0:03:53		0:07:05	
999	3012	13:25:32	2	1	3	0:00:06	0:00:00		0:07:15	
3	3532	13:25:44	2	0	2	0:00:12	0:00:00	0:01:38	0:07:29	
2	3531	13:25:55	1	1	2	0:00:11	0:00:00		0:07:32	0:04:22
1	3012	13:26:01	2	1	3	0:00:06	0:00:34		0:07:52	
1	3526	13:26:35	3	1	4	0:00:34	0:00:34		0:07:53	
1	3527	13:26:59	4	1	5	0:00:24	0:00:24		0:08:28	
3	3531	13:27:22	4	0	4	0:00:23	0:00:00	0:01:38	0:08:31	
2	3530	13:27:50	3	1	4	0:00:28	0:00:00		0:08:36	0:02:23
3	3530	13:28:45	3	0	3	0:00:56	0:00:00	0:01:24	0:08:37	
1	3400	13:29:42	4	0	4	0:00:56	0:02:43		0:09:06	
4	111	13:30:00	4	0	4	0:00:18	0:00:00		0:09:15	
1	3531	13:31:58	5	0	5	0:01:58	0:02:17		0:10:41	
4	111	13:32:18	5	0	5	0:00:20	0:00:00			
1	3529	13:33:15	6	0	6	0:00:57	0:01:16			
4	111	13:33:30	6	0	6	0:00:15	0:00:00			
1	3532	13:34:50	7	0	7	0:01:20	0:01:35			
2	3012	13:35:11	6	1	7	0:00:21	0:00:00			0:09:10
3	3012	13:35:44	6	0	6	0:00:33	0:00:00			
2	3526	13:36:10	5	1	6	0:00:26	0:00:00			0:09:35
3	3526	13:37:56	5	0	5	0:01:46	0:00:00	0:02:12		
1	3530	13:38:00	6	0	6	0:00:04	0:03:10			

Figure A.9 - Field data for Feb12p.1 data file (continued).

• Crane #6 servicing "NEWARK BAY" - SEA LAND						.				
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
6.1	111	13:38:24	6	0	6	0:00:24	0:00:00			
7.1	111	13:40:24	6	0	6	0:01:59	0:00:00			
2	3527	13:40:54	5	1	6	0:00:30	0:00:00			0:13:55
4	111	13:41:00	5	1	6	0:00:06	0:00:00			
5	111	13:41:12	5	1	6	0:00:12	0:00:00			
3	3527	13:41:39	5	0	5	0:00:27	0:00:00	0:03:43		
2	3529	13:42:03	4	1	5	0:00:24	0:00:00			0:08:48
1	3012	13:42:19	5	1	6	0:00:17	0:04:19			
4	111	13:42:43	5	1	6	0:00:24	0:00:00			
5	111	13:42:59	5	1	6	0:00:16	0:00:00			
3	3529	13:43:22	5	0	5	0:00:23	0:00:00	0:01:43		
2	3400	13:43:38	4	1	5	0:00:15	0:00:00			0:13:56
3	3400	13:44:59	4	0	4	0:01:21	0:00:00	0:01:37		
2	3532	13:45:08	3	1	4	0:00:10	0:00:00			0:10:19
3	3532	13:46:03	3	0	3	0:00:55	0:00:00	0:01:04		
2	3531	13:46:17	2	1	3	0:00:14	0:00:00			0:14:19
1	3526	13:46:31	3	1	4	0:00:14	0:04:12			
3	3531	13:47:05	3	0	3	0:00:33	0:00:00	0:01:01		
2	3530	13:47:23	2	1	3	0:00:19	0:00:00			0:09:23
3	3530	13:48:12	2	0	2	0:00:48	0:00:00	0:01:07		
2	3012	13:48:29	1	1	2	0:00:18	0:00:00			0:06:10
1	3527	13:49:11	2	1	3	0:00:41	0:02:40			
3	3012	13:49:36	2	0	2	0:00:25	0:00:00	0:01:24		
2	3526	13:49:50	1	1	2	0:00:14	0:00:00			0:03:19
1	3529	13:49:54	2	1	3	0:00:04	0:00:43			
1	3400	13:49:58	3	1	4	0:00:04	0:00:04			
3	3526	13:50:37	3	0	3	0:00:39	0:00:00	0:01:02		
2	3527	13:51:02	2	1	3	0:00:25	0:00:00			0:01:51
3	3527	13:52:03	2	0	2	0:01:01	0:00:00	0:01:26		
2	3529	13:52:32	1	1	2	0:00:29	0:00:00			0:02:38
1	3531	13:52:36	2	1	3	0:00:04	0:02:38			
3	3529	13:53:29	2	0	2	0:00:53	0:00:00	0:01:26		
2	3400	13:53:40	1	1	2	0:00:11	0:00:00			0:03:42
1	3530	13:54:26	2	1	3	0:00:46	0:01:50			
3	3400	13:54:44	2	0	2	0:00:18	0:00:00	0:01:15		
2	3532	13:54:50	1	1	2	0:00:06	0:00:00			
3	3532	13:55:41	1	0	1	0:00:51	0:00:00			
1	3526	13:55:51	2	0	2	0:00:10	0:01:25			
2	3531	13:55:56	1	1	2	0:00:05	0:00:00			0:03:20
3	3531	13:56:47	1	0	1	0:00:51	0:00:00	0:01:07		
2	3530	13:58:00	0	1	1	0:01:13	0:00:00			0:03:34
3	3530	13:58:26	0	0	0	0:00:25	0:00:00	0:00:25		
1	3529	13:58:37	1	0	1	0:00:12	0:02:47			
1	3527	13:58:43	2	0	2	0:00:05	0:00:05			
2	3526	13:59:10	1	1	2	0:00:27	0:00:00			0:03:19
1	3532	13:59:48	2	1	3	0:00:38	0:01:05			
3	3526	14:00:05	2	0	2	0:00:17	0:00:00	0:01:39		
2	3527	14:00:26	1	1	2	0:00:21	0:00:00			0:01:44
999	999	14:00:52	1	1	2	0:00:26	0:00:00			

Figure A.9 - Field data for Feb12p.1 data file (continued).

• Crane #6 servicing "NEWARK BAY" - SEA LAND										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
3	3527	14:01:34	1	0	1	0:00:42	0:00:00	0:01:29		
1	3400	14:01:41	2	0	2	0:00:08	0:01:53			
2	3529	14:01:56	1	1	2	0:00:15	0:00:00			0:03:18
3	3529	14:02:50	1	0	1	0:00:54	0:00:00	0:01:16		
1	3531	14:02:59	2	0	2	0:00:10	0:01:18			
1	3012	14:03:02	3	0	3	0:00:03	0:00:03			
2	3012	14:03:14	2	1	3	0:00:12	0:00:00			
3	3012	14:03:58	2	0	2	0:00:43	0:00:00	0:01:08		
999	3529	14:04:01	2	0	2	0:00:04	0:00:00			
2	3400	14:04:14	1	1	2	0:00:12	0:00:00			0:02:33
1	3530	14:04:42	2	1	3	0:00:28	0:01:40			
3	3400	14:05:15	2	0	2	0:00:33	0:00:00	0:01:17		
2	3532	14:05:24	1	1	2	0:00:09	0:00:00			0:05:36
3	3532	14:06:11	1	0	1	0:00:47	0:00:00	0:02:13		
2	3531	14:06:28	0	1	1	0:00:18	0:00:00			0:03:29
3	3531	14:07:12	0	0	0	0:00:43	0:00:00	0:00:43		
2	3530	14:07:25	0	1	1	0:00:13	0:02:43			0:02:43
1	3526	14:07:57	1	1	2	0:00:33	0:00:33			
3	3530	14:08:13	1	0	1	0:00:16	0:00:00	0:00:48		
2	3526	14:08:45	0	1	1	0:00:32	0:00:00			0:00:48
3	3526	14:09:09	0	0	0	0:00:24	0:00:00	0:00:24		
6	111	14:09:41	0	0	0	0:00:32	0:00:00			
2	3012	14:10:01	0	1	1	0:00:20	0:02:04			0:00:00
4	111	14:11:02	0	1	1	0:01:02	0:00:00			
			7	1	8					
7	111	14:15:00	7	1	8	0:00:00	0:00:00			
3	3012	14:18:09	7	0	7	0:03:09	0:00:00	0:08:09		
2	3400	14:18:50	6	1	7	0:00:40	0:00:00			
3	3400	14:20:14	6	0	6	0:01:25	0:00:00	0:02:05		
2	3532	14:20:31	5	1	6	0:00:17	0:00:00			
3	3532	14:21:54	5	0	5	0:01:23	0:00:00	0:01:40		
2	3531	14:22:17	4	1	5	0:00:22	0:00:00			
3	3531	14:23:21	4	0	4	0:01:04	0:00:00	0:01:26		
2	3530	14:23:42	3	1	4	0:00:21	0:00:00			
3	3530	14:25:03	3	0	3	0:01:21	0:00:00	0:01:42		
2	3526	14:25:17	2	1	3	0:00:14	0:00:00			
3	3526	14:26:19	2	0	2	0:01:02	0:00:00	0:01:16		
2	3529	14:26:42	1	1	2	0:00:23	0:00:00			
1	3012	14:26:47	2	1	3	0:00:05	0:16:46			
3	3529	14:27:36	2	0	2	0:00:50	0:00:00	0:01:18		
1	3532	14:27:45	3	0	3	0:00:08	0:00:58			
1	3400	14:27:54	4	0	4	0:00:09	0:00:09			
2	3527	14:28:14	3	1	4	0:00:20	0:00:00			
3	3527	14:28:37	3	0	3	0:00:23	0:00:00	0:01:01		
2	3012	14:28:52	2	1	3	0:00:15	0:00:00			0:02:05
1	3531	14:28:59	3	1	4	0:00:08	0:01:06			
3	3012	14:30:16	3	0	3	0:01:16	0:00:00	0:01:39		
2	3400	14:30:45	2	1	3	0:00:29	0:00:00			0:02:51
3	3400	14:31:43	2	0	2	0:00:59	0:00:00	0:01:28		

Figure A.9 - Field data for Feb12p.1 data file (continued).

• Crane #6 servicing "NEWARK BAY" - SEA LAND										
• February 12, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	time
Event	Truck	H:MM:SS	Queue	Service	System	time	times	time	Vehicles	in queue
2	3532	14:32:00	1	1	2	0:00:16	0:00:00			0:04:15
1	3530	14:32:08	2	1	3	0:00:08	0:03:09			
3	3532	14:33:12	2	0	2	0:01:05	0:00:00	0:01:29		
2	3531	14:33:29	1	1	2	0:00:16	0:00:00			0:04:29
1	3526	14:33:33	2	1	3	0:00:04	0:01:25			
1	3529	14:34:19	3	1	4	0:00:46	0:00:46			
3	3531	14:34:50	3	0	3	0:00:31	0:00:00	0:01:38		
2	3530	14:35:10	2	1	3	0:00:20	0:00:00			0:03:02
1	3012	14:35:53	3	1	4	0:00:43	0:01:34			
3	3530	14:36:10	3	0	3	0:00:17	0:00:00	0:01:19		
2	3526	14:36:29	2	1	3	0:00:20	0:00:00			0:02:56
1	3527	14:37:08	3	1	4	0:00:39	0:01:16			
3	3526	14:37:40	3	0	3	0:00:31	0:00:00	0:01:30		
2	3529	14:38:01	2	1	3	0:00:21	0:00:00			0:03:42
1	3532	14:38:08	3	1	4	0:00:07	0:00:59			
3	3529	14:38:52	3	0	3	0:00:44	0:00:00	0:01:12		
2	3527	14:39:24	2	1	3	0:00:32	0:00:00			0:02:16
1	3531	14:39:31	3	1	4	0:00:07	0:01:23			
1	3400	14:40:07	4	1	5	0:00:35	0:00:35			
3	3527	14:40:24	4	0	4	0:00:18	0:00:00	0:01:32		
2	3012	14:40:42	3	1	4	0:00:18	0:00:00			0:04:49
3	3012	14:41:58	3	0	3	0:01:16	0:00:00	0:01:34		
2	3400	14:42:14	2	1	3	0:00:16	0:00:00			0:02:07
1	3530	14:42:26	3	1	4	0:00:12	0:02:20			
3	3400	14:43:27	3	0	3	0:01:01	0:00:00	0:01:29		
2	3532	14:43:41	2	1	3	0:00:14	0:00:00			0:05:33
3	3532	14:44:42	2	0	2	0:01:02	0:00:00	0:01:16		
2	3531	14:45:00	1	1	2	0:00:18	0:00:00			0:05:29
3	3531	14:46:07	1	0	1	0:01:07	0:00:00	0:01:25		
2	3530	14:46:40	0	1	1	0:00:33	0:00:00			0:04:14
3	3530	14:47:31	0	0	0	0:00:50	0:00:00	0:00:50		
6	111	14:50:47	0	0	0	0:03:16	0:00:00			
4	111	14:51:41	0	0	0	0:00:54	0:00:00			
6	111	14:53:14	0	0	0	0:01:33	0:00:00			
7	111	14:59:27	0	0	0	0:06:13	0:00:00			
6	111	15:00:10	0	0	0	0:00:43	0:00:00			
7	111	15:00:26	0	0	0	0:00:17	0:00:00			

Figure A.10 - Field data for Mar7p.1 data file.

• Crane #3 servicing "ACT III"										
• March 7, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, al
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
			1	1	2					
3	13	13:37:22	1	0	1	0:00:00	0:00:00		0:02:58	
2	10	13:37:44	0	1	1	0:00:22	0:00:00		0:03:43	
1	1	13:38:27	1	1	2	0:00:44	0:01:06		0:04:31	
3	10	13:38:33	1	0	1	0:00:06	0:00:00	0:00:49	0:04:56	
2	1	13:38:50	0	1	1	0:00:17	0:00:00		0:04:56	0:00:23
1	6	13:39:48	1	1	2	0:00:58	0:01:21		0:05:07	
3	1	13:39:52	1	0	1	0:00:04	0:00:00	0:01:02	0:05:31	
2	6	13:40:06	0	1	1	0:00:14	0:00:00		0:05:38	0:00:18
1	14	13:40:34	1	1	2	0:00:28	0:00:46		0:06:32	
999	15	13:40:44	1	1	2	0:00:10	0:00:00		0:07:14	
3	6	13:40:52	1	0	1	0:00:08	0:00:00	0:00:46	0:10:19	
2	14	13:41:11	0	1	1	0:00:19	0:00:00		0:10:41	0:00:37
3	14	13:41:58	0	0	0	0:00:46	0:00:00	0:00:46	0:11:26	
2	3	13:42:31	0	1	1	0:00:33	0:01:57		0:12:15	0:00:00
1	13	13:43:00	1	1	2	0:00:30	0:00:30		0:20:09	
3	3	13:43:17	1	0	1	0:00:17	0:00:00	0:00:46	0:21:49	
2	13	13:43:32	0	1	1	0:00:15	0:00:00		0:22:09	0:00:32
1	1	13:44:23	1	1	2	0:00:51	0:01:23			
3	13	13:44:31	1	0	1	0:00:08	0:00:00	0:00:59		
2	10	13:44:51	0	1	1	0:00:20	0:00:00			
1	1	13:45:08	1	1	2	0:00:16	0:00:45			
3	10	13:45:42	1	0	1	0:00:34	0:00:00	0:00:20		
2	1	13:45:57	0	1	1	0:00:15	0:00:00			0:00:50
3	1	13:46:47	0	0	0	0:00:49	0:00:00	0:00:49		
2	6	13:47:24	0	1	1	0:00:37	0:02:16			0:00:00
1	14	13:47:29	1	1	2	0:00:05	0:00:05			
3	6	13:48:02	1	0	1	0:00:33	0:00:00	0:00:38		
2	14	13:48:22	0	1	1	0:00:20	0:00:00			0:00:53
1	3	13:48:24	1	1	2	0:00:02	0:00:55			
3	14	13:49:21	1	0	1	0:00:57	0:00:00	0:00:59		
1	13	13:49:27	2	0	2	0:00:06	0:01:03			
2	3	13:49:44	1	1	2	0:00:17	0:00:00			0:01:20
3	3	13:50:26	1	0	1	0:00:43	0:00:00	0:01:06		
1	10	13:50:38	2	0	2	0:00:12	0:01:11			
2	13	13:50:47	1	1	2	0:00:10	0:00:00			0:01:21
3	13	13:51:30	1	0	1	0:00:42	0:00:00	0:01:03		
1	6	13:51:44	2	0	2	0:00:15	0:01:07			
2	10	13:51:54	1	1	2	0:00:09	0:00:00			0:01:16
1	14	13:52:18	2	1	3	0:00:24	0:00:34			
3	10	13:53:06	2	0	2	0:00:48	0:00:00	0:01:37		
2	6	13:53:35	1	1	2	0:00:29	0:00:00			0:01:51
1	1	13:54:00	2	1	3	0:00:25	0:01:42			
3	6	13:54:13	2	0	2	0:00:13	0:00:00	0:01:07		
2	14	13:54:33	1	1	2	0:00:20	0:00:00			0:02:15
3	14	13:55:17	1	0	1	0:00:43	0:00:00	0:01:04		
2	1	13:55:38	0	1	1	0:00:21	0:00:00			0:01:38
3	1	13:56:21	0	0	0	0:00:43	0:00:00	0:00:43		
6	111	13:57:20	0	0	0	0:00:59	0:00:00			

Figure A.10 - Field data for Mar7p.1 data file (continued).

• Crane #3 servicing "ACT III"										
• March 7, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, al
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
2	3	14:00:45	0	1	1	0:03:25	0:06:45			0:00:00
7	111	14:00:48	0	1	1	0:00:03	0:00:00			
3	3	14:01:18	0	0	0	0:00:30	0:00:00	0:00:33		
2	13	14:02:11	0	1	1	0:00:52	0:01:25			0:00:00
3	13	14:02:32	0	0	0	0:00:21	0:00:00	0:00:21		
6	111	14:03:24	0	0	0	0:00:52	0:00:00			
2	10	14:04:32	0	1	1	0:01:08	0:02:21			0:00:00
7	111	14:04:34	0	1	1	0:00:02	0:00:00			
3	10	14:04:57	0	0	0	0:00:23	0:00:00	0:00:25		
6	111	14:06:40	0	0	0	0:01:43	0:00:00			
2	5	14:09:06	0	1	1	0:02:26	0:04:34			0:00:00
7	111	14:09:08	0	1	1	0:00:02	0:00:00			
3	5	14:09:53	0	0	0	0:00:45	0:00:00	0:00:47		
2	4	14:10:15	0	1	1	0:00:22	0:01:10			
3	4	14:11:15	0	0	0	0:01:00	0:00:00	0:01:00		
6	111	14:12:22	0	0	0	0:01:07	0:00:00			
2	7	14:12:38	0	1	1	0:00:17	0:02:23			0:00:00
7	111	14:12:41	0	1	1	0:00:02	0:00:00			
3	7	14:12:51	0	0	0	0:00:10	0:00:00	0:00:12		
2	3	14:13:33	0	1	1	0:00:42	0:00:55			0:00:00
3	3	14:13:52	0	0	0	0:00:19	0:00:00	0:00:19		
2	4	14:14:11	0	1	1	0:00:19	0:00:38			
1	5	14:14:13	1	1	2	0:00:02	0:00:02			
3	4	14:15:01	1	0	1	0:00:48	0:00:00	0:00:51		
2	5	14:15:11	0	1	1	0:00:10	0:00:00			0:00:58
3	5	14:15:55	0	0	0	0:00:44	0:00:00	0:00:44		
2	6	14:16:22	0	1	1	0:00:27	0:02:09			0:00:00
1	1	14:16:30	1	1	2	0:00:08	0:00:08			
1	7	14:16:54	2	1	3	0:00:24	0:00:24			
3	6	14:17:11	2	0	2	0:00:17	0:00:00	0:00:49		
999	-1	14:17:39	2	0	2	0:00:29	0:00:00			
2	1	14:17:47	1	1	2	0:00:08	0:00:00			
3	1	14:18:12	1	0	1	0:00:25	0:00:00	0:01:02		
2	7	14:18:42	0	1	1	0:00:29	0:00:00			0:01:48
999	8	14:18:48	0	1	1	0:00:06	0:00:00			
3	7	14:20:17	0	0	0	0:01:29	0:00:00	0:01:35		
6	111	14:21:14	0	0	0	0:00:56	0:00:00			
7	111	14:26:07	0	0	0	0:04:53	0:00:00			
2	9	14:26:10	0	1	1	0:00:04	0:09:17			0:00:00
3	9	14:26:22	0	0	0	0:00:12	0:00:00	0:00:12		
2	10	14:26:45	0	1	1	0:00:23	0:00:35			0:00:00
3	10	14:27:20	0	0	0	0:00:35	0:00:00	0:00:35		
4	111	14:28:12	0	0	0	0:00:52	0:00:00			
5	111	14:28:45	0	0	0	0:00:33	0:00:00			

Figure A.11 - Field data for Mar7p.2 data file.

• Crane #3 servicing "ACT III"										
• March 7, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
			0	0	0					
1	3	14:33:19	1	0	1	0:00:00	0:00:00		0:02:38	0:00:00
1	1	14:33:22	2	0	2	0:00:03	0:00:03		0:02:40	0:00:00
1	6	14:33:25	3	0	3	0:00:03	0:00:03		0:02:52	0:00:00
1	10	14:33:33	4	0	4	0:00:07	0:00:07		0:02:56	0:00:00
1	13	14:33:38	5	0	5	0:00:06	0:00:06		0:03:03	0:00:00
1	14	14:34:02	6	0	6	0:00:24	0:00:24		0:03:05	0:00:00
2	3	14:36:57	5	1	6	0:02:54	0:00:00		0:03:08	0:00:00
3	3	14:38:28	5	0	5	0:01:31	0:00:00		0:03:13	0:00:45
2	13	14:38:44	4	1	5	0:00:16	0:00:00		0:03:15	0:00:57
3	13	14:39:55	4	0	4	0:01:11	0:00:00	0:01:27	0:03:19	0:01:05
2	1	14:40:13	3	1	4	0:00:18	0:00:00		0:03:22	0:01:15
3	1	14:41:01	3	0	3	0:00:48	0:00:00	0:01:07	0:03:25	0:01:18
2	6	14:41:24	2	1	3	0:00:22	0:00:00		0:03:28	0:01:20
1	3	14:42:04	3	1	4	0:00:40	0:08:01		0:03:29	0:01:27
3	6	14:42:52	3	0	3	0:00:48	0:00:00	0:01:50	0:03:32	0:01:29
1	13	14:43:00	4	0	4	0:00:08	0:00:56		0:03:32	0:01:46
2	10	14:43:09	3	1	4	0:00:09	0:00:00		0:03:36	0:01:47
3	10	14:44:05	3	0	3	0:00:56	0:00:00	0:01:13	0:03:36	0:01:48
2	14	14:44:33	2	1	3	0:00:28	0:00:00		0:03:38	0:01:58
1	12	14:44:51	3	1	4	0:00:18	0:01:51		0:03:39	0:02:05
1	1	14:44:55	4	1	5	0:00:04	0:00:04		0:03:40	0:02:06
3	14	14:45:10	4	0	4	0:00:16	0:00:00	0:01:05	0:03:41	0:02:15
2	3	14:45:34	3	1	4	0:00:23	0:00:00		0:03:51	0:02:20
3	3	14:46:13	3	0	3	0:00:39	0:00:00	0:01:03	0:03:53	0:02:26
1	6	14:46:23	4	0	4	0:00:10	0:01:28		0:03:57	0:02:27
2	13	14:46:46	3	1	4	0:00:23	0:00:00		0:03:57	0:02:28
3	13	14:47:33	3	0	3	0:00:46	0:00:00	0:01:19	0:03:58	0:02:30
2	1	14:47:52	2	1	3	0:00:20	0:00:00		0:03:58	0:02:35
1	10	14:47:56	3	1	4	0:00:03	0:01:33		0:04:07	0:02:41
1	14	14:48:03	4	1	5	0:00:07	0:00:07		0:04:25	0:02:51
3	1	14:48:44	4	0	4	0:00:42	0:00:00	0:01:11	0:04:25	0:02:54
2	6	14:49:04	3	1	4	0:00:20	0:00:00		0:05:04	0:02:58
1	3	14:49:27	4	1	5	0:00:23	0:01:24		0:05:19	0:03:03
3	6	14:50:06	4	0	4	0:00:39	0:00:00	0:01:22	0:05:33	0:03:17
1	13	14:50:11	5	0	5	0:00:05	0:00:45		0:06:20	0:03:30
2	10	14:50:23	4	1	5	0:00:12	0:00:00		0:06:27	0:03:37
3	10	14:51:12	4	0	4	0:00:49	0:00:00	0:01:06	0:06:42	0:03:47
2	14	14:51:40	3	1	4	0:00:28	0:00:00		0:10:28	
1	1	14:51:59	4	1	5	0:00:19	0:01:48		0:10:31	
3	14	14:52:02	4	0	4	0:00:03	0:00:00	0:00:50	0:10:51	
2	3	14:52:20	3	1	4	0:00:19	0:00:00		0:11:31	
3	3	14:52:50	3	0	3	0:00:30	0:00:00	0:00:49	0:11:42	
2	13	14:53:02	2	1	3	0:00:11	0:00:00		0:15:24	
1	6	14:53:27	3	1	4	0:00:26	0:01:28			
3	13	14:54:12	3	0	3	0:00:45	0:00:00	0:01:22		
1	10	14:54:20	4	0	4	0:00:08	0:00:53			
2	1	14:54:27	3	1	4	0:00:07	0:00:00			
1	14	14:54:41	4	1	5	0:00:14	0:00:21			

Figure A.11 - Field data for Mar7p.2 data file (continued).

• Crane #3 servicing "ACT III"										
• March 7, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
3	1	14:55:41	4	0	4	0:01:00	0:00:00	0:01:29		
2	6	14:56:02	3	1	4	0:00:21	0:00:00			
3	6	14:56:29	3	0	3	0:00:26	0:00:00	0:00:48		
1	3	14:56:31	4	0	4	0:00:02	0:01:50			
2	10	14:56:55	3	1	4	0:00:24	0:00:00			
3	10	14:57:25	3	0	3	0:00:30	0:00:00			
2	14	14:57:44	2	1	3	0:00:19	0:00:00			
1	13	14:58:09	3	1	4	0:00:25	0:01:38			
3	14	14:58:11	3	0	3	0:00:03	0:00:00	0:00:47		
2	3	14:58:29	2	1	3	0:00:18	0:00:00			
3	3	14:58:54	2	0	2	0:00:25	0:00:00	0:00:43		
2	13	14:59:05	1	1	2	0:00:11	0:00:00			
1	1	14:59:10	2	1	3	0:00:05	0:01:02			
3	13	15:00:07	2	0	2	0:00:56	0:00:00	0:01:12		
2	1	15:00:25	1	1	2	0:00:19	0:00:00			
1	6	15:00:35	2	1	3	0:00:10	0:01:25			
1	10	15:01:23	3	1	4	0:00:47	0:00:47			
1	14	15:01:36	4	1	5	0:00:14	0:00:14			
3	1	15:02:34	4	0	4	0:00:57	0:00:00	0:02:27		
2	6	15:02:56	3	1	4	0:00:22	0:00:00			
1	3	15:03:19	4	1	5	0:00:23	0:01:43			
3	6	15:03:36	4	0	4	0:00:17	0:00:00	0:01:02		
2	10	15:03:53	3	1	4	0:00:17	0:00:00			
1	13	15:04:05	4	1	5	0:00:12	0:00:46			
3	10	15:04:24	4	0	4	0:00:19	0:00:00	0:00:48		
2	14	15:04:53	3	1	4	0:00:29	0:00:00			
3	14	15:05:23	3	0	3	0:00:30	0:00:00	0:00:59		
1	6	15:07:17	4	0	4	0:01:55	0:03:12			
1	10	15:08:02	5	0	5	0:00:45	0:00:45			
1	14	15:08:25	6	0	6	0:00:23	0:00:23			
6	111	15:08:46	6	0	6	0:00:20	0:00:00			
2	3	15:11:11	5	1	6	0:02:25	0:00:00			
3	3	15:21:52	5	0	5	0:10:41	0:00:00			
2	13	15:22:10	4	1	5	0:00:18	0:00:00			
3	13	15:23:10	4	0	4	0:01:00	0:00:00	0:01:18		
2	1	15:23:30	3	1	4	0:00:20	0:00:00			
1	14	15:23:49	4	1	5	0:00:20	0:15:24			
3	1	15:24:15	4	0	4	0:00:25	0:00:00	0:01:05		
2	6	15:24:41	3	1	4	0:00:27	0:00:00			
3	6	15:25:05	3	0	3	0:00:24	0:00:00	0:00:51		
1	3	15:25:11	4	0	4	0:00:05	0:01:21			
2	10	15:25:26	3	1	4	0:00:15	0:00:00			
3	10	15:26:01	3	0	3	0:00:35	0:00:00	0:00:55		
1	13	15:26:06	4	0	4	0:00:06	0:00:56			
2	14	15:26:16	3	1	4	0:00:09	0:00:00			
3	14	15:26:57	3	0	3	0:00:41	0:00:00	0:00:56		
2	3	15:27:15	2	1	3	0:00:19	0:00:00			
1	1	15:27:43	3	1	4	0:00:28	0:01:37			
3	3	15:28:01	3	0	3	0:00:18	0:00:00	0:01:04		

Figure A.11 - Field data for Mar7p.2 data file (continued).

• Crane #3 servicing "ACT III"										
• March 7, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
2	13	15:28:22	2	1	3	0:00:20	0:00:00			
1	6	15:28:41	3	1	4	0:00:19	0:00:58			
3	13	15:28:50	3	0	3	0:00:09	0:00:00	0:00:49		
2	1	15:29:12	2	1	3	0:00:22	0:00:00			
1	10	15:29:33	3	1	4	0:00:21	0:00:52			
3	1	15:29:39	3	0	3	0:00:06	0:00:00	0:00:49		
2	6	15:29:59	2	1	3	0:00:20	0:00:00			
1	14	15:30:36	3	1	4	0:00:37	0:01:03			
3	6	15:30:42	3	0	3	0:00:06	0:00:00	0:01:03		
2	10	15:30:59	2	1	3	0:00:18	0:00:00			
3	10	15:31:55	2	0	2	0:00:55	0:00:00	0:01:13		
2	14	15:32:23	1	1	2	0:00:28	0:00:00			
1	3	15:32:26	2	1	3	0:00:03	0:01:50			
1	13	15:32:47	3	1	4	0:00:21	0:00:21			
3	14	15:32:51	3	0	3	0:00:04	0:00:00	0:00:56		
2	3	15:33:10	2	1	3	0:00:19	0:00:00			
3	3	15:33:36	2	0	2	0:00:26	0:00:00	0:00:45		
2	13	15:33:51	1	1	2	0:00:15	0:00:00			
3	13	15:34:22	1	0	1	0:00:31	0:00:00	0:00:46		
6	111	15:35:08	1	0	1	0:00:46	0:00:00			
2	1	15:40:21	0	1	1	0:05:13	0:00:00			
7	111	15:40:24	0	1	1	0:00:03	0:00:00			
3	1	15:40:35	0	0	0	0:00:11	0:00:00	0:00:14		
2	6	15:41:33	0	1	1	0:00:58	0:08:46			
3	6	15:41:40	0	0	0	0:00:07	0:00:00	0:00:07		
2	10	15:42:26	0	1	1	0:00:46	0:00:52			
3	10	15:42:42	0	0	0	0:00:16	0:00:00	0:00:16		
2	14	15:43:19	0	1	1	0:00:37	0:00:53			
3	14	15:44:38	0	0	0	0:01:19	0:00:00	0:01:19		
2	3	15:45:18	0	1	1	0:00:40	0:01:59			
3	3	15:45:28	0	0	0	0:00:10	0:00:00	0:00:10		
2	13	15:45:54	0	1	1	0:00:25	0:00:35			
3	13	15:46:18	0	0	0	0:00:24	0:00:00	0:00:24		
2	1	15:47:17	0	1	1	0:01:00	0:01:24			
3	1	15:47:46	0	0	0	0:00:29	0:00:00	0:00:29		
2	6	15:48:07	0	1	1	0:00:21	0:00:50			
1	10	15:49:02	1	1	2	0:00:54	0:00:54			
1	14	15:49:42	2	1	3	0:00:40	0:00:40			
3	6	15:50:03	2	0	2	0:00:21	0:00:00	0:01:56		
2	10	15:50:22	1	1	2	0:00:19	0:00:00			
1	3	15:50:47	2	1	3	0:00:25	0:01:05			
3	10	15:51:21	2	0	2	0:00:33	0:00:00	0:01:18		
2	14	15:51:48	1	1	2	0:00:27	0:00:00			
1	13	15:51:51	2	1	3	0:00:03	0:01:04			
3	14	15:52:21	2	0	2	0:00:30	0:00:00	0:01:00		
2	3	15:52:35	1	1	2	0:00:14	0:00:00			
3	3	15:53:16	1	0	1	0:00:41	0:00:00	0:00:55		
2	13	15:53:38	0	1	1	0:00:22	0:00:00			
3	13	15:54:11	0	0	0	0:00:34	0:00:00	0:00:34		

Figure A.12 - Field data for Mar8a.1 data file.

• Crane #3 servicing "TNT Express"										
• March 8, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	Time
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	in queue
			5	0	5					
2	10	8:18:48	4	1	5	0:00:00	0:00:00		0:02:53	0:00:00
999	5	8:18:52	4	1	5	0:00:04	0:00:00		0:03:06	0:00:00
999	13	8:18:57	4	1	5	0:00:05	0:00:00		0:03:15	0:00:00
									0:03:23	0:00:00
3	10	8:35:36	4	0	4	0:16:39	0:00:00		0:03:28	0:00:00
2	5	8:35:55	3	1	4	0:00:19	0:00:00		0:03:31	0:00:00
3	5	8:38:13	3	0	3	0:02:18	0:00:00	0:02:37	0:04:03	0:00:00
2	13	8:38:30	2	1	3	0:00:16	0:00:00		0:04:48	0:00:00
1	10	8:38:51	3	1	4	0:00:22	0:20:03		0:05:30	0:00:19
3	13	8:39:39	3	0	3	0:00:48	0:00:00	0:01:26	0:07:29	0:00:43
2	7	8:39:53	2	1	3	0:00:14	0:00:00		0:07:29	0:01:07
1	14	8:40:39	3	1	4	0:00:46	0:01:48		0:07:51	0:01:24
3	7	8:40:52	3	0	3	0:00:12	0:00:00	0:01:13	0:08:51	0:01:38
2	1	8:41:07	2	1	3	0:00:15	0:00:00		0:09:05	0:01:47
1	5	8:41:45	3	1	4	0:00:38	0:01:05		0:09:07	0:02:31
3	1	8:42:25	3	0	3	0:00:41	0:00:00	0:01:34	0:09:38	0:03:28
2	10	8:42:43	2	1	3	0:00:17	0:00:00		0:13:12	0:03:51
1	13	8:43:42	3	1	4	0:00:59	0:01:57		0:14:22	0:04:12
3	10	8:43:55	3	0	3	0:00:14	0:00:00	0:01:30	0:16:09	0:04:29
2	14	8:44:08	2	1	3	0:00:12	0:00:00		0:16:46	0:04:51
3	14	8:46:11	2	0	2	0:02:03	0:00:00	0:02:16	0:17:21	0:05:06
2	5	8:46:35	1	1	2	0:00:25	0:00:00			0:05:51
1	10	8:46:48	2	1	3	0:00:13	0:03:07			0:06:12
3	5	8:47:29	2	0	2	0:00:41	0:00:00	0:01:18		
2	13	8:47:53	1	1	2	0:00:24	0:00:00			
3	13	8:49:09	1	0	1	0:01:15	0:00:00	0:01:40		
2	10	8:49:20	0	1	1	0:00:11	0:00:00			
		16:33:48								
2	1	9:20:35	0	1	1	0:31:16	0:33:47			
1	5	9:20:47	1	1	2	0:00:11	0:00:11			
1	14	9:20:50	2	1	3	0:00:03	0:00:03			
1	13	9:20:52	3	1	4	0:00:03	0:00:03			
1	10	9:20:55	4	1	5	0:00:02	0:00:02			
3	1	9:22:56	4	0	4	0:02:02	0:00:00	0:02:21		
1	7	9:23:00	5	0	5	0:00:04	0:02:06			
2	5	9:23:13	4	1	5	0:00:12	0:00:00			
4	111	9:23:34	4	1	5	0:00:21	0:00:00			
5	111	9:24:15	4	1	5	0:00:41	0:00:00			
3	5	9:25:41	4	0	4	0:01:26	0:00:00	0:02:44		
2	14	9:26:05	3	1	4	0:00:25	0:00:00			
3	14	9:27:40	3	0	3	0:01:34	0:00:00	0:01:59		
2	13	9:27:54	2	1	3	0:00:14	0:00:00			
1	1	9:28:26	3	1	4	0:00:32	0:05:26			
1	5	9:29:04	4	1	5	0:00:37	0:00:37			
3	13	9:29:46	4	0	4	0:00:42	0:00:00	0:02:06		
2	10	9:30:04	3	1	4	0:00:18	0:00:00			
3	10	9:31:04	3	0	3	0:01:00	0:00:00	0:01:18		

Figure A.12 - Field data for Mar8a.1 data file (continued).

• Crane #3 servicing "TNT Express"										
• March 8, 1991									Backcycle	
						elapsed	Inter	Service	Time, all	Time
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	in queue
1	14	9:31:08	4	0	4	0:00:04	0:02:04			
2	7	9:31:28	3	1	4	0:00:20	0:00:00			
1	13	9:32:52	4	1	5	0:01:44	0:01:44			
3	7	9:33:57	4	0	4	0:01:05	0:00:00			
2	1	9:34:17	3	1	4	0:00:20	0:00:00			
3	1	9:34:54	3	0	3	0:00:37	0:00:00	0:00:57		
2	5	9:35:15	2	1	3	0:00:21	0:00:00			
3	5	9:35:54	2	0	2	0:00:39	0:00:00	0:01:00		
2	14	9:36:13	1	1	2	0:00:19	0:00:00			
3	14	9:37:05	1	0	1	0:00:52	0:00:00	0:01:11		
2	13	9:37:21	0	1	1	0:00:16	0:00:00			
1	1	9:39:42	1	1	2	0:02:21	0:06:50			
3	13	9:40:26	1	0	1	0:00:44	0:00:00	0:03:05		
2	1	9:40:49	0	1	1	0:00:23	0:00:00			
3	1	9:41:19	0	0	0	0:00:30	0:00:00			
		20:08:44								
1	10	9:49:33	1	0	1	0:08:14	0:09:51			
2	10	9:49:55	0	1	1	0:00:22	0:00:00			
1	7	9:50:06	1	1	2	0:00:12	0:00:34			
3	10	9:51:24	1	0	1	0:01:18	0:00:00	0:01:30		
1	14	9:51:27	2	0	2	0:00:03	0:01:21			
2	7	9:51:44	1	1	2	0:00:17	0:00:00			
1	5	9:52:41	2	1	3	0:00:56	0:01:13			
3	7	9:52:48	2	0	2	0:00:08	0:00:00	0:01:24		
2	14	9:53:14	1	1	2	0:00:26	0:00:00			
3	14	9:53:47	1	0	1	0:00:32	0:00:00	0:00:59		
2	5	9:54:04	0	1	1	0:00:17	0:00:00			
1	1	9:54:30	1	1	2	0:00:26	0:01:50			
3	5	9:54:51	1	0	1	0:00:21	0:00:00	0:00:47		
2	1	9:55:14	0	1	1	0:00:22	0:00:00			
3	1	9:55:57	0	0	0	0:00:44	0:00:00	0:00:44		
2	13	9:57:46	0	1	1	0:01:49	0:03:16			
3	13	9:58:19	0	0	0	0:00:33	0:00:00	0:00:33		
2	10	9:58:53	0	1	1	0:00:34	0:01:07			
3	10	10:00:12	0	0	0	0:01:18	0:00:00	0:01:18		
2	14	10:01:16	0	1	1	0:01:04	0:02:22			
1	7	10:01:55	1	1	2	0:00:39	0:00:39			
3	14	10:02:00	1	0	1	0:00:06	0:00:00	0:00:45		
2	7	10:02:13	0	1	1	0:00:13	0:00:00			
1	5	10:03:42	1	1	2	0:01:29	0:01:48			
1	1	10:05:03	2	1	3	0:01:21	0:01:21			
1	13	10:07:57	3	1	4	0:02:54	0:02:54			
1	10	10:08:02	4	1	5	0:00:05	0:00:05			

Figure A.13 - Field data for Mar8a.2 data file.

• Crane #3 servicing "TNT Express"										
• March 8, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
			0	0	0					
999	50	10:59:40	0	0	0	0:00:00	0:00:00		0:02:56	0:00:00
2	5	10:59:44	0	1	1	0:00:04	0:00:04		0:03:03	0:01:01
1	1	11:00:26	1	1	2	0:00:42	0:00:42		0:03:15	0:02:12
1	13	11:00:29	2	1	3	0:00:03	0:00:03		0:03:23	0:02:34
1	10	11:00:33	3	1	4	0:00:05	0:00:05		0:03:40	0:03:29
1	14	11:00:36	4	1	5	0:00:03	0:00:03		0:03:44	0:04:23
3	5	11:01:03	4	0	4	0:00:27	0:00:00	0:01:19	0:03:44	0:04:23
2	1	11:01:27	3	1	4	0:00:24	0:00:00		0:03:45	0:04:42
3	1	11:02:26	3	0	3	0:00:59	0:00:00	0:01:23	0:03:47	0:04:46
2	13	11:02:41	2	1	3	0:00:14	0:00:00		0:03:50	0:05:09
1	7	11:02:44	3	1	4	0:00:04	0:02:08		0:03:56	0:06:26
3	13	11:03:40	3	0	3	0:00:56	0:00:00	0:01:14	0:04:14	0:06:49
2	10	11:04:02	2	1	3	0:00:22	0:00:00		0:04:16	0:07:36
3	10	11:04:56	2	0	2	0:00:53	0:00:00	0:01:15	0:04:49	0:08:15
1	5	11:04:59	3	0	3	0:00:03	0:02:15			0:08:21
2	14	11:05:22	2	1	3	0:00:23	0:00:00			0:08:31
1	1	11:06:07	3	1	4	0:00:45	0:01:08			0:08:49
3	14	11:06:51	3	0	3	0:00:45	0:00:00	0:01:56		
2	7	11:07:07	2	1	3	0:00:16	0:00:00			
3	7	11:08:04	2	0	2	0:00:57	0:00:00	0:01:13		
2	1	11:08:10	1	1	2	0:00:06	0:00:00			
1	13	11:08:30	2	1	3	0:00:25	0:02:23			
1	10	11:08:42	3	1	4	0:00:13	0:00:13			
3	1	11:09:24	3	0	3	0:00:42	0:00:00			
2	5	11:09:41	2	1	3	0:00:17	0:00:00			
3	5	11:10:50	2	0	2	0:01:09	0:00:00	0:01:26		
2	13	11:11:04	1	1	2	0:00:14	0:00:00			
1	14	11:11:07	2	1	3	0:00:04	0:02:25			
1	7	11:11:27	3	1	4	0:00:20	0:00:20			
1	1	11:13:08	4	1	5	0:01:41	0:01:41			
3	13	11:13:34	4	0	4	0:00:25	0:00:00	0:02:43		
2	10	11:13:52	3	1	4	0:00:18	0:00:00			
1	5	11:14:40	4	1	5	0:00:48	0:01:31			
3	10	11:15:04	4	0	4	0:00:24	0:00:00	0:01:30		
2	14	11:15:30	3	1	4	0:00:27	0:00:00			
1	13	11:17:17	4	1	5	0:01:47	0:02:38			
1	10	11:18:19	5	1	6	0:01:02	0:01:02			
3	14	11:19:35	5	0	5	0:01:16	0:00:00	0:04:31		
2	7	11:19:48	4	1	5	0:00:14	0:00:00			
3	7	11:21:18	4	0	4	0:01:29	0:00:00	0:01:43		
2	1	11:21:40	3	1	4	0:00:22	0:00:00			
1	14	11:22:31	4	1	5	0:00:52	0:04:12			
3	1	11:22:38	4	0	4	0:00:07	0:00:00	0:01:20		
2	5	11:22:55	3	1	4	0:00:17	0:00:00			
1	7	11:24:21	4	1	5	0:01:26	0:01:49			
3	5	11:24:30	4	0	4	0:00:09	0:00:00	0:01:52		
2	13	11:24:53	3	1	4	0:00:24	0:00:00			
1	1	11:26:52	4	1	5	0:01:59	0:02:32			

Figure A.13 - Field data for Mar8a.2 data file (continued).

• Crane #3 servicing "TNT Express"										
• March 8, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
3	13	11:26:54	4	0	4	0:00:02	0:00:00	0:02:25		
2	10	11:27:08	3	1	4	0:00:14	0:00:00			
3	10	11:28:56	3	0	3	0:01:48	0:00:00	0:02:02		
2	14	11:29:21	2	1	3	0:00:24	0:00:00			
3	14	11:30:35	2	0	2	0:01:14	0:00:00	0:01:38		
1	13	11:30:39	3	0	3	0:00:04	0:03:47			
2	7	11:30:47	2	1	3	0:00:08	0:00:00			
3	7	11:32:10	2	0	2	0:01:23	0:00:00	0:01:35		

Figure A.14 - Field data for Mar8p.1 data file.

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #2 servicing "TNT Express"										
2	• March 8, 1991									Backcycle	Time in
3							elapsed	Inter	Service	Time, all	Queue, al
4	Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
5				0	0	0					
6	6	111	14:05:56	0	0	0	0:00:00	0:00:00		0:01:46	0:00:00
7	2	15	14:06:58	0	1	1	0:01:01	0:01:01		0:02:07	0:00:00
8	7	111	14:07:01	0	1	1	0:00:03	0:00:00		0:02:16	0:00:00
9	3	15	14:07:16	0	0	0	0:00:15	0:00:00	0:00:18	0:02:30	0:00:00
10	2	4	14:11:15	0	1	1	0:03:59	0:04:17		0:02:30	0:00:00
11	3	4	14:11:41	0	0	0	0:00:26	0:00:00	0:00:26	0:02:33	0:00:00
12	2	3	14:12:09	0	1	1	0:00:27	0:00:54		0:02:34	0:00:00
13	1	8	14:12:35	1	1	2	0:00:26	0:00:26		0:02:38	0:00:00
14	4	111	14:13:11	1	1	2	0:00:36	0:00:00		0:02:40	0:00:00
15	5	111	14:13:26	1	1	2	0:00:15	0:00:00		0:02:44	0:00:00
16	4	111	14:15:41	1	1	2	0:02:15	0:00:00		0:03:08	0:00:00
17	5	111	14:15:50	1	1	2	0:00:09	0:00:00		0:03:09	0:00:00
18	3	3	14:16:11	1	0	1	0:00:21	0:00:00	0:04:03	0:03:31	0:00:00
19	2	8	14:16:28	0	1	1	0:00:17	0:00:00		0:03:34	0:00:00
20	1	5	14:16:33	1	1	2	0:00:05	0:03:58		0:03:37	0:00:00
21	3	8	14:18:12	1	0	1	0:01:39	0:00:00	0:01:43	0:04:13	0:00:00
22	2	9	14:18:53	0	1	1	0:00:42	0:00:00		0:04:23	0:00:00
23	1	2	14:19:06	1	1	2	0:00:13	0:02:33		0:04:36	0:00:00
24	1	19	14:19:39	2	1	3	0:00:33	0:00:33		0:04:38	0:00:00
25	3	9	14:21:09	2	0	2	0:01:30	0:00:00	0:02:16	0:04:50	0:00:22
26	2	5	14:21:34	1	1	2	0:00:25	0:00:00		0:04:58	0:00:34
27	3	5	14:22:11	1	0	1	0:00:37	0:00:00	0:01:02	0:05:18	0:00:43
28	2	2	14:22:35	0	1	1	0:00:24	0:00:00		0:05:25	0:00:56
29	3	2	14:23:06	0	0	0	0:00:31	0:00:00	0:00:31	0:05:31	0:01:31
30	2	19	14:24:11	0	1	1	0:01:05	0:04:32		0:05:34	0:01:34
31	3	19	14:24:44	0	0	0	0:00:33	0:00:00	0:00:33	0:05:56	0:01:51
32	6	111	14:25:31	0	0	0	0:00:46	0:00:00		0:06:08	0:02:02
33	1	3	14:36:30	1	0	1	0:11:00	0:12:19		0:06:08	0:02:02
34	7	111	14:36:36	1	0	1	0:00:05	0:00:00		0:06:17	0:02:10
35	2	3	14:37:05	0	1	1	0:00:29	0:00:00		0:06:21	0:02:28
36	1	14	14:39:03	1	1	2	0:01:59	0:02:33		0:06:23	0:02:49
37	3	3	14:40:28	1	0	1	0:01:25	0:00:00	0:03:23	0:06:38	0:02:57
38	2	14	14:40:54	0	1	1	0:00:26	0:00:00		0:06:50	0:03:05
39	3	14	14:41:41	0	0	0	0:00:47	0:00:00	0:00:47	0:07:03	0:03:35
40	2	5	14:43:06	0	1	1	0:01:25	0:04:02		0:07:04	0:03:40
41	3	5	14:43:27	0	0	0	0:00:22	0:00:00	0:00:22	0:07:17	0:03:40
42	2	15	14:44:09	0	1	1	0:00:41	0:01:03		0:07:53	0:03:43
43	crane idle with container									0:08:13	0:03:44
44	1	14	14:50:51	1	0	1	0:06:42	0:06:42		0:08:24	0:03:48
45	1	10	14:51:22	2	0	2	0:00:31	0:00:31		0:08:37	0:03:49
46	1	7	14:51:38	3	0	3	0:00:16	0:00:16		0:08:59	0:03:53
47	1	1	14:53:08	4	0	4	0:01:30	0:01:30		0:10:01	0:05:01
48	1	13	14:53:18	5	0	5	0:00:10	0:00:10		0:10:17	0:05:16
49	8	13	14:53:54	5	0	5	0:00:37	0:00:00		0:13:29	0:05:51
50	7.1	111	14:56:25	5	0	5	0:02:31	0:00:00		0:18:31	0:05:55
51	1	5	14:56:56	6	0	6	0:00:31	0:03:38		0:20:54	0:06:04
52	2	13	14:57:02	5	1	6	0:00:06	0:00:00		0:25:24	0:06:24

Figure A.14 - Field data for Mar8p.1 data file (continued).

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #2 servicing "TNT Express"										
2	• March 8, 1991									Backcycle	Time in
3							elapsed	Inter	Service	Time, all	Queue, al
4	Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
53	3	13	14:57:54	5	0	5	0:00:53	0:00:00		1:17:00	0:06:30
54	2	1	14:58:24	4	1	5	0:00:30	0:00:00			0:06:53
55	3	1	15:00:17	4	0	4	0:01:53	0:00:00	0:02:23		0:07:42
56	2	5	15:00:44	3	1	4	0:00:27	0:00:00			0:09:26
57	1	13	15:01:31	4	1	5	0:00:48	0:04:35			0:09:59
58	3	5	15:01:48	4	0	4	0:00:17	0:00:00	0:01:31		0:10:35
59	2	7	15:02:13	3	1	4	0:00:25	0:00:00			0:15:03
60	1	1	15:05:48	4	1	5	0:03:35	0:04:16			
61	1	5	15:06:01	5	1	6	0:00:13	0:00:13			0:18:20
62	3	7	15:06:06	5	0	5	0:00:05	0:00:00	0:04:18		0:19:02
63	2	10	15:06:25	4	1	5	0:00:20	0:00:00			0:19:36
64	3	10	15:07:34	4	0	4	0:01:09	0:00:00	0:01:29		0:21:10
65	2	14	15:08:00	3	1	4	0:00:25	0:00:00			0:22:21
66	3	14	15:08:58	3	0	3	0:00:58	0:00:00	0:01:24		
67	2	13	15:09:13	2	1	3	0:00:15	0:00:00			
68	1	7	15:09:40	3	1	4	0:00:27	0:03:39			
69	3	13	15:10:04	3	0	3	0:00:24	0:00:00	0:01:05		
70	2	1	15:10:25	2	1	3	0:00:21	0:00:00			
71	3	1	15:12:02	2	0	2	0:01:59	0:00:00			
72	2	5	15:12:25	1	1	2	0:00:23	0:00:00			
73	3	5	15:13:02	1	0	1	0:00:37	0:00:00	0:01:00		
74	2	7	15:13:20	0	1	1	0:00:18	0:00:00			
75	1	10	15:13:42	1	1	2	0:00:22	0:04:02			
76	1	1	15:13:48	2	1	3	0:00:06	0:00:06			
77	3	7	15:14:21	2	0	2	0:00:33	0:00:00	0:01:01		
78	2	10	15:14:39	1	1	2	0:00:18	0:00:00			
79	1	13	15:14:54	2	1	3	0:00:15	0:01:05			
80	4	111	15:15:32	2	1	3	0:00:39	0:00:00			
81	5	111	15:15:53	2	1	3	0:00:21	0:00:00			
82	3	10	15:16:06	2	0	2	0:00:13	0:00:00	0:01:45		
83	2	13	15:16:25	1	1	2	0:00:19	0:00:00			
84	3	13	15:17:43	1	0	1	0:01:19	0:00:00	0:01:38		
85	2	14	15:17:59	0	1	1	0:00:15	0:00:00			
86	1	1	15:18:24	1	1	2	0:00:26	0:03:31			
87	3	14	15:20:06	1	0	1	0:01:42	0:00:00	0:02:08		
88	2	1	15:20:26	0	1	1	0:00:20	0:00:00			
89	1	7	15:20:29	1	1	2	0:00:03	0:02:05			
90	3	1	15:21:31	1	0	1	0:01:02	0:00:00	0:01:04		
91	2	5	15:21:51	0	1	1	0:00:20	0:00:00			
92	1	10	15:23:09	1	1	2	0:01:19	0:02:40			
93	3	5	15:23:50	1	0	1	0:00:40	0:00:00	0:01:59		
94	1	13	15:24:00	2	0	2	0:00:10	0:00:51			
95	2	7	15:24:04	1	1	2	0:00:04	0:00:00			
96	3	7	15:25:15	1	0	1	0:01:10	0:00:00	0:01:25		
97	1	14	15:25:24	2	0	2	0:00:10	0:01:24			
98	2	10	15:25:37	1	1	2	0:00:13	0:00:00			
99	3	10	15:26:38	1	0	1	0:01:01	0:00:00	0:01:24		
100	2	13	15:26:57	0	1	1	0:00:19	0:00:00			

Figure A.14 - Field data for Mar8p.1 data file (continued).

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #2 servicing "TNT Express"										
2	• March 8, 1991									Backcycle	Time in
3							elapsed	Inter	Service	Time, all	Queue, all
4	Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
101	1	1	15:28:09	1	1	2	0:01:12	0:02:44			
102	3	13	15:28:47	1	0	1	0:00:38	0:00:00	0:01:49		
103	2	14	15:29:07	0	1	1	0:00:20	0:00:00			
104	3	14	15:30:01	0	0	0	0:00:54	0:00:00	0:00:54		
105	2	1	15:30:24	0	1	1	0:00:23	0:02:16			
106	1	5	15:30:40	1	1	2	0:00:15	0:00:15			
107	3	1	15:31:05	1	0	1	0:00:26	0:00:00	0:00:41		
108	2	5	15:31:23	0	1	1	0:00:18	0:00:00			
109	3	5	15:32:14	0	0	0	0:00:51	0:00:00	0:00:51		
110	2	7	15:33:07	0	1	1	0:00:53	0:02:28			
111	4	111	15:33:11	0	1	1	0:00:04	0:00:00			
112	5	111	15:33:17	0	1	1	0:00:06	0:00:00			
113	999	96	15:34:11	0	1	1	0:00:54	0:00:00			
114	1	14	15:34:24	1	1	2	0:00:12	0:01:17			
115	3	7	15:34:27	1	0	1	0:00:03	0:00:00	0:01:19		
116	999	96	15:34:46	1	0	1	0:00:19	0:00:00			
117	8	96	15:36:01	1	0	1	0:01:15	0:00:00			
118	2	14	15:36:26	0	1	1	0:00:25	0:00:00			
119	3	14	15:36:52	0	0	0	0:00:26	0:00:00	0:00:26		
120	2	13	15:37:11	0	1	1	0:00:18	0:02:47			
121	3	13	15:38:21	0	0	0	0:01:10	0:00:00	0:01:10		
122	2	1	15:40:04	0	1	1	0:01:44	0:02:54			
123	3	1	15:40:31	0	0	0	0:00:27	0:00:00	0:00:27		
124	6.1	111	15:40:41	0	0	0	0:00:10	0:00:00			
125	7.1	111	15:40:54	0	0	0	0:00:13	0:00:00			
126	6	111	15:41:47	0	0	0	0:00:53	0:00:00			
127	7	111	15:42:13	0	0	0	0:00:25	0:00:00			
128	2	5	15:42:15	0	1	1	0:00:02	0:02:11			
129	3	5	15:42:24	0	0	0	0:00:09	0:00:00	0:00:09		
130	2	7	15:43:04	0	1	1	0:00:40	0:00:49			
131	3	7	15:43:26	0	0	0	0:00:23	0:00:00	0:00:23		
132	2	14	15:43:55	0	1	1	0:00:29	0:00:52			
133	3	14	15:44:27	0	0	0	0:00:32	0:00:00	0:00:32		
134	2	1	15:45:29	0	1	1	0:01:02	0:01:33			
135	3	1	15:45:46	0	0	0	0:00:18	0:00:00	0:00:18		
136	4	111	15:46:59	0	0	0	0:01:12	0:00:00			
137	5	111	15:47:28	0	0	0	0:00:30	0:00:00			
138	2	7	15:48:04	0	1	1	0:00:36	0:02:35			
139	4	111	15:48:52	0	1	1	0:00:47	0:00:00			
140	5	111	15:49:17	0	1	1	0:00:26	0:00:00			
141	2	5	15:49:42	0	2	2	0:00:24	0:01:37			
142	3	5	15:50:09	0	1	1	0:00:27	0:00:00	0:00:27		
143	3	7	15:51:16	0	0	0	0:01:07	0:00:00	0:03:11		
144	6	111	15:52:28	0	0	0	0:01:13	0:00:00			
145	7	111	15:53:16	0	0	0	0:00:48	0:00:00			
146	2	5	15:53:18	0	1	1	0:00:02	0:03:36			
147	3	5	15:53:38	0	0	0	0:00:20	0:00:00	0:00:20		
148	2	1	15:53:59	0	1	1	0:00:22	0:00:42			

Figure A.14 - Field data for Mar8p.1 data file (continued).

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #2 servicing "TNT Express"										
2	• March 8, 1991									Backcycle	Time in
3							elapsed	Inter	Service	Time, all	Queue, all
4	Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
149	3	1	15:54:47	0	0	0	0:00:48	0:00:00	0:00:48		
150	2	16	15:55:29	0	1	1	0:00:42	0:01:29			
151	6	111	15:56:04	0	1	1	0:00:35	0:00:00			
152	7	111	15:56:46	0	1	1	0:00:42	0:00:00			
153	3	16	15:57:16	0	0	0	0:00:30	0:00:00	0:01:47		
154	2	7	15:57:37	0	1	1	0:00:21	0:02:08			
155	3	7	15:58:38	0	0	0	0:01:01	0:00:00	0:01:01		
156	2	5	15:59:03	0	1	1	0:00:24	0:01:26			
157	3	5	15:59:38	0	0	0	0:00:35	0:00:00	0:00:35		
158	2	1	16:00:21	0	1	1	0:00:44	0:01:19			
159	1	14	16:02:58	1	1	2	0:02:37	0:02:37			
160	1	13	16:03:44	2	1	3	0:00:46	0:00:46			
161	1	7	16:04:34	3	1	4	0:00:50	0:00:50			
162	1	5	16:06:01	4	1	5	0:01:27	0:01:27			
163	1	4	16:07:59	5	1	6	0:01:58	0:01:58			
164	3	1	16:18:38	5	0	5	0:10:39	0:00:00	0:18:17		
165	6.1	111	16:18:50	5	0	5	0:00:12	0:00:00			
166	7.1	111	16:21:14	5	0	5	0:02:24	0:00:00			
167	2	14	16:22:00	4	1	5	0:00:46	0:00:00			
168	3	14	16:23:05	4	0	4	0:01:05	0:00:00	0:04:27		
169	2	13	16:23:20	3	1	4	0:00:15	0:00:00			
170	3	13	16:23:48	3	0	3	0:00:28	0:00:00	0:00:43		
171	2	5	16:24:21	2	1	3	0:00:33	0:00:00			
172	3	5	16:24:47	2	0	2	0:00:26	0:00:00	0:00:59		
173	6.1	111	16:25:01	2	0	2	0:00:14	0:00:00			
174	7.1	111	16:25:23	2	0	2	0:00:22	0:00:00			
175	1	14	16:25:39	3	0	3	0:00:16	0:17:40			
176	2	7	16:25:44	2	1	3	0:00:05	0:00:00			
177	1	13	16:26:28	3	1	4	0:00:43	0:00:48			
178	2	13	16:26:49	2	2	4	0:00:22	0:00:00			
179	3	7	16:27:16	2	1	3	0:00:26	0:00:00	0:02:29		
180	3	13	16:28:06	2	0	2	0:00:51	0:00:00	0:03:19		
181	1	5	16:28:18	3	0	3	0:00:12	0:01:51			
182	2	14	16:28:28	2	1	3	0:00:10	0:00:00			
183	1	1	16:28:55	3	1	4	0:00:26	0:00:36			
184	3	14	16:29:52	3	0	3	0:00:58	0:00:00	0:01:46		
185	1	7	16:29:59	4	0	4	0:00:07	0:01:04			
186	2	4	16:30:20	3	1	4	0:00:21	0:00:00			
187	1	13	16:30:36	4	1	5	0:00:16	0:00:37			
188	1	14	16:31:59	5	1	6	0:01:23	0:01:23			
189	3	4	16:32:55	5	0	5	0:00:56	0:00:00	0:03:03		
190	4	111	16:33:45	5	0	5	0:00:50	0:00:00			
191	5	111	16:34:10	5	0	5	0:00:25	0:00:00			
192	2	5	16:34:13	4	1	5	0:00:03	0:00:00			
193	3	5	16:34:31	4	0	4	0:00:18	0:00:00	0:01:36		
194	2	1	16:34:58	3	1	4	0:00:27	0:00:00			
195	3	1	16:35:27	3	0	3	0:00:28	0:00:00	0:00:56		
196	2	7	16:35:50	2	1	3	0:00:23	0:00:00			

Figure A.14 - Field data for Mar8p.1 data file (continued).

	A	B	C	D	E	F	G	H	I	J	K
1	• Crane #2 servicing "TNT Express"										
2	• March 8, 1991									Backcycle	Time in
3							elapsed	Inter	Service	Time, all	Queue, al
4	Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Veh's
197	3	7	16:37:12	2	0	2	0:01:23	0:00:00	0:01:46		
198	2	13	16:37:30	1	1	2	0:00:17	0:00:00			
199	1	5	16:37:40	2	1	3	0:00:10	0:05:40			
200	1	1	16:38:00	3	1	4	0:00:21	0:00:21			
201	3	13	16:38:05	3	0	3	0:00:05	0:00:00	0:00:53		
202	2	14	16:38:29	2	1	3	0:00:24	0:00:00			
203	3	14	16:39:22	2	0	2	0:00:53	0:00:00	0:01:17		
204	1	7	16:39:43	3	0	3	0:00:21	0:01:43			
205	2	5	16:39:49	2	1	3	0:00:06	0:00:00			
206	3	5	16:40:13	2	0	2	0:00:24	0:00:00	0:00:51		
207	1	13	16:40:43	3	0	3	0:00:30	0:01:01			
208	2	1	16:41:05	2	1	3	0:00:22	0:00:00			
209	3	1	16:43:08	2	0	2	0:02:03	0:00:00	0:02:54		
210	2	7	16:43:32	1	1	2	0:00:24	0:00:00			
211	1	10	16:43:38	2	1	3	0:00:06	0:02:55			
212	3	7	16:44:00	2	0	2	0:00:22	0:00:00	0:00:52		
213	2	13	16:44:23	1	1	2	0:00:23	0:00:00			
214	3	13	16:44:41	1	0	1	0:00:18	0:00:00	0:00:41		
215	2	10	16:45:12	0	1	1	0:00:31	0:00:00			
216	4	111	16:45:19	0	1	1	0:00:07	0:00:00			

Figure A.15 - Field data for Mar9p.1 data file.

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, al
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
			0	0	0					
2	51	12:01:50	0	1	1	0:00:00	0:00:00		0:03:49	0:00:00
1	22	12:03:20	1	1	2	0:01:29	0:01:29		0:03:56	
1	49	12:03:24	2	1	3	0:00:04	0:00:04		0:04:16	
3	51	12:04:02	2	0	2	0:00:38	0:00:00	0:02:11	0:04:19	
2	22	12:04:12	1	1	2	0:00:10	0:00:00		0:04:20	0:00:52
3	22	12:05:16	1	0	1	0:01:04	0:00:00	0:01:15	0:04:30	
2	49	12:05:32	0	1	1	0:00:16	0:00:00		0:04:36	0:02:08
1	33	12:05:44	1	1	2	0:00:11	0:02:20		0:04:37	
1	54	12:06:15	2	1	3	0:00:31	0:00:31		0:04:43	
3	49	12:06:39	2	0	2	0:00:24	0:00:00	0:01:07	0:04:46	
2	33	12:06:59	1	1	2	0:00:20	0:00:00		0:04:48	0:01:15
3	33	12:07:58	1	0	1	0:00:59	0:00:00	0:01:19	0:04:49	
2	54	12:08:09	0	1	1	0:00:11	0:00:00		0:04:56	0:01:54
3	54	12:09:18	0	0	0	0:01:09	0:00:00	0:01:09	0:05:00	
2	51	12:10:23	0	1	1	0:01:05	0:04:08		0:05:00	0:00:00
1	55	12:10:51	1	1	2	0:00:28	0:00:28		0:05:00	
3	51	12:11:27	1	0	1	0:00:36	0:00:00	0:01:04	0:05:01	
2	55	12:11:50	0	1	1	0:00:23	0:00:00		0:05:02	0:00:59
1	59	12:12:15	1	1	2	0:00:25	0:01:24		0:05:04	
1	63	12:12:24	2	1	3	0:00:09	0:00:09		0:05:04	
3	55	12:13:30	2	0	2	0:01:06	0:00:00	0:01:40	0:05:07	
2	59	12:13:51	1	1	2	0:00:20	0:00:00		0:05:08	0:01:36
1	54	12:14:18	2	1	3	0:00:27	0:01:53		0:05:11	
3	59	12:15:06	2	0	2	0:00:48	0:00:00	0:01:35	0:05:12	
2	63	12:15:22	1	1	2	0:00:16	0:00:00		0:05:12	0:02:57
1	51	12:16:39	2	1	3	0:01:17	0:02:21		0:05:13	
3	63	12:16:54	2	0	2	0:00:16	0:00:00	0:01:49	0:05:14	
2	54	12:17:13	1	1	2	0:00:18	0:00:00		0:05:16	0:02:55
3	54	12:18:46	1	0	1	0:01:33	0:00:00	0:01:51	0:05:21	
2	51	12:18:59	0	1	1	0:00:14	0:00:00		0:05:26	0:02:20
1	46	12:19:06	1	1	2	0:00:07	0:02:28		0:05:33	
3	51	12:20:04	1	0	1	0:00:57	0:00:00	0:01:05	0:05:35	
1	59	12:20:07	2	0	2	0:00:03	0:01:00		0:05:37	
2	46	12:20:24	1	1	2	0:00:17	0:00:00		0:05:44	0:01:17
1	63	12:21:11	2	1	3	0:00:47	0:01:04		0:05:46	
3	46	12:21:21	2	0	2	0:00:10	0:00:00	0:01:17	0:05:47	
2	59	12:21:48	1	1	2	0:00:27	0:00:00		0:05:47	0:01:41
3	59	12:24:03	1	0	1	0:02:15	0:00:00	0:02:42	0:05:48	
2	63	12:24:26	0	1	1	0:00:23	0:00:00		0:05:49	0:03:15
1	54	12:24:40	1	1	2	0:00:14	0:03:29		0:05:52	
1	51	12:26:06	2	1	3	0:01:26	0:01:26		0:05:53	
3	63	12:26:19	2	0	2	0:00:13	0:00:00	0:01:53	0:05:54	
2	54	12:26:34	1	1	2	0:00:16	0:00:00		0:05:54	0:01:54
1	46	12:27:15	2	1	3	0:00:40	0:01:09		0:05:54	
3	54	12:27:48	2	0	2	0:00:34	0:00:00	0:01:30	0:05:54	
2	51	12:27:59	1	1	2	0:00:11	0:00:00		0:06:01	0:01:53
3	51	12:29:39	1	0	1	0:01:40	0:00:00	0:01:51	0:06:02	
2	46	12:29:53	0	1	1	0:00:14	0:00:00		0:06:02	0:02:39

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, al
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
1	5	12:31:42	1	1	2	0:01:48	0:04:27		0:06:04	
3	46	12:31:49	1	0	1	0:00:07	0:00:00	0:01:55	0:06:11	
1	59	12:32:01	2	0	2	0:00:13	0:00:20		0:06:12	
2	5	12:32:20	1	1	2	0:00:19	0:00:00		0:06:14	0:00:39
3	5	12:33:01	1	0	1	0:00:40	0:00:00	0:01:12	0:06:15	
6.1	111	12:33:39	1	0	1	0:00:38	0:00:00		0:06:21	
7.1	111	12:33:46	1	0	1	0:00:08	0:00:00		0:06:23	
2	63	12:33:59	1	1	2	0:00:12	0:00:00		0:06:26	
3	63	12:34:43	1	0	1	0:00:44	0:00:00	0:01:43	0:06:31	
2	59	12:34:56	0	1	1	0:00:13	0:00:00		0:06:32	0:02:55
1	54	12:35:18	1	1	2	0:00:21	0:03:16		0:06:39	
3	59	12:36:17	1	0	1	0:01:00	0:00:00	0:01:21	0:06:41	
2	54	12:36:40	0	1	1	0:00:22	0:00:00		0:06:46	0:01:22
1	46	12:37:42	1	1	2	0:01:02	0:02:24		0:06:47	
3	54	12:38:18	1	0	1	0:00:37	0:00:00	0:01:39	0:06:48	
2	46	12:38:33	0	1	1	0:00:15	0:00:00		0:06:50	0:00:51
1	5	12:38:45	1	1	2	0:00:12	0:01:03		0:06:51	
3	46	12:40:24	1	0	1	0:01:39	0:00:00	0:01:51	0:06:57	
2	5	12:40:38	0	1	1	0:00:14	0:00:00		0:07:03	0:01:53
1	59	12:41:19	1	1	2	0:00:41	0:02:34		0:07:03	
3	5	12:41:51	1	0	1	0:00:31	0:00:00	0:01:13	0:07:06	
2	59	12:42:28	0	1	1	0:00:38	0:00:00		0:07:07	0:01:09
1	54	12:43:31	1	1	2	0:01:03	0:02:12		0:07:09	
999	61	12:43:36	1	1	2	0:00:05	0:00:00		0:07:10	
3	59	12:43:38	1	0	1	0:00:02	0:00:00	0:01:10	0:07:29	
8	61	12:43:58	1	0	1	0:00:20	0:00:00		0:07:56	
2	51	12:44:14	1	1	2	0:00:16	0:00:00		0:07:59	
3	51	12:45:07	1	0	1	0:00:53	0:00:00	0:01:28	0:08:13	
2	54	12:45:51	0	1	1	0:00:44	0:00:00		0:08:17	0:02:19
1	46	12:46:19	1	1	2	0:00:28	0:02:47		0:08:25	
3	54	12:46:50	1	0	1	0:00:31	0:00:00	0:00:59	0:08:37	
2	46	12:47:03	0	1	1	0:00:13	0:00:00		0:08:57	0:00:44
3	46	12:48:43	0	0	0	0:01:41	0:00:00	0:01:41	0:09:08	
2	63	12:49:13	0	1	1	0:00:30	0:02:55		0:09:16	0:00:00
1	5	12:50:01	1	1	2	0:00:48	0:00:48		0:10:27	
3	63	12:51:36	1	0	1	0:01:35	0:00:00	0:02:23	0:10:29	
1	54	12:52:10	2	0	2	0:00:34	0:02:08		0:11:01	
6	11	12:52:14	2	0	2	0:00:04	0:00:00		0:12:30	
7.1	11	12:52:36	2	0	2	0:00:23	0:00:00		0:12:54	
2	54	12:52:47	1	1	2	0:00:11	0:00:00		0:13:07	
3	54	12:53:24	1	0	1	0:00:37	0:00:00	0:01:48	0:14:30	
6.1	111	12:53:58	1	0	1	0:00:33	0:00:00			
7.1	111	12:55:58	1	0	1	0:02:00	0:00:00			
2	5	12:56:24	0	1	1	0:00:26	0:00:00			
1	59	12:56:46	1	1	2	0:00:22	0:04:36			
3	5	12:57:57	1	0	1	0:01:12	0:00:00	0:01:33		
1	51	12:58:00	2	0	2	0:00:03	0:01:15			
1	46	12:58:09	3	0	3	0:00:09	0:00:09			
2	46	12:58:44	2	1	3	0:00:34	0:00:00			

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, al
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
1	63	12:59:22	3	1	4	0:00:38	0:01:13			
3	46	12:59:53	3	0	3	0:00:31	0:00:00	0:01:55		
2	59	12:59:59	2	1	3	0:00:06	0:00:00			0:03:13
1	54	13:01:10	3	1	4	0:01:11	0:01:48			
3	59	13:01:22	3	0	3	0:00:12	0:00:00	0:01:29		
2	51	13:01:34	2	1	3	0:00:12	0:00:00			
3	51	13:02:46	2	0	2	0:01:13	0:00:00	0:01:24		
999	63	13:02:55	2	0	2	0:00:09	0:00:00			
8	63	13:05:40	2	0	2	0:02:44	0:00:00			
2	54	13:06:15	1	1	2	0:00:36	0:00:00			
3	54	13:06:47	1	0	1	0:00:32	0:00:00	0:04:01		
			0	0	0	0:00:00	0:00:00			
1	54	13:16:45	1	0	1	0:09:58	0:15:36			
1	51	13:16:49	2	0	2	0:00:04	0:00:04			
1	5	13:17:08	3	0	3	0:00:19	0:00:19			
2	61	13:17:19	2	1	3	0:00:11	0:00:00			
1	59	13:17:24	3	1	4	0:00:06	0:00:16			
3	61	13:17:59	3	0	3	0:00:35	0:00:00			
1	63	13:18:16	4	0	4	0:00:17	0:00:51			
1	46	13:18:19	5	0	5	0:00:04	0:00:04			
2	5	13:18:23	4	1	5	0:00:04	0:00:00			
3	5	13:19:19	4	0	4	0:00:57	0:00:00	0:01:20		
2	59	13:19:30	3	1	4	0:00:10	0:00:00			
3	59	13:20:40	3	0	3	0:01:11	0:00:00	0:01:21		
2	63	13:21:14	2	1	3	0:00:34	0:00:00			
3	63	13:22:34	2	0	2	0:01:19	0:00:00	0:01:53		
1	51	13:22:51	3	0	3	0:00:18	0:04:32			
2	54	13:23:04	2	1	3	0:00:12	0:00:00			
3	54	13:24:03	2	0	2	0:00:59	0:00:00	0:01:29		
2	46	13:24:13	1	1	2	0:00:10	0:00:00			
3	46	13:25:30	1	0	1	0:01:17	0:00:00	0:01:27		
2	51	13:25:41	0	1	1	0:00:11	0:00:00			
3	51	13:26:30	0	0	0	0:00:49	0:00:00	0:00:49		
1	59	13:27:20	1	0	1	0:00:49	0:04:28			
6.1	111	13:27:29	1	0	1	0:00:09	0:00:00			
1	5	13:27:32	2	0	2	0:00:04	0:00:13			
2	59	13:27:43	1	1	2	0:00:10	0:00:00			0:00:23
7.1	111	13:27:46	1	1	2	0:00:04	0:00:00			
3	59	13:28:16	1	0	1	0:00:30	0:00:00	0:01:46		
2	5	13:28:26	0	1	1	0:00:10	0:00:00			0:00:53
1	63	13:29:25	1	1	2	0:00:59	0:01:53			
3	5	13:29:41	1	0	1	0:00:16	0:00:00	0:01:15		
2	63	13:29:46	0	1	1	0:00:06	0:00:00			0:00:21
3.1	63	13:30:21	0	1	1	0:00:34	0:00:00			
2	54	13:31:06	0	2	2	0:00:46	0:01:41			0:00:00
1	46	13:32:01	1	2	3	0:00:55	0:00:55			
3	63	13:33:09	1	1	2	0:01:08	0:00:00	0:03:23		
1	59	13:33:12	2	1	3	0:00:03	0:01:10			
3.1	54	13:33:32	2	1	3	0:00:20	0:00:00			

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, al
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
2	46	13:33:59	1	2	3	0:00:27	0:00:00			0:01:58
1	5	13:35:16	2	2	4	0:01:17	0:02:04			
3	54	13:35:45	2	1	3	0:00:29	0:00:00	0:02:36		
3.1	46	13:35:58	2	1	3	0:00:13	0:00:00			
1	51	13:36:59	3	1	4	0:01:01	0:01:43			
2	51	13:37:27	2	2	4	0:00:27	0:00:00			0:00:27
3	46	13:38:03	2	1	3	0:00:36	0:00:00	0:02:17		
3.1	51	13:38:23	2	1	3	0:00:20	0:00:00			
2	59	13:38:44	1	2	3	0:00:21	0:00:00			0:05:33
1	63	13:39:12	2	2	4	0:00:27	0:02:12			
3	51	13:40:53	2	1	3	0:01:41	0:00:00	0:02:50		
3.1	59	13:41:18	2	1	3	0:00:25	0:00:00			
2	5	13:41:39	1	2	3	0:00:22	0:00:00			0:06:23
1	54	13:42:48	2	2	4	0:01:09	0:03:36			
3	59	13:43:37	2	1	3	0:00:49	0:00:00	0:02:44		
3.1	5	13:44:06	2	1	3	0:00:29	0:00:00			
1	46	13:44:26	3	1	4	0:00:19	0:01:38			
2	63	13:44:35	2	2	4	0:00:10	0:00:00			0:05:24
3	5	13:46:27	2	1	3	0:01:52	0:00:00	0:02:50		
3.1	63	13:46:49	2	1	3	0:00:22	0:00:00			
2	54	13:47:10	1	2	3	0:00:20	0:00:00			0:04:22
1	51	13:49:50	2	2	4	0:02:40	0:05:24			
3	63	13:50:07	2	1	3	0:00:17	0:00:00	0:03:39		
3	54	13:50:28	2	0	2	0:00:21	0:00:00	0:03:18		
1	59	13:50:46	3	0	3	0:00:19	0:00:57			
2	46	13:50:54	2	1	3	0:00:08	0:00:00			0:06:29
3	46	13:52:07	2	0	2	0:01:13	0:00:00	0:01:40		
2	51	13:52:29	1	1	2	0:00:22	0:00:00			0:02:39
3	51	13:53:33	1	0	1	0:01:04	0:00:00	0:01:25		
2	59	13:53:56	0	1	1	0:00:23	0:00:00			0:03:09
3	59	13:55:23	0	0	0	0:01:28	0:00:00	0:01:28		
2	5	13:55:43	0	1	1	0:00:20	0:04:57			0:00:00
1	63	13:55:55	1	1	2	0:00:12	0:00:12			
1	54	13:56:19	2	1	3	0:00:25	0:00:25			
3	5	13:56:53	2	0	2	0:00:34	0:00:00	0:01:10		
1	46	13:57:07	3	0	3	0:00:14	0:00:48			
2	63	13:57:14	2	1	3	0:00:07	0:00:00			0:01:19
3	63	13:58:21	2	0	2	0:01:08	0:00:00	0:01:28		
2	54	13:58:43	1	1	2	0:00:22	0:00:00			0:02:24
3	54	13:59:40	1	0	1	0:00:57	0:00:00	0:01:19		
2	46	13:59:59	0	1	1	0:00:19	0:00:00			0:02:52
1	51	14:00:30	1	1	2	0:00:31	0:03:23			
3	46	14:01:03	1	0	1	0:00:33	0:00:00	0:01:04		
2	51	14:01:22	0	1	1	0:00:19	0:00:00			0:00:52
3	51	14:02:29	0	0	0	0:01:07	0:00:00	0:01:07		
			0	0	0	0:00:00	0:00:00			
1	46	14:15:28	1	0	1	0:12:59	0:14:58			
1	51	14:15:30	2	0	2	0:00:02	0:00:02			
1	5	14:15:32	3	0	3	0:00:02	0:00:02			

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
1	54	14:15:42	4	0	4	0:00:10	0:00:10			
1	63	14:15:45	5	0	5	0:00:03	0:00:03			
1	59	14:15:48	6	0	6	0:00:03	0:00:03			
2	77	14:17:18	5	1	6	0:01:30	0:00:00			
3	77	14:18:56	5	0	5	0:01:38	0:00:00			
2	46	14:19:20	4	1	5	0:00:24	0:00:00			
3	46	14:20:18	4	0	4	0:00:58	0:00:00	0:01:22		
2	51	14:20:30	3	1	4	0:00:12	0:00:00			
1	63	14:22:08	4	1	5	0:01:38	0:06:20			
3	51	14:22:18	4	0	4	0:00:10	0:00:00	0:02:00		
2	59	14:22:43	3	1	4	0:00:25	0:00:00			
3	59	14:23:44	3	0	3	0:01:02	0:00:00	0:01:27		
2	5	14:24:02	2	1	3	0:00:17	0:00:00			
3	5	14:25:18	2	0	2	0:01:17	0:00:00	0:01:34		
2	63	14:25:41	1	1	2	0:00:22	0:00:00			
3	63	14:27:08	1	0	1	0:01:28	0:00:00	0:01:50		
2	54	14:27:28	0	1	1	0:00:20	0:00:00			
1	46	14:28:21	1	1	2	0:00:52	0:06:13			
3	54	14:28:35	1	0	1	0:00:14	0:00:00	0:01:06		
1	59	14:28:48	2	0	2	0:00:14	0:00:28			
1	5	14:29:14	3	0	3	0:00:25	0:00:25			
2	46	14:29:21	2	1	3	0:00:07	0:00:00			
1	51	14:29:25	3	1	4	0:00:04	0:00:11			
3	46	14:30:33	3	0	3	0:01:09	0:00:00	0:01:59		
2	51	14:30:57	2	1	3	0:00:24	0:00:00			0:01:33
1	63	14:31:54	3	1	4	0:00:57	0:02:30			
3	51	14:33:12	3	0	3	0:01:18	0:00:00	0:02:39		
2	59	14:33:40	2	1	3	0:00:27	0:00:00			
1	54	14:33:42	3	1	4	0:00:02	0:01:48			
3	59	14:35:00	3	0	3	0:01:18	0:00:00	0:01:48		
2	5	14:35:34	2	1	3	0:00:35	0:00:00			0:06:21
1	46	14:35:45	3	1	4	0:00:10	0:02:03			
3	5	14:36:30	3	0	3	0:00:45	0:00:00	0:01:30		
6	111	14:37:36	3	0	3	0:01:06	0:00:00			
1	51	14:38:16	4	0	4	0:00:40	0:02:31			
7	111	14:38:30	4	0	4	0:00:14	0:00:00			
2	63	14:38:38	3	1	4	0:00:08	0:00:00			0:06:44
3	63	14:39:27	3	0	3	0:00:49	0:00:00	0:02:57		
2	54	14:41:14	2	1	3	0:01:47	0:00:00			0:07:32
1	5	14:41:18	3	1	4	0:00:04	0:03:02			
3	54	14:43:12	3	0	3	0:01:53	0:00:00	0:03:45		
2	46	14:43:42	2	1	3	0:00:30	0:00:00			0:07:57
1	63	14:44:10	3	1	4	0:00:28	0:02:52			
1	59	14:44:23	4	1	5	0:00:12	0:00:12			
3	46	14:46:26	4	0	4	0:02:03	0:00:00	0:03:14		
2	51	14:47:23	3	1	4	0:00:57	0:00:00			0:09:07
1	54	14:47:37	4	1	5	0:00:15	0:03:15			
3	51	14:49:59	4	0	4	0:02:22	0:00:00	0:03:34		
2	59	14:50:20	3	1	4	0:00:21	0:00:00			

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
1	46	14:51:02	4	1	5	0:00:42	0:03:25			
3	59	14:52:51	4	0	4	0:01:48	0:00:00	0:02:51		
2	5	14:53:17	3	1	4	0:00:26	0:00:00			0:11:58
1	51	14:54:18	4	1	5	0:01:01	0:03:16			
3	5	14:55:43	4	0	4	0:01:25	0:00:00	0:02:52		
2	63	14:56:15	3	1	4	0:00:32	0:00:00			0:12:05
1	59	14:57:11	4	1	5	0:00:56	0:02:53			
3	63	14:57:32	4	0	4	0:00:21	0:00:00	0:01:49		
4	111	14:59:14	4	0	4	0:01:42	0:00:00			
5	111	14:59:41	4	0	4	0:00:26	0:00:00			
2	54	14:59:59	3	1	4	0:00:19	0:00:00			
1	5	15:00:14	4	1	5	0:00:14	0:03:03			
3	54	15:00:59	4	0	4	0:00:45	0:00:00	0:03:27		
2	46	15:01:10	3	1	4	0:00:11	0:00:00			0:10:08
1	63	15:01:21	4	1	5	0:00:11	0:01:07			
3	46	15:02:41	4	0	4	0:01:20	0:00:00	0:01:42		
2	51	15:02:58	3	1	4	0:00:17	0:00:00			0:08:40
3	51	15:03:57	3	0	3	0:01:00	0:00:00	0:01:17		
2	59	15:04:07	2	1	3	0:00:10	0:00:00			0:06:57
3	59	15:05:30	2	0	2	0:01:23	0:00:00	0:01:32		
2	5	15:05:40	1	1	2	0:00:10	0:00:00			0:05:27
1	54	15:06:13	2	1	3	0:00:33	0:04:53			
3	5	15:08:15	2	0	2	0:02:02	0:00:00	0:02:45		
2	63	15:08:35	1	1	2	0:00:20	0:00:00			0:07:14
1	51	15:09:45	2	1	3	0:01:10	0:03:32			
1	59	15:10:34	3	1	4	0:00:49	0:00:49			
1	46	15:11:05	4	1	5	0:00:32	0:00:32			
3	63	15:12:41	4	0	4	0:01:36	0:00:00	0:04:26		
2	54	15:13:07	3	1	4	0:00:26	0:00:00			0:06:54
1	5	15:14:19	4	1	5	0:01:12	0:03:14			
3	54	15:15:36	4	0	4	0:01:17	0:00:00	0:02:55		
2	46	15:15:47	3	1	4	0:00:11	0:00:00			0:04:42
3	46	15:18:48	3	0	3	0:03:01	0:00:00	0:03:12		
1	63	15:18:52	4	0	4	0:00:04	0:04:33			
2	51	15:19:06	3	1	4	0:00:15	0:00:00			0:09:22
3	51	15:20:01	3	0	3	0:00:54	0:00:00	0:01:13		
2	59	15:20:14	2	1	3	0:00:13	0:00:00			0:09:41
1	54	15:21:09	3	1	4	0:00:55	0:02:17			
3	59	15:22:27	3	0	3	0:01:18	0:00:00	0:02:26		
2	5	15:22:41	2	1	3	0:00:14	0:00:00			0:08:22
3	5	15:24:19	2	0	2	0:01:38	0:00:00	0:01:51		
2	63	15:24:46	1	1	2	0:00:28	0:00:00			0:05:54
1	46	15:25:28	2	1	3	0:00:42	0:04:19			
1	51	15:25:47	3	1	4	0:00:19	0:00:19			
3	63	15:27:21	3	0	3	0:01:34	0:00:00	0:03:02		
2	54	15:27:38	2	1	3	0:00:17	0:00:00			0:06:29
1	59	15:27:54	3	1	4	0:00:15	0:02:06			
3	54	15:28:58	3	0	3	0:01:05	0:00:00	0:01:37		
2	46	15:29:11	2	1	3	0:00:13	0:00:00			0:03:43

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
1	5	15:29:19	3	1	4	0:00:08	0:01:25			
3	46	15:30:30	3	0	3	0:01:11	0:00:00	0:01:32		
2	51	15:30:47	2	1	3	0:00:17	0:00:00			0:04:59
3	51	15:31:45	2	0	2	0:00:58	0:00:00	0:01:15		
2	59	15:31:58	1	1	2	0:00:13	0:00:00			0:04:04
1	63	15:32:42	2	1	3	0:00:44	0:03:23			
3	59	15:33:31	2	0	2	0:00:50	0:00:00	0:01:46		
2	5	15:33:42	1	1	2	0:00:11	0:00:00			0:04:23
1	54	15:34:14	2	1	3	0:00:32	0:01:33			
3	5	15:35:26	2	0	2	0:01:12	0:00:00	0:01:55		
2	63	15:35:48	1	1	2	0:00:22	0:00:00			0:03:06
1	46	15:36:56	2	1	3	0:01:08	0:02:42			
3	63	15:38:13	2	0	2	0:01:17	0:00:00	0:02:47		
2	54	15:38:26	1	1	2	0:00:13	0:00:00			0:04:12
1	51	15:38:35	2	1	3	0:00:09	0:01:39			
1	59	15:38:39	3	1	4	0:00:04	0:00:04			
1	5	15:40:02	4	1	5	0:01:23	0:01:23			
3	54	15:40:23	4	0	4	0:00:21	0:00:00	0:02:10		
2	46	15:40:41	3	1	4	0:00:18	0:00:00			0:03:45
3	46	15:42:39	3	0	3	0:01:58	0:00:00	0:02:16		
2	51	15:42:54	2	1	3	0:00:15	0:00:00			0:04:19
3	51	15:44:21	2	0	2	0:01:27	0:00:00	0:01:42		
1	63	15:44:28	3	0	3	0:00:07	0:04:26			
2	59	15:44:31	2	1	3	0:00:03	0:00:00			0:05:52
1	54	15:45:35	3	1	4	0:01:04	0:01:07			
3	59	15:45:51	3	0	3	0:00:17	0:00:00	0:01:31		
2	5	15:46:05	2	1	3	0:00:14	0:00:00			0:06:03
3	5	15:47:05	2	0	2	0:01:00	0:00:00	0:01:14		
2	63	15:47:21	1	1	2	0:00:16	0:00:00			0:02:53
3	63	15:48:50	1	0	1	0:01:30	0:00:00	0:01:45		
2	54	15:49:06	0	1	1	0:00:16	0:00:00			0:03:32
1	46	15:49:45	1	1	2	0:00:39	0:04:10			
1	51	15:50:10	2	1	3	0:00:25	0:00:25			
3	54	15:50:18	2	0	2	0:00:08	0:00:00	0:01:28		
2	46	15:51:04	1	1	2	0:00:46	0:00:00			
3	46	15:51:41	1	0	1	0:00:37	0:00:00			
2	51	15:51:53	0	1	1	0:00:12	0:00:00			0:01:43
1	59	15:52:39	1	1	2	0:00:46	0:02:29			
1	5	15:53:20	2	1	3	0:00:41	0:00:41			
3	51	15:53:22	2	0	2	0:00:03	0:00:00	0:01:41		
1	54	15:56:12	3	0	3	0:02:50	0:02:53			
1	46	15:58:29	4	0	4	0:02:16	0:02:16			
1	51	15:59:09	5	0	5	0:00:41	0:00:41			
1	63	15:59:52	6	0	6	0:00:43	0:00:43			
2	59	16:01:39	5	1	6	0:01:47	0:00:00			0:09:00
3	59	16:02:19	5	0	5	0:00:40	0:00:00	0:08:56		
2	5	16:02:38	4	1	5	0:00:20	0:00:00			0:09:18
3	5	16:03:39	4	0	4	0:01:01	0:00:00	0:01:21		
2	63	16:03:59	3	1	4	0:00:20	0:00:00			0:04:07

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
2	54	16:04:15	2	2	4	0:00:16	0:00:00			0:08:03
3	63	16:06:08	2	1	3	0:01:53	0:00:00	0:02:29		
2	46	16:07:23	1	2	3	0:01:15	0:00:00			
3	54	16:08:43	1	1	2	0:01:20	0:00:00			
3.1	46	16:09:29	1	1	2	0:00:46	0:00:00			
2	51	16:10:02	0	2	2	0:00:33	0:00:00			0:10:52
1	59	16:10:56	1	2	3	0:00:54	0:11:04			
3	46	16:11:31	1	1	2	0:00:35	0:00:00	0:02:48		
3.1	51	16:12:02	1	1	2	0:00:31	0:00:00			
2	59	16:12:38	0	2	2	0:00:35	0:00:00			0:01:42
1	5	16:12:47	1	2	3	0:00:09	0:01:52			
1	63	16:13:18	2	2	4	0:00:31	0:00:31			
1	54	16:14:44	3	2	5	0:01:27	0:01:27			
3	51	16:14:52	3	1	4	0:00:08	0:00:00	0:04:51		
2	5	16:15:22	2	2	4	0:00:29	0:00:00			0:02:35
3.1	59	16:15:33	2	2	4	0:00:11	0:00:00			
1	46	16:17:43	3	2	5	0:02:10	0:02:59			
3	59	16:17:55	3	1	4	0:00:12	0:00:00	0:03:03		
3.1	5	16:18:22	3	1	4	0:00:26	0:00:00			
2	63	16:18:50	2	2	4	0:00:28	0:00:00			0:05:32
3	5	16:20:47	2	1	3	0:01:57	0:00:00	0:02:52		
3.1	63	16:21:10	2	1	3	0:00:23	0:00:00			
2	54	16:21:39	1	2	3	0:00:29	0:00:00			0:06:55
1	51	16:22:48	2	2	4	0:01:09	0:05:05			
3	63	16:23:39	2	1	3	0:00:51	0:00:00	0:02:52		
3.1	54	16:24:34	2	1	3	0:00:55	0:00:00			
2	46	16:25:19	1	2	3	0:00:45	0:00:00			0:07:36
3	54	16:28:05	1	1	2	0:02:46	0:00:00	0:04:25		
3	46	16:28:32	1	0	1	0:00:27	0:00:00	0:03:13		
2	51	16:29:03	0	1	1	0:00:31	0:00:00			0:06:15
3	51	16:30:18	0	0	0	0:01:15	0:00:00	0:01:15		
2	59	16:30:26	0	1	1	0:00:08	0:07:37			0:00:00
1	5	16:31:14	1	1	2	0:00:48	0:00:48			
1	63	16:31:56	2	1	3	0:00:42	0:00:42			
3	59	16:32:11	2	0	2	0:00:15	0:00:00	0:01:46		
1	54	16:34:50	3	0	3	0:02:39	0:02:54			
1	51	16:38:40	4	0	4	0:03:49	0:03:49			
1	46	16:38:42	5	0	5	0:00:03	0:00:03			
1	59	16:38:47	6	0	6	0:00:04	0:00:04			
2	5	16:39:28	5	1	6	0:00:41	0:00:00			0:08:14
3	5	16:43:41	5	0	5	0:04:13	0:00:00	0:11:30		
2	63	16:44:14	4	1	5	0:00:32	0:00:00			0:12:17
3	63	16:45:58	4	0	4	0:01:44	0:00:00	0:02:17		
2	54	16:46:17	3	1	4	0:00:19	0:00:00			0:11:26
3	54	16:47:37	3	0	3	0:01:20	0:00:00	0:01:39		
2	46	16:48:00	2	1	3	0:00:23	0:00:00			0:09:18
1	5	16:48:19	3	1	4	0:00:19	0:09:32			
3	46	16:49:28	3	0	3	0:01:09	0:00:00	0:01:51		
2	51	16:49:43	2	1	3	0:00:15	0:00:00			0:11:03

Figure A.15 - Field data for Mar9p.1 data file (continued).

• Crane #3 servicing "GUAYAMA" - PRIMMI ship										
• March 9, 1991									Backcycle	Time in
						elapsed	Inter	Service	Time, all	Queue, all
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Vehicles	Vehicles
1	63	16:51:36	3	1	4	0:01:53	0:03:17			
1	54	16:52:26	4	1	5	0:00:50	0:00:50			
3	51	16:53:02	4	0	4	0:00:37	0:00:00	0:03:34		
2	59	16:53:20	3	1	4	0:00:18	0:00:00			0:14:34
3	59	16:54:25	3	0	3	0:01:05	0:00:00	0:01:23		
1	46	16:56:00	4	0	4	0:01:35	0:03:34			
2	63	16:56:16	3	1	4	0:00:16	0:00:00			0:04:41

Figure A.16 - Field data for Mar9p.2 data file.

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
			0	1	1					
3	58	12:05:16	0	0	0	0:00:00	0:00:00		0:01:34	0:00:03
6.1	0	12:06:16	0	0	0	0:01:01	0:00:00		0:01:37	0:00:04
7.1	0	12:06:35	0	0	0	0:00:19	0:00:00		0:01:40	0:00:06
1	62	12:06:42	1	0	1	0:00:07	0:01:26		0:01:49	0:00:07
2	62	12:07:01	0	1	1	0:00:19	0:00:00		0:01:51	0:00:08
3	62	12:07:20	0	0	0	0:00:19	0:00:00	0:00:19	0:01:55	0:00:22
2	52	12:07:40	0	1	1	0:00:20	0:00:58		0:01:57	0:00:34
3	52	12:08:14	0	0	0	0:00:34	0:00:00	0:00:34	0:01:59	0:00:37
6.1	0	12:09:04	0	0	0	0:00:49	0:00:00		0:02:00	0:01:00
1	58	12:10:35	1	0	1	0:01:31	0:02:55		0:02:02	0:01:07
1	61	12:10:55	2	0	2	0:00:20	0:00:20		0:02:06	0:01:11
2	61	12:11:03	1	1	2	0:00:07	0:00:00		0:02:13	0:01:28
7.1	0	12:11:04	1	1	2	0:00:01	0:00:00		0:02:14	0:01:35
3	61	12:11:39	1	0	1	0:00:35	0:00:00	0:03:25	0:02:23	0:02:08
2	58	12:11:50	0	1	1	0:00:11	0:00:00		0:02:28	0:02:47
1	62	12:12:11	1	1	2	0:00:20	0:01:15		0:02:30	0:03:06
3	58	12:12:18	1	0	1	0:00:08	0:00:00	0:00:28	0:02:33	0:03:08
2	62	12:12:35	0	1	1	0:00:16	0:00:00		0:03:06	0:03:11
1	47	12:13:00	1	1	2	0:00:26	0:00:50		0:03:08	0:03:14
3	62	12:13:25	1	0	1	0:00:24	0:00:00	0:00:50	0:03:11	0:03:34
2	47	12:13:32	0	1	1	0:00:08	0:00:00		0:03:20	0:03:37
1	52	12:13:36	1	1	2	0:00:04	0:00:36		0:03:26	0:03:45
3	47	12:14:28	1	0	1	0:00:51	0:00:00	0:00:55	0:03:32	0:04:06
2	52	12:14:42	0	1	1	0:00:14	0:00:00		0:03:43	0:04:09
3	52	12:15:47	0	0	0	0:01:05	0:00:00	0:01:05	0:03:44	0:04:15
6.1	0	12:16:35	0	0	0	0:00:48	0:00:00		0:03:52	0:04:17
1	61	12:17:50	1	0	1	0:01:15	0:04:13		0:03:54	0:04:22
2	61	12:17:58	0	1	1	0:00:08	0:00:00		0:04:00	0:04:22
7.1	0	12:18:00	0	1	1	0:00:01	0:00:00		0:06:40	
1	58	12:18:28	1	1	2	0:00:28	0:00:38			
2	58	12:18:58	0	2	2	0:00:30	0:00:00			
1	62	12:19:28	1	2	3	0:00:30	0:01:00			
3	58	12:20:10	1	1	2	0:00:42	0:00:00	0:01:12		
1	47	12:20:33	2	1	3	0:00:23	0:01:05			
2	62	12:20:58	1	2	3	0:00:25	0:00:00			
3	62	12:21:31	1	1	2	0:00:33	0:00:00	0:01:21		
1	52	12:22:31	2	1	3	0:01:00	0:01:58			
999	52	12:23:15	2	1	3	0:00:43	0:00:00			
999	-1	12:23:22	2	1	3	0:00:07	0:00:00			
999	-1	12:24:10	2	1	3	0:00:48	0:00:00			
6.1	0	12:25:08	2	1	3	0:00:58	0:00:00			
1	58	12:27:11	3	1	4	0:02:04	0:04:40			
1	62	12:27:47	4	1	5	0:00:35	0:00:35			
8	52	12:37:19	3	1	4	0:09:32	0:00:00			
3	61	12:37:23	3	0	3	0:00:04	0:00:00	0:19:25		
7.1	0	12:39:25	3	0	3	0:02:03	0:00:00			
999	-1	12:39:43	3	0	3	0:00:18	0:00:00			
999	-1	12:40:00	3	0	3	0:00:17	0:00:00			

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
2	47	12:40:09	2	1	3	0:00:09	0:00:00			
3	47	12:40:56	2	0	2	0:00:47	0:00:00	0:03:33		
2	58	12:41:20	1	1	2	0:00:23	0:00:00			
3	58	12:43:14	1	0	1	0:01:55	0:00:00	0:02:18		
2	62	12:43:29	0	1	1	0:00:14	0:00:00			
1	61	12:43:54	1	1	2	0:00:25	0:16:07			
3	62	12:44:13	1	0	1	0:00:20	0:00:00	0:00:45		
2	61	12:44:27	0	1	1	0:00:14	0:00:00			
1	52	12:45:20	1	1	2	0:00:53	0:01:26			
3	61	12:45:50	1	0	1	0:00:30	0:00:00	0:01:23		
2	52	12:46:01	0	1	1	0:00:11	0:00:00			
3	52	12:47:12	0	0	0	0:01:11	0:00:00	0:01:11		
6.1	0	12:47:56	0	0	0	0:00:43	0:00:00			
1	58	12:49:23	1	0	1	0:01:27	0:04:03			
2	58	12:49:33	0	1	1	0:00:10	0:00:00			
7.1	0	12:49:34	0	1	1	0:00:01	0:00:00			
1	61	12:49:55	1	1	2	0:00:20	0:00:32			
3	58	12:50:02	1	0	1	0:00:07	0:00:00	0:00:29		
2	61	12:50:21	0	1	1	0:00:19	0:00:00			
1	47	12:51:01	1	1	2	0:00:40	0:01:06			
3	61	12:51:11	1	0	1	0:00:10	0:00:00	0:00:50		
2	47	12:51:25	0	1	1	0:00:14	0:00:00			
1	52	12:52:19	1	1	2	0:00:53	0:01:18			
3	47	12:52:34	1	0	1	0:00:16	0:00:00	0:01:09		
2	52	12:52:48	0	1	1	0:00:14	0:00:00			
3	52	12:54:19	0	0	0	0:01:31	0:00:00	0:01:31		
6.1	0	12:54:42	0	0	0	0:00:23	0:00:00			
7.1	0	12:54:47	0	0	0	0:00:05	0:00:00			
2	60	12:54:51	0	1	1	0:00:04	0:02:32			
1	58	12:55:08	1	1	2	0:00:17	0:00:17			
3	60	12:55:31	1	0	1	0:00:23	0:00:00	0:00:40		
2	58	12:55:41	0	1	1	0:00:10	0:00:00			
1	61	12:55:44	1	1	2	0:00:03	0:00:36			
1	62	12:56:04	2	1	3	0:00:20	0:00:20			
3	58	12:56:12	2	0	2	0:00:08	0:00:00	0:00:31		
2	61	12:56:24	1	1	2	0:00:13	0:00:00			
3	61	12:57:01	1	0	1	0:00:37	0:00:00	0:00:49		
2	62	12:57:14	0	1	1	0:00:13	0:00:00			
3	62	12:57:53	0	0	0	0:00:39	0:00:00	0:00:39		
1	47	12:58:40	1	0	1	0:00:47	0:02:36			
2	47	12:58:48	0	1	1	0:00:07	0:00:00			
1	52	12:59:00	1	1	2	0:00:13	0:00:20			
3	47	12:59:56	1	0	1	0:00:56	0:00:00	0:01:09		
2	52	13:00:22	0	1	1	0:00:25	0:00:00			
1	60	13:00:35	1	1	2	0:00:13	0:01:34			
3	52	13:00:48	1	0	1	0:00:14	0:00:00	0:00:26		
2	60	13:01:05	0	1	1	0:00:17	0:00:00			
1	61	13:01:19	1	1	2	0:00:14	0:00:44			
3	60	13:01:56	1	0	1	0:00:37	0:00:00	0:00:51		

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
2	61	13:02:10	0	1	1	0:00:14	0:00:00			
1	58	13:02:20	1	1	2	0:00:10	0:01:01			
3	61	13:03:05	1	0	1	0:00:45	0:00:00	0:00:55		
2	58	13:03:17	0	1	1	0:00:12	0:00:00			
1	62	13:03:20	1	1	2	0:00:03	0:01:00			
1	47	13:04:55	2	1	3	0:01:35	0:01:35			
3	58	13:04:58	2	0	2	0:00:04	0:00:00	0:01:41		
2	62	13:05:07	1	1	2	0:00:09	0:00:00			
3	62	13:05:33	1	0	1	0:00:26	0:00:00	0:00:35		
4	0	13:05:38	1	0	1	0:00:05	0:00:00			
5	0	13:06:20	1	0	1	0:00:42	0:00:00			
2	47	13:07:41	0	1	1	0:01:21	0:00:00			
3	47	13:08:43	0	0	0	0:01:02	0:00:00	0:01:02		
1	52	13:08:56	1	0	1	0:00:13	0:04:02			
2	52	13:09:09	0	1	1	0:00:12	0:00:00			
1	60	13:09:32	1	1	2	0:00:24	0:00:36			
3	52	13:10:30	1	0	1	0:00:57	0:00:00	0:01:21		
2	60	13:10:55	0	1	1	0:00:25	0:00:00			
1	61	13:11:02	1	1	2	0:00:08	0:01:30			
3	60	13:12:40	1	0	1	0:01:38	0:00:00	0:01:45		
4	0	13:12:49	1	0	1	0:00:09	0:00:00			
5	0	13:13:24	1	0	1	0:00:36	0:00:00			
2	61	13:13:30	0	1	1	0:00:06	0:00:00			
1	58	13:13:57	1	1	2	0:00:28	0:02:55			
1	47	13:14:57	2	1	3	0:01:00	0:01:00			
3	61	13:20:16	2	0	2	0:05:19	0:00:00			
2	58	13:20:30	1	1	2	0:00:14	0:00:00			
1	62	13:20:56	2	1	3	0:00:25	0:05:59			
3	58	13:21:20	2	0	2	0:00:24	0:00:00			
8	62	13:22:12	1	0	1	0:00:53	0:00:00			
2	47	13:22:19	0	1	1	0:00:07	0:00:00			
3	47	13:22:48	0	0	0	0:00:29	0:00:00	0:00:29		
2	52	13:23:20	0	1	1	0:00:32	0:02:24			
2	60	13:23:49	0	2	2	0:00:29	0:00:29			
3	52	13:24:22	0	1	1	0:00:33	0:00:00	0:01:02		
4	0	13:24:29	0	1	1	0:00:07	0:00:00			
5	0	13:24:47	0	1	1	0:00:17	0:00:00			
1	61	13:25:21	1	1	2	0:00:35	0:01:32			
3	60	13:26:31	1	0	1	0:01:10	0:00:00	0:02:42		
2	61	13:26:37	0	1	1	0:00:06	0:00:00			
1	62	13:26:53	1	1	2	0:00:16	0:01:32			
1	47	13:27:40	2	1	3	0:00:47	0:00:47			
1	52	13:29:04	3	1	4	0:01:24	0:01:24			
3	61	13:29:15	3	0	3	0:00:11	0:00:00	0:02:38		
2	62	13:29:49	2	1	3	0:00:34	0:00:00			
3	62	13:30:52	2	0	2	0:01:03	0:00:00	0:01:37		
1	60	13:30:57	3	0	3	0:00:05	0:01:54			
2	47	13:31:19	2	1	3	0:00:21	0:00:00			
3	47	13:31:53	2	0	2	0:00:34	0:00:00	0:01:01		

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MMSS	Queue	Service	System	time	Times	time	Time	Time
2	52	13:32:14	1	1	2	0:00:21	0:00:00			
3	52	13:34:06	1	0	1	0:01:51	0:00:00	0:02:13		
1	62	13:36:04	2	0	2	0:01:58	0:05:07			
2	60	13:39:52	1	1	2	0:03:48	0:00:00			
3	60	13:41:27	1	0	1	0:01:34	0:00:00			
1	47	13:42:26	2	0	2	0:01:00	0:06:22			
2	62	13:42:52	1	1	2	0:00:26	0:00:00			
3	62	13:43:37	1	0	1	0:00:44	0:00:00	0:02:10		
4.1	111	13:44:18	1	0	1	0:00:42	0:00:00			
5.1	111	13:44:46	1	0	1	0:00:28	0:00:00			
2	47	13:44:50	0	1	1	0:00:04	0:00:00			
3	47	13:45:16	0	0	0	0:00:26	0:00:00			
6.1	111	13:46:40	0	0	0	0:01:24	0:00:00			
1	61	13:46:48	1	0	1	0:00:08	0:04:21			
8	61	13:47:33	0	0	0	0:00:45	0:00:00			
7.1	11	13:47:54	0	0	0	0:00:21	0:00:00			
1	62	13:48:25	1	0	1	0:00:31	0:01:38			
1	60	13:48:29	2	0	2	0:00:03	0:00:03			
2	58	13:51:11	1	1	2	0:02:42	0:00:00			
1	61	13:51:22	2	1	3	0:00:12	0:02:54			
3	58	13:52:01	2	0	2	0:00:39	0:00:00			
2	62	13:52:41	1	1	2	0:00:40	0:00:00			
8	61	13:52:54	0	1	1	0:00:13	0:00:00			
1	47	13:53:01	1	1	2	0:00:07	0:01:38			
3	62	13:53:27	1	0	1	0:00:26	0:00:00	0:01:26		
4	0	13:53:28	1	0	1	0:00:02	0:00:00			
5	0	13:53:40	1	0	1	0:00:11	0:00:00			
2	60	13:55:11	0	1	1	0:01:32	0:00:00			
3	60	13:56:20	0	0	0	0:01:09	0:00:00	0:01:09		
2	47	13:56:24	0	1	1	0:00:03	0:03:23			
3	47	13:57:49	0	0	0	0:01:25	0:00:00	0:01:25		
1	62	13:59:41	1	0	1	0:01:53	0:03:18			
999	0	14:00:39	1	0	1	0:00:58	0:00:00			
2	62	14:01:14	0	1	1	0:00:35	0:00:00			
3	62	14:02:05	0	0	0	0:00:51	0:00:00			
2	61	14:02:30	0	1	1	0:00:25	0:02:49			
1	52	14:02:54	1	1	2	0:00:24	0:00:24			
3	61	14:04:03	1	0	1	0:01:09	0:00:00			
2	52	14:04:08	0	1	1	0:00:05	0:00:00			
3	52	14:05:15	0	0	0	0:01:07	0:00:00	0:01:07		
4.1	0	14:05:27	0	0	0	0:00:12	0:00:00			
5.1	0	14:05:45	0	0	0	0:00:18	0:00:00			
1	62	14:06:12	1	0	1	0:00:26	0:03:18			
2	62	14:06:23	0	1	1	0:00:11	0:00:00			
3	62	14:06:42	0	0	0	0:00:19	0:00:00	0:00:19		
4.1	0	14:07:12	0	0	0	0:00:30	0:00:00			
5.1	0	14:07:34	0	0	0	0:00:22	0:00:00			
2	58	14:07:53	0	1	1	0:00:19	0:01:41			
3	58	14:08:52	0	0	0	0:00:59	0:00:00	0:00:59		

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
1	47	14:10:23	1	0	1	0:01:31	0:02:30			
999	0	14:10:26	1	0	1	0:00:03	0:00:00			
1	60	14:12:01	2	0	2	0:01:35	0:01:38			
2	47	14:14:27	1	1	2	0:02:25	0:00:00			
3	47	14:15:06	1	0	1	0:00:39	0:00:00	0:06:14		
1	52	14:15:28	2	0	2	0:00:22	0:03:27			
2	52	14:15:35	1	1	2	0:00:07	0:00:00			
2	60	14:16:11	0	2	2	0:00:36	0:00:00			
3	60	14:17:32	0	1	1	0:01:21	0:00:00			
3	52	14:17:42	0	0	0	0:00:10	0:00:00	0:02:07		
1	58	14:18:50	1	0	1	0:01:08	0:03:22			
2	58	14:20:40	0	1	1	0:01:49	0:00:00			
1	61	14:21:33	1	1	2	0:00:53	0:02:43			
3.1	58	14:22:24	1	1	2	0:00:51	0:00:00			
1	47	14:22:45	2	1	3	0:00:21	0:01:12			
2	61	14:22:49	1	2	3	0:00:05	0:00:00			
3	58	14:24:22	1	1	2	0:01:32	0:00:00	0:06:40		
3.1	61	14:24:25	1	1	2	0:00:04	0:00:00			
2	47	14:24:52	0	2	2	0:00:27	0:00:00			
1	52	14:25:11	1	2	3	0:00:19	0:02:27			
3.1	47	14:26:38	1	2	3	0:01:26	0:00:00			
3	61	14:26:42	1	1	2	0:00:04	0:00:00	0:03:52		
2	52	14:26:58	0	2	2	0:00:16	0:00:00			
1	62	14:27:15	1	2	3	0:00:17	0:02:03			
1	60	14:27:19	2	2	4	0:00:04	0:00:04			
3	47	14:28:35	2	1	3	0:01:16	0:00:00	0:03:43		
3.1	52	14:28:41	2	1	3	0:00:06	0:00:00			
2	60	14:29:48	1	2	3	0:01:08	0:00:00			
3	52	14:30:32	1	1	2	0:00:43	0:00:00	0:01:57		
3.1	60	14:30:50	1	1	2	0:00:18	0:00:00			
1	58	14:30:53	2	1	3	0:00:03	0:03:34			
2	62	14:31:06	1	2	3	0:00:13	0:00:00			
1	61	14:31:30	2	2	4	0:00:25	0:00:37			
3	60	14:32:45	2	1	3	0:01:14	0:00:00	0:02:13		
3.1	62	14:32:59	2	1	3	0:00:14	0:00:00			
2	58	14:33:28	1	2	3	0:00:30	0:00:00			
3	62	14:34:58	1	1	2	0:01:30	0:00:00	0:02:14		
3.1	58	14:35:07	1	1	2	0:00:08	0:00:00			
2	61	14:35:33	0	2	2	0:00:26	0:00:00			
1	47	14:35:36	1	2	3	0:00:03	0:04:06			
1	52	14:36:36	2	2	4	0:01:00	0:01:00			
3	58	14:37:12	2	1	3	0:00:36	0:00:00	0:03:44		
3.1	61	14:37:27	2	1	3	0:00:15	0:00:00			
2	47	14:37:50	1	2	3	0:00:23	0:00:00			
3	61	14:39:14	1	1	2	0:01:24	0:00:00	0:02:02		
3.1	47	14:39:17	1	1	2	0:00:03	0:00:00			
2	52	14:39:38	0	2	2	0:00:21	0:00:00			
1	62	14:40:51	1	2	3	0:01:13	0:04:15			
3	47	14:41:01	1	1	2	0:00:11	0:00:00	0:03:11		

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MMSS	Queue	Service	System	time	Times	time	Time	Time
3.1	52	14:41:10	1	1	2	0:00:08	0:00:00			
1	60	14:41:13	2	1	3	0:00:03	0:00:22			
2	60	14:42:02	1	2	3	0:00:50	0:00:00			
3	52	14:42:52	1	1	2	0:00:50	0:00:00	0:01:51		
3.1	60	14:43:00	1	1	2	0:00:08	0:00:00			
2	62	14:43:19	0	2	2	0:00:18	0:00:00			
3	60	14:44:30	0	1	1	0:01:12	0:00:00	0:02:28		
3.1	62	14:44:37	0	1	1	0:00:06	0:00:00			
1	58	14:44:58	1	1	2	0:00:22	0:03:45			
1	61	14:45:02	2	1	3	0:00:04	0:00:04			
2	58	14:45:36	1	2	3	0:00:34	0:00:00			
3	62	14:46:19	1	1	2	0:00:44	0:00:00	0:01:49		
3.1	58	14:46:25	1	1	2	0:00:06	0:00:00			
2	61	14:46:50	0	2	2	0:00:25	0:00:00			
1	47	14:48:10	1	2	3	0:01:20	0:03:08			
3	58	14:49:02	1	1	2	0:00:52	0:00:00	0:03:26		
3.1	61	14:49:09	1	1	2	0:00:07	0:00:00			
1	52	14:49:17	2	1	3	0:00:08	0:01:07			
2	47	14:49:37	1	2	3	0:00:21	0:00:00			
1	60	14:50:45	2	2	4	0:01:08	0:01:28			
3	61	14:51:08	2	1	3	0:00:22	0:00:00	0:02:06		
3.1	47	14:51:26	2	1	3	0:00:18	0:00:00			
2	52	14:51:52	1	2	3	0:00:26	0:00:00			
3	47	14:53:07	1	1	2	0:01:15	0:00:00	0:02:00		
3.1	52	14:53:13	1	1	2	0:00:05	0:00:00			
2	60	14:53:38	0	2	2	0:00:25	0:00:00			
3	52	14:54:58	0	1	1	0:01:20	0:00:00	0:03:06		
1	62	14:55:07	1	1	2	0:00:09	0:04:22			
3.1	60	14:55:11	1	1	2	0:00:04	0:00:00			
2	62	14:55:28	0	2	2	0:00:17	0:00:00			
3	60	14:57:10	0	1	1	0:01:42	0:00:00	0:03:32		
3.1	62	14:57:14	0	1	1	0:00:05	0:00:00			
3	62	14:59:22	0	0	0	0:02:08	0:00:00	0:03:54		
6.1	0	14:59:24	0	0	0	0:00:02	0:00:00			
1	58	14:59:29	1	0	1	0:00:05	0:04:22			
1	47	14:59:35	2	0	2	0:00:06	0:00:06			
1	61	14:59:38	3	0	3	0:00:03	0:00:03			
7.1	0	14:59:48	3	0	3	0:00:09	0:00:00			
2	58	14:59:53	2	1	3	0:00:06	0:00:00			
3.1	58	15:00:11	2	1	3	0:00:18	0:00:00			
2	61	15:00:34	1	2	3	0:00:23	0:00:00			
1	52	15:00:50	2	2	4	0:00:15	0:01:11			
1	60	15:02:25	3	2	5	0:01:35	0:01:35			
3	58	15:02:29	3	1	4	0:00:05	0:00:00	0:03:08		
3.1	61	15:02:34	3	1	4	0:00:05	0:00:00			
2	47	15:03:19	2	2	4	0:00:44	0:00:00			
3	61	15:04:25	2	1	3	0:01:06	0:00:00	0:01:55		
3.1	47	15:04:30	2	1	3	0:00:05	0:00:00			
2	52	15:04:49	1	2	3	0:00:19	0:00:00			

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MMSS	Queue	Service	System	time	Times	time	Time	Time
1	62	15:05:39	2	2	4	0:00:49	0:03:14			
3	47	15:06:02	2	1	3	0:00:24	0:00:00	0:01:37		
3.1	52	15:06:07	2	1	3	0:00:05	0:00:00			
2	60	15:06:40	1	2	3	0:00:33	0:00:00			
3	52	15:07:42	1	1	2	0:01:02	0:00:00	0:01:40		
3.1	60	15:07:52	1	1	2	0:00:10	0:00:00			
2	62	15:08:11	0	2	2	0:00:19	0:00:00			
1	58	15:09:15	1	2	3	0:01:04	0:03:37			
1	61	15:09:23	2	2	4	0:00:07	0:00:07			
3	60	15:10:10	2	1	3	0:00:47	0:00:00	0:01:59		
3.1	62	15:10:17	2	1	3	0:00:08	0:00:00			
2	58	15:10:37	1	2	3	0:00:20	0:00:00			
1	47	15:11:31	2	2	4	0:00:53	0:02:08			
3	62	15:12:33	2	1	3	0:01:02	0:00:00	0:02:23		
3.1	58	15:12:38	2	1	3	0:00:05	0:00:00			
2	61	15:13:06	1	2	3	0:00:28	0:00:00			
1	52	15:14:41	2	2	4	0:01:36	0:03:11			
1	60	15:15:16	3	2	5	0:00:34	0:00:34			
3	58	15:15:52	3	1	4	0:00:37	0:00:00	0:03:20		
3.1	61	15:16:18	3	1	4	0:00:25	0:00:00			
2	47	15:16:56	2	2	4	0:00:38	0:00:00			
3.1	47	15:18:17	2	2	4	0:01:21	0:00:00			
3	61	15:18:22	2	1	3	0:00:06	0:00:00	0:02:30		
2	52	15:18:36	1	2	3	0:00:13	0:00:00			
1	62	15:19:32	2	2	4	0:00:57	0:04:17			
3	47	15:19:57	2	1	3	0:00:24	0:00:00	0:01:34		
3.1	52	15:20:00	2	1	3	0:00:03	0:00:00			
2	60	15:20:39	1	2	3	0:00:39	0:00:00			
3	52	15:22:29	1	1	2	0:01:50	0:00:00	0:02:33		
3.1	60	15:22:39	1	1	2	0:00:09	0:00:00			
2	62	15:22:56	0	2	2	0:00:18	0:00:00			
1	61	15:23:41	1	2	3	0:00:45	0:04:09			
3	60	15:24:40	1	1	2	0:00:59	0:00:00	0:04:00		
3	62	15:24:46	1	0	1	0:00:07	0:00:00	0:01:50		
999	-1	15:25:46	1	0	1	0:01:00	0:00:00			
1	58	15:26:47	2	0	2	0:01:01	0:03:06			
1	47	15:26:56	3	0	3	0:00:08	0:00:08			
2	58	15:27:59	2	1	3	0:01:04	0:00:00			
3	58	15:29:18	2	0	2	0:01:18	0:00:00	0:04:31		
2	61	15:29:37	1	1	2	0:00:19	0:00:00			
1	52	15:29:43	2	1	3	0:00:06	0:02:47			
1	60	15:29:52	3	1	4	0:00:08	0:00:08			
3	61	15:30:20	3	0	3	0:00:28	0:00:00	0:01:02		
2	47	15:30:39	2	1	3	0:00:20	0:00:00			
3	47	15:32:38	2	0	2	0:01:59	0:00:00	0:02:19		
2	52	15:32:56	1	1	2	0:00:18	0:00:00			
3	52	15:33:38	1	0	1	0:00:42	0:00:00	0:01:00		
2	60	15:33:54	0	1	1	0:00:16	0:00:00			
3	60	15:34:47	0	0	0	0:00:52	0:00:00	0:01:09		

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
1	62	15:34:49	1	0	1	0:00:03	0:04:57			
999	-1	15:35:44	1	0	1	0:00:55	0:00:00			
1	61	15:37:20	2	0	2	0:01:35	0:02:31			
2	62	15:39:19	1	1	2	0:01:59	0:00:00			
3	62	15:40:02	1	0	1	0:00:43	0:00:00	0:05:16		
2	61	15:40:38	0	1	1	0:00:36	0:00:00			
1	47	15:41:04	1	1	2	0:00:26	0:03:45			
1	52	15:41:33	2	1	3	0:00:28	0:00:28			
1	60	15:41:37	3	1	4	0:00:05	0:00:05			
3	61	15:41:58	3	0	3	0:00:20	0:00:00	0:01:20		
2	47	15:42:27	2	1	3	0:00:30	0:00:00			
3	47	15:43:01	2	0	2	0:00:33	0:00:00	0:01:03		
6	0	15:43:53	2	0	2	0:00:52	0:00:00			
7	0	15:45:35	2	0	2	0:01:42	0:00:00			
1	62	15:45:55	3	0	3	0:00:20	0:04:17			
4	0	15:47:51	3	0	3	0:01:57	0:00:00			
999	61	15:48:13	3	0	3	0:00:22	0:00:00			
5	0	15:49:01	3	0	3	0:00:47	0:00:00			
999	-1	15:50:18	3	0	3	0:01:17	0:00:00			
4	0	15:50:36	3	0	3	0:00:18	0:00:00			
5	0	15:51:09	3	0	3	0:00:33	0:00:00			
4	0	15:51:13	3	0	3	0:00:04	0:00:00			
5	0	15:51:19	3	0	3	0:00:06	0:00:00			
4	0	15:51:54	3	0	3	0:00:35	0:00:00			
1	61	15:53:03	4	0	4	0:01:09	0:07:08			
2	52	15:53:06	3	1	4	0:00:03	0:00:00			
3	52	15:53:50	3	0	3	0:00:43	0:00:00			
2	60	15:54:14	2	1	3	0:00:24	0:00:00			
2	62	15:55:27	1	1	2	0:01:13	0:00:00			
3	62	15:56:01	1	0	1	0:00:34	0:00:00	0:02:11		
2	61	15:56:43	0	1	1	0:00:42	0:00:00			
3	61	15:56:53	0	0	0	0:00:10	0:00:00	0:00:10		
1	47	15:57:15	1	0	1	0:00:22	0:04:12			
2	47	15:57:40	0	1	1	0:00:25	0:00:00			
3	47	15:57:54	0	0	0	0:00:14	0:00:00	0:00:14		
6	0	15:58:32	0	0	0	0:00:38	0:00:00			
1	52	15:58:37	1	0	1	0:00:05	0:01:22			
7	0	15:58:54	1	0	1	0:00:17	0:00:00			
2	52	15:58:59	0	1	1	0:00:05	0:00:00			
3	52	15:59:13	0	0	0	0:00:14	0:00:00	0:00:14		
6	0	16:00:09	0	0	0	0:00:56	0:00:00			
1	60	16:00:46	1	0	1	0:00:37	0:02:09			
7	0	16:00:52	1	0	1	0:00:06	0:00:00			
2	60	16:00:57	0	1	1	0:00:05	0:00:00			
3	60	16:01:11	0	0	0	0:00:14	0:00:00	0:00:14		
1	58	16:01:15	1	0	1	0:00:04	0:00:29			
2	58	16:01:40	0	1	1	0:00:25	0:00:00			
1	61	16:02:03	1	1	2	0:00:23	0:00:48			
1	62	16:02:07	2	1	3	0:00:04	0:00:04			

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
3	58	16:02:27	2	0	2	0:00:19	0:00:00	0:00:47		
2	62	16:02:52	1	1	2	0:00:25	0:00:00			
1	47	16:02:58	2	1	3	0:00:07	0:00:51			
3	62	16:06:04	2	0	2	0:03:06	0:00:00	0:03:37		
2	61	16:06:23	1	1	2	0:00:19	0:00:00			
3	61	16:07:34	1	0	1	0:01:12	0:00:00	0:01:30		
1	52	16:07:40	2	0	2	0:00:06	0:04:42			
2	47	16:08:00	1	1	2	0:00:20	0:00:00			
3	47	16:08:50	1	0	1	0:00:50	0:00:00	0:01:16		
1	60	16:08:59	2	0	2	0:00:09	0:01:19			
2	52	16:09:11	1	1	2	0:00:12	0:00:00			
1	58	16:09:22	2	1	3	0:00:10	0:00:23			
3	52	16:10:03	2	0	2	0:00:42	0:00:00	0:01:13		
2	60	16:10:30	1	1	2	0:00:27	0:00:00			
3	60	16:11:02	1	0	1	0:00:32	0:00:00	0:00:58		
1	62	16:11:05	2	0	2	0:00:03	0:01:43			
2	62	16:11:07	1	1	2	0:00:02	0:00:00			
3	62	16:11:09	1	0	1	0:00:02	0:00:00			
1	52	16:12:07	2	0	2	0:00:58	0:01:02			
1	60	16:12:10	3	0	3	0:00:03	0:00:03			
1	61	16:12:44	4	0	4	0:00:34	0:00:34			
1	47	16:12:58	5	0	5	0:00:14	0:00:14			
2	58	16:12:59	4	1	5	0:00:01	0:00:00			
3	58	16:13:12	4	0	4	0:00:13	0:00:00			
2	52	16:13:33	3	1	4	0:00:22	0:00:00			
1	58	16:13:56	4	1	5	0:00:23	0:00:58			
3	52	16:14:02	4	0	4	0:00:06	0:00:00	0:00:29		
2	61	16:14:39	3	1	4	0:00:37	0:00:00			
3	61	16:14:59	3	0	3	0:00:20	0:00:00	0:00:57		
2	47	16:15:20	2	1	3	0:00:20	0:00:00			
3	47	16:15:59	2	0	2	0:00:40	0:00:00	0:01:00		
4	0	16:16:36	2	0	2	0:00:37	0:00:00			
5	0	16:17:21	2	0	2	0:00:45	0:00:00			
1	52	16:17:24	3	0	3	0:00:03	0:03:28			
2	52	16:17:27	2	1	3	0:00:03	0:00:00			
3	52	16:18:14	2	0	2	0:00:47	0:00:00			
2	60	16:18:35	1	1	2	0:00:20	0:00:00			
1	62	16:18:40	2	1	3	0:00:05	0:01:16			
1	61	16:18:45	3	1	4	0:00:05	0:00:05			
1	47	16:18:50	4	1	5	0:00:05	0:00:05			
3	60	16:19:04	4	0	4	0:00:14	0:00:00	0:00:29		
2	58	16:19:20	3	1	4	0:00:17	0:00:00			
3	58	16:20:13	3	0	3	0:00:53	0:00:00	0:01:09		
2	62	16:20:29	2	1	3	0:00:16	0:00:00			
3	62	16:21:08	2	0	2	0:00:39	0:00:00	0:00:55		
2	61	16:21:27	1	1	2	0:00:19	0:00:00			
3	61	16:22:06	1	0	1	0:00:39	0:00:00	0:00:58		
2	47	16:22:22	0	1	1	0:00:16	0:00:00			
1	52	16:22:27	1	1	2	0:00:05	0:03:37			

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
3	47	16:23:24	1	0	1	0:00:57	0:00:00	0:01:02		
2	52	16:23:35	0	1	1	0:00:11	0:00:00			
1	60	16:24:04	1	1	2	0:00:29	0:01:37			
3	52	16:24:14	1	0	1	0:00:10	0:00:00	0:00:39		
2	60	16:24:35	0	1	1	0:00:22	0:00:00			
1	58	16:25:29	1	1	2	0:00:54	0:01:26			
3	60	16:25:36	1	0	1	0:00:06	0:00:00	0:01:00		
2	58	16:25:55	0	1	1	0:00:20	0:00:00			
3	58	16:26:38	0	0	0	0:00:42	0:00:00	0:00:42		
1	62	16:26:41	1	0	1	0:00:03	0:01:12			
2	62	16:26:54	0	1	1	0:00:13	0:00:00			
3	62	16:27:44	0	0	0	0:00:51	0:00:00	0:00:51		
1	61	16:27:48	1	0	1	0:00:04	0:01:07			
2	61	16:28:01	0	1	1	0:00:13	0:00:00			
1	47	16:28:21	1	1	2	0:00:20	0:00:33			
1	52	16:28:40	2	1	3	0:00:19	0:00:19			
3	61	16:28:45	2	0	2	0:00:04	0:00:00	0:00:43		
2	47	16:29:02	1	1	2	0:00:17	0:00:00			
3	47	16:29:40	1	0	1	0:00:39	0:00:00	0:00:56		
2	52	16:29:53	0	1	1	0:00:13	0:00:00			
1	60	16:30:01	1	1	2	0:00:09	0:01:21			
3	52	16:31:30	1	0	1	0:01:29	0:00:00	0:01:37		
2	60	16:31:44	0	1	1	0:00:14	0:00:00			
3	60	16:32:34	0	0	0	0:00:50	0:00:00	0:00:50		
1	62	16:33:02	1	0	1	0:00:28	0:03:01			
2	62	16:33:10	0	1	1	0:00:07	0:00:00			
1	61	16:33:27	1	1	2	0:00:17	0:00:25			
1	58	16:33:36	2	1	3	0:00:09	0:00:09			
3	62	16:33:52	2	0	2	0:00:16	0:00:00	0:00:43		
2	61	16:34:07	1	1	2	0:00:15	0:00:00			
3	61	16:35:34	1	0	1	0:01:27	0:00:00	0:01:42		
999	-1	16:36:03	1	0	1	0:00:29	0:00:00			
2	58	16:36:11	0	1	1	0:00:08	0:00:00			
1	52	16:36:18	1	1	2	0:00:06	0:02:42			
3	58	16:36:53	1	0	1	0:00:35	0:00:00	0:00:41		
1	47	16:37:02	2	0	2	0:00:09	0:00:44			
1	60	16:37:04	3	0	3	0:00:02	0:00:02			
2	52	16:37:10	2	1	3	0:00:06	0:00:00			
3	52	16:38:18	2	0	2	0:01:08	0:00:00	0:01:25		
2	47	16:38:38	1	1	2	0:00:20	0:00:00			
1	62	16:39:11	2	1	3	0:00:34	0:02:07			
3	47	16:39:46	2	0	2	0:00:35	0:00:00	0:01:28		
2	60	16:39:59	1	1	2	0:00:14	0:00:00			
1	61	16:40:06	2	1	3	0:00:07	0:00:55			
3	60	16:40:48	2	0	2	0:00:42	0:00:00	0:01:02		
2	62	16:40:59	1	1	2	0:00:11	0:00:00			
3	62	16:42:07	1	0	1	0:01:08	0:00:00	0:01:18		
2	61	16:42:22	0	1	1	0:00:16	0:00:00			
1	52	16:42:36	1	1	2	0:00:13	0:02:30			

Figure A.16 - Field data for Mar9p.2 data file (continued).

• Crane #3 servicing "GUAYAMA"										
• March 9, 1991									Ordered	Ordered
						elapsed	Inter	Service	Dbl Ser	Dbl Inter
Event	Truck	H:MM:SS	Queue	Service	System	time	Times	time	Time	Time
3	61	16:43:07	1	0	1	0:00:31	0:00:00	0:00:44		
2	52	16:43:17	0	1	1	0:00:10	0:00:00			
3	52	16:43:47	0	0	0	0:00:30	0:00:00	0:00:30		
2	58	16:44:02	0	1	1	0:00:15	0:01:26			
3	58	16:44:50	0	0	0	0:00:48	0:00:00	0:00:48		
1	47	16:44:54	1	0	1	0:00:04	0:00:52			
2	47	16:45:04	0	1	1	0:00:10	0:00:00			
3	47	16:45:35	0	0	0	0:00:30	0:00:00	0:00:30		
1	60	16:45:49	1	0	1	0:00:14	0:00:55			
2	60	16:46:09	0	1	1	0:00:20	0:00:00			
3	60	16:46:35	0	0	0	0:00:26	0:00:00	0:00:26		
1	61	16:47:02	1	0	1	0:00:27	0:01:13			
2	61	16:47:07	0	1	1	0:00:05	0:00:00			
3	61	16:47:32	0	0	0	0:00:25	0:00:00	0:00:25		
1	62	16:47:42	1	0	1	0:00:10	0:00:40			
2	62	16:47:55	0	1	1	0:00:13	0:00:00			
1	52	16:47:59	1	1	2	0:00:04	0:00:17			
3	62	16:48:33	1	0	1	0:00:34	0:00:00	0:00:38		
2	52	16:48:45	0	1	1	0:00:12	0:00:00			
3	52	16:49:41	0	0	0	0:00:56	0:00:00	0:00:56		
1	58	16:49:58	1	0	1	0:00:17	0:01:58			
2	58	16:50:07	0	1	1	0:00:09	0:00:00			
1	60	16:50:39	1	1	2	0:00:32	0:00:41			
3	58	16:51:05	1	0	1	0:00:26	0:00:00	0:00:58		
999	-1	16:51:43	1	0	1	0:00:38	0:00:00			
1	61	16:52:49	2	0	2	0:01:05	0:02:10			
1	47	16:52:58	3	0	3	0:00:09	0:00:09			
1	62	16:54:01	4	0	4	0:01:03	0:01:03			
1	52	16:54:17	5	0	5	0:00:16	0:00:16			

APPENDIX B. KOLMOGOROV-SMIRNOFF DISTRIBUTION TEST RESULTS

Figure B.1 - Cumulative frequency of service times for Jan7p.1 data file.
Best fit is the Erlang(2) distribution. Sample is 60 observations.

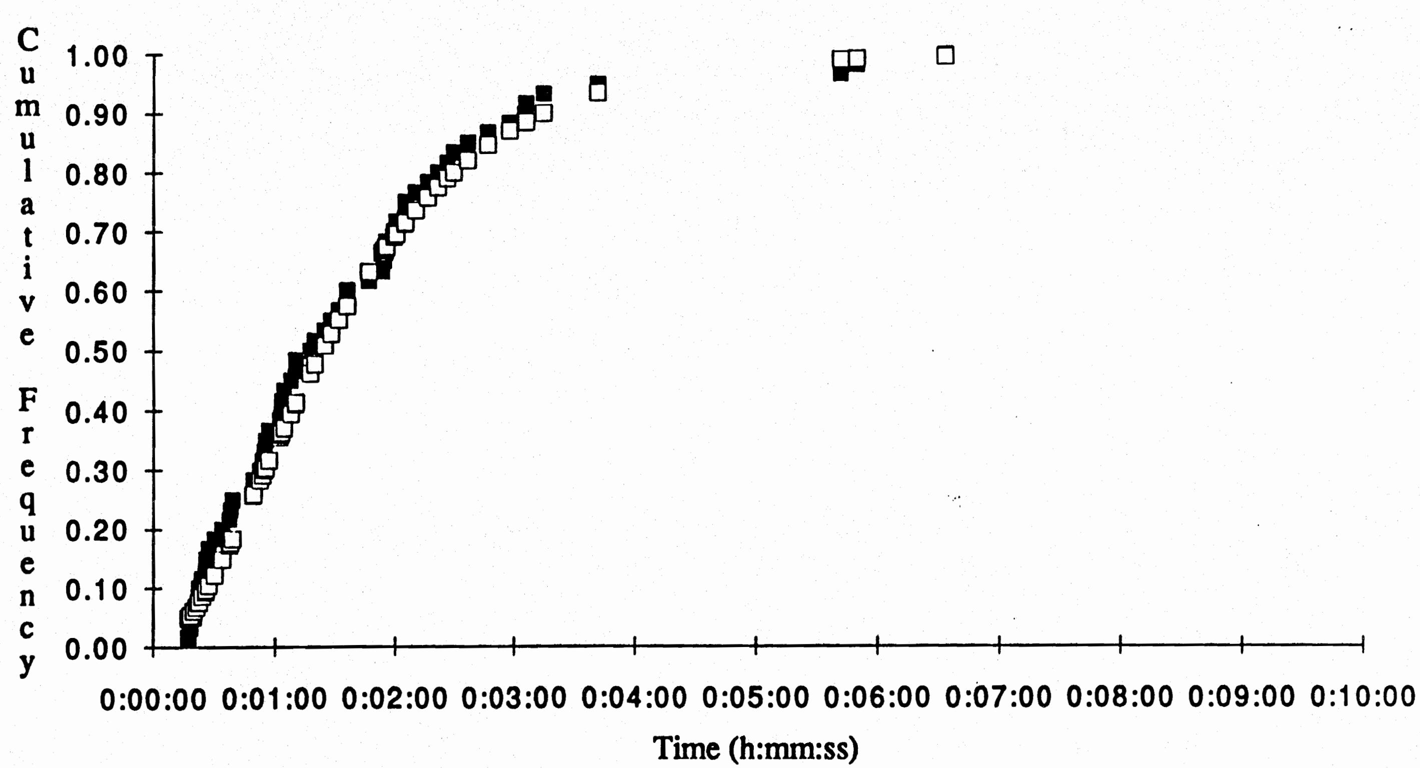


Figure B.2 - Cumulative frequency of interarrival times for Jan7p.1 data file. Best fit is the exponential distribution. Sample is 59 observations.

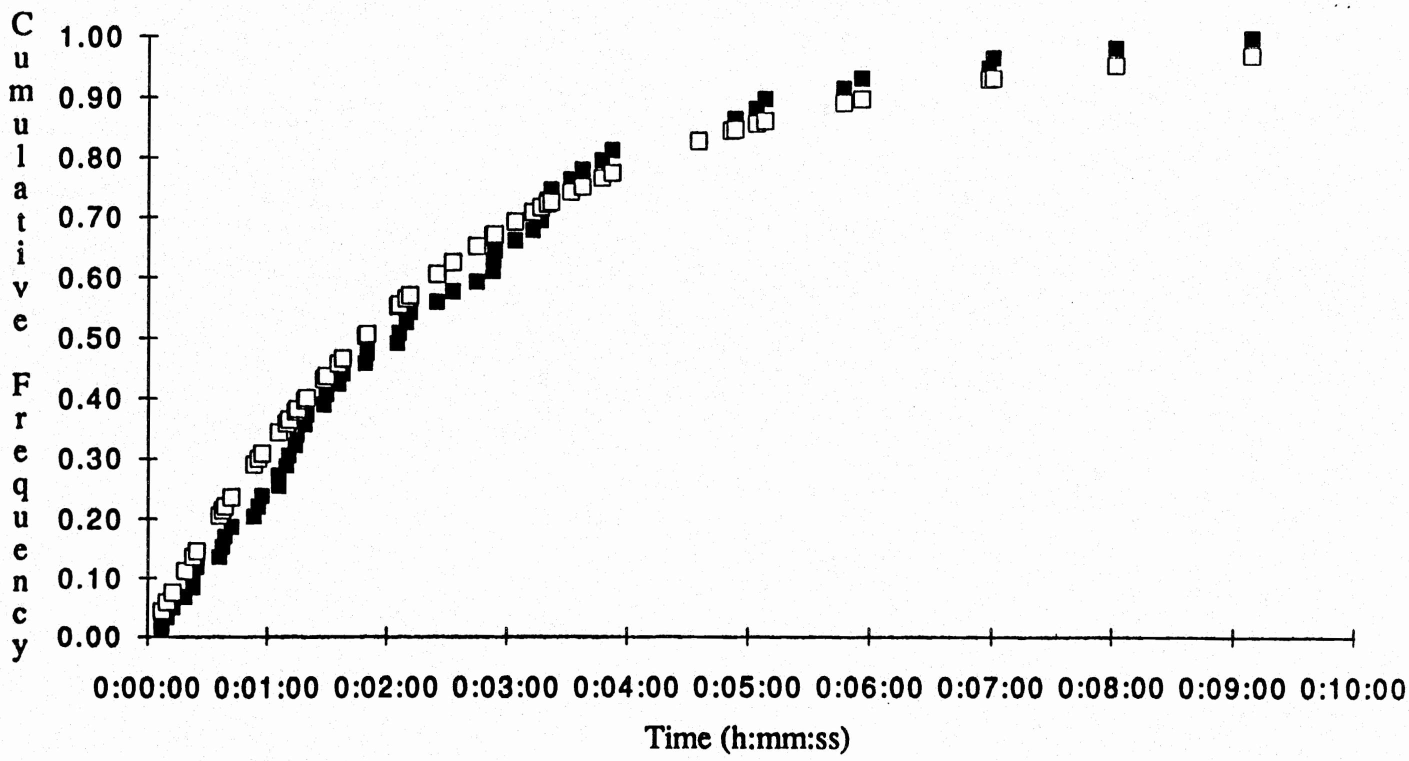


Figure B.3 - Cumulative frequency of backcycle times for Jan7p.1 data file.
Best fit is the Erlang(2) distribution. Sample is 50 observations.

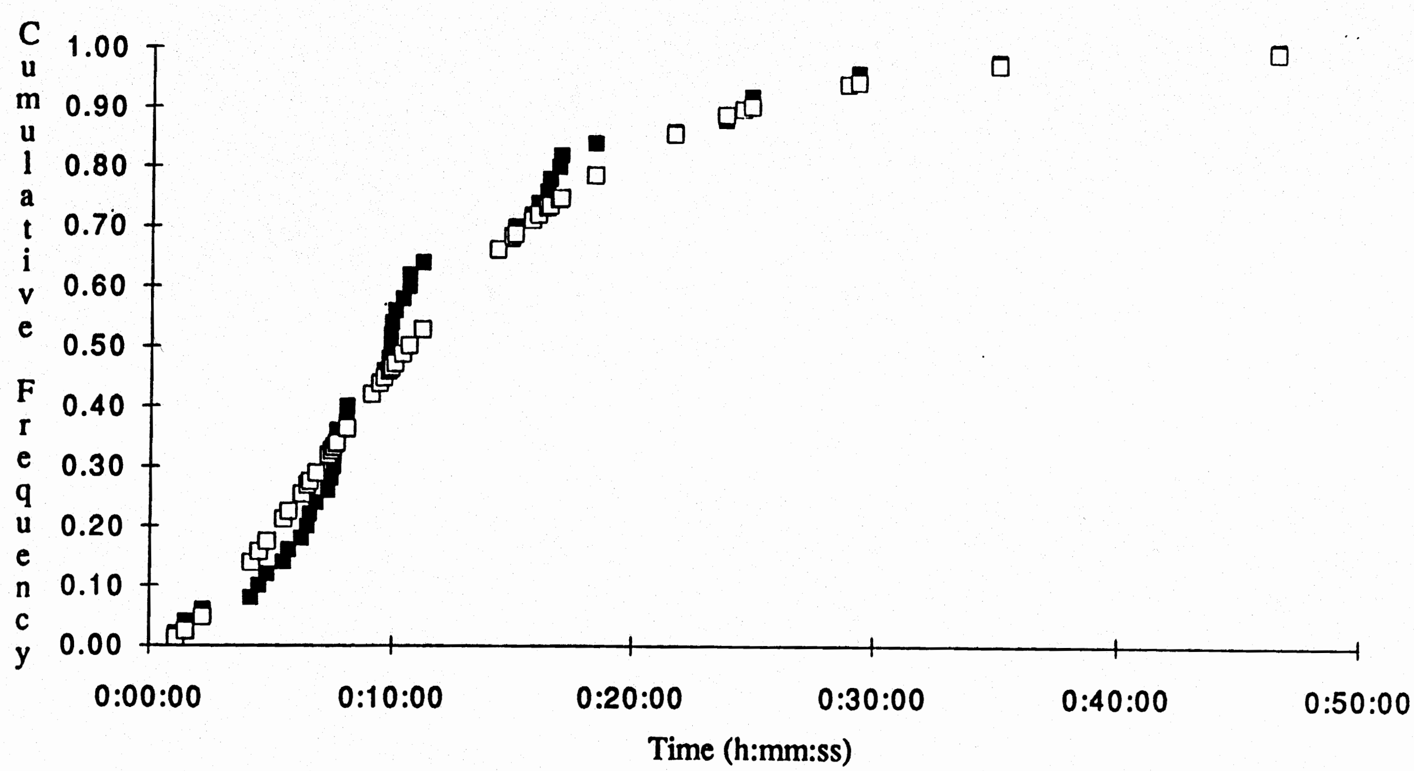


Figure B.4 - Cumulative frequency of service times for Jan7p.2 data file. Best fit is the Erlang(3) distribution. Sample is 37 observations.

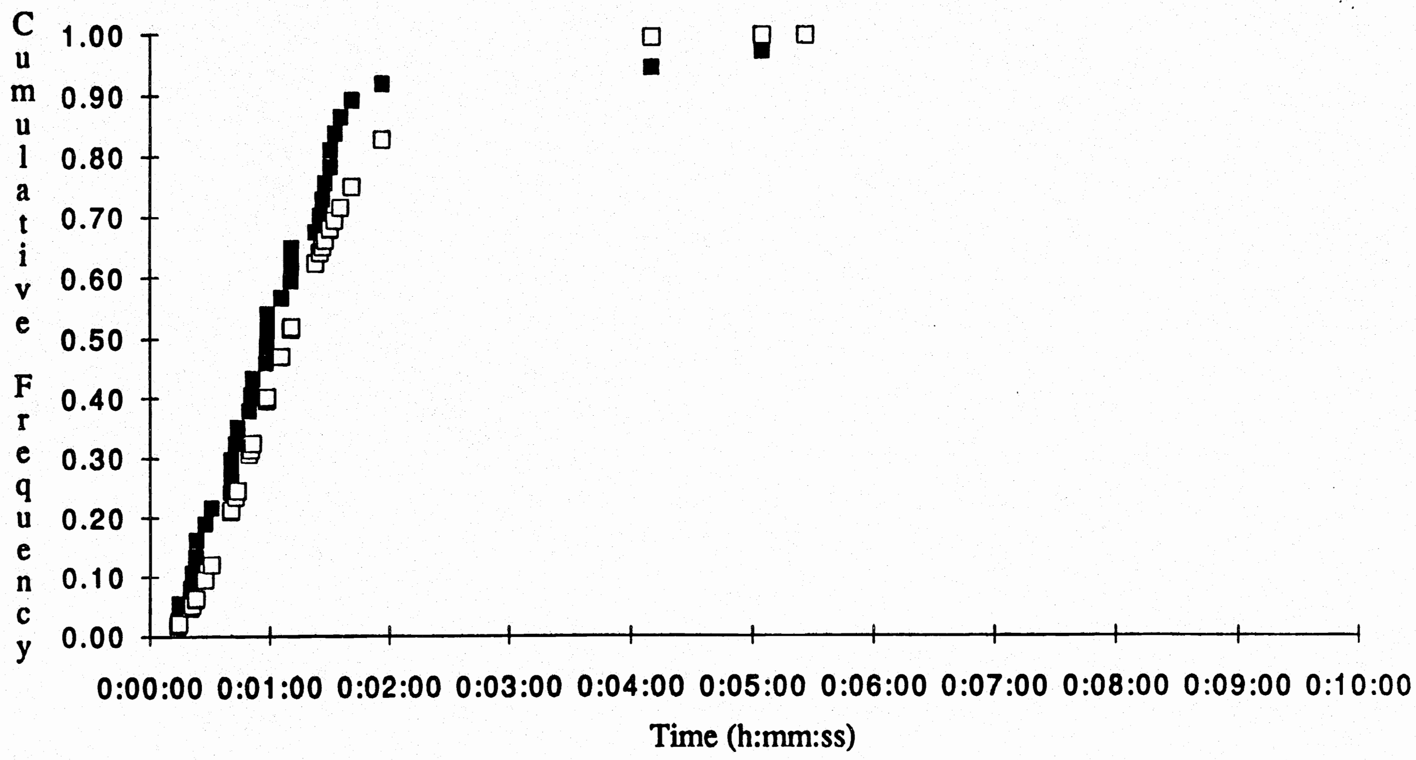


Figure B.5 - Cumulative frequency of interarrival times for Jan7p.2 data file. Best fit is the Erlang(2) distribution. Sample is 39 observations.

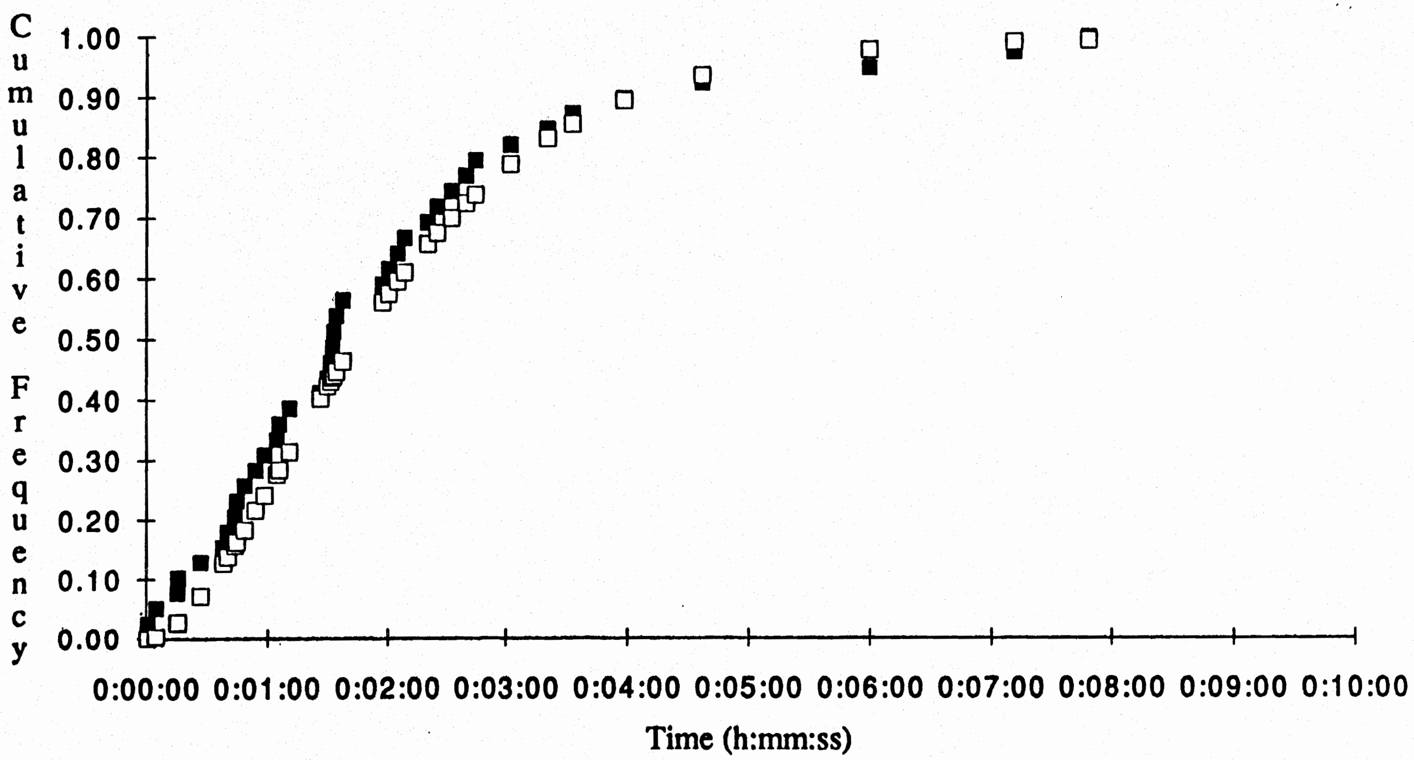


Figure B.6 - Cumulative frequency of backcycle times for Jan7p.2 data file. Best fit is the Erlang(7) distribution. Sample is 26 observations.

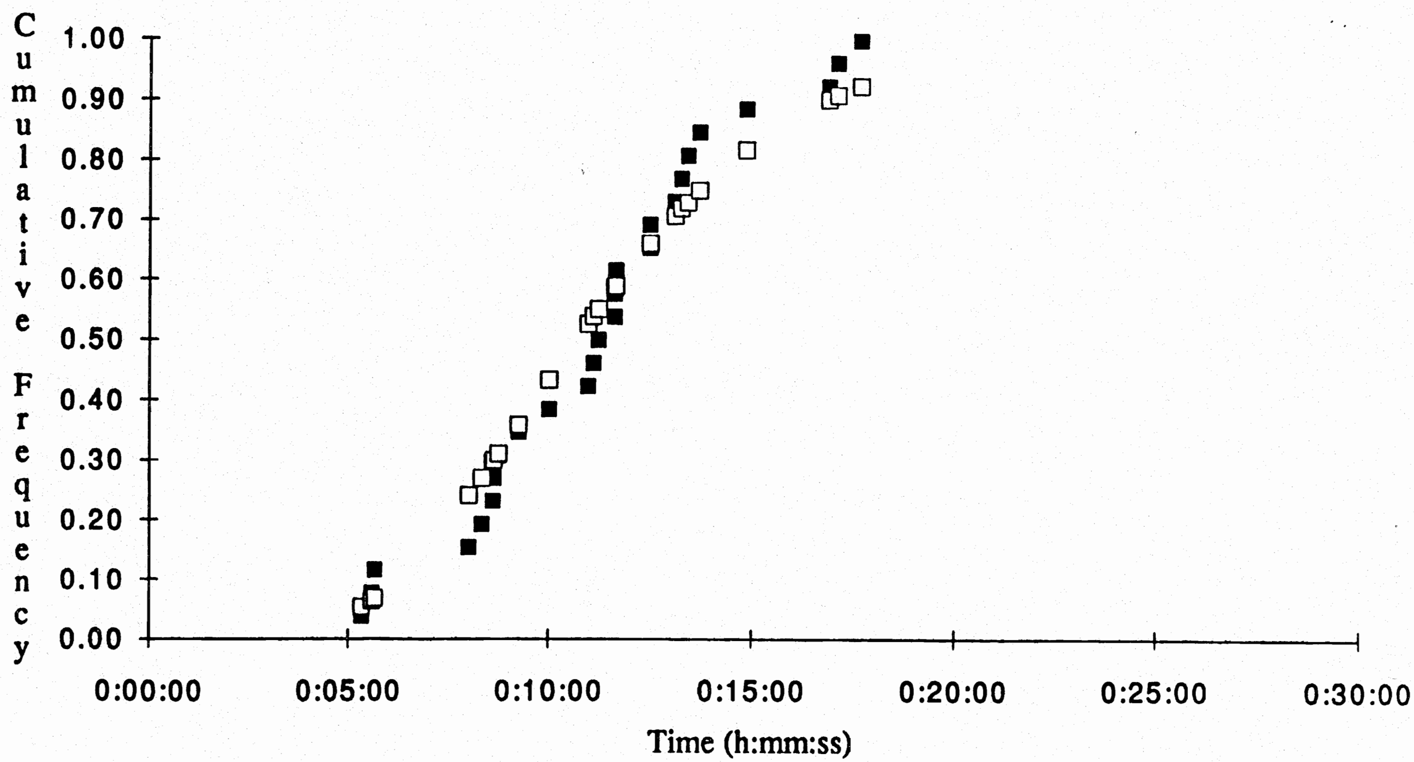


Figure B.7 - Cumulative frequency of service times for Feb11a.1 data file.
Best fit is the Erlang(7) distribution. Sample is 41 observations.

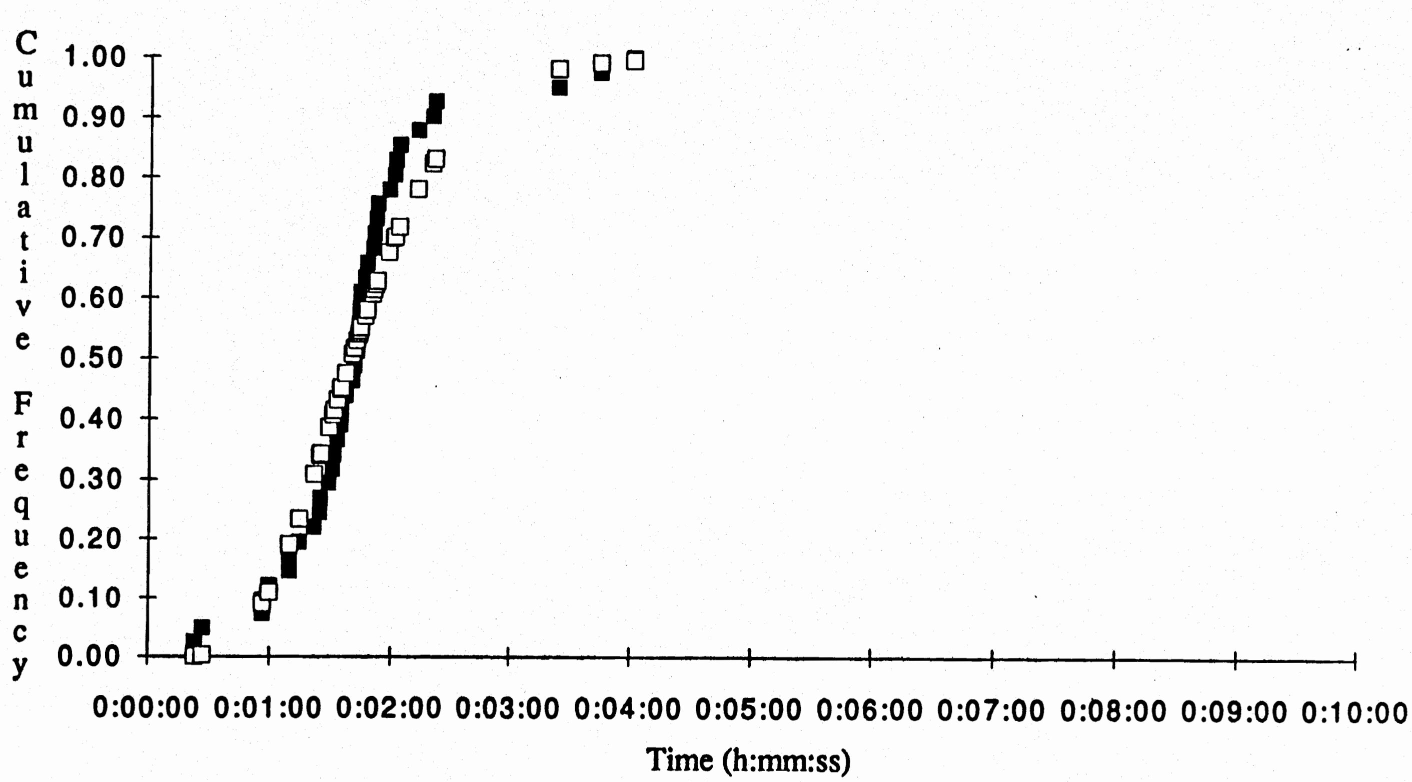


Figure B.8 - Cumulative frequency of interarrival times for Feb11a.1 data file. Best fit is the Erlang(3) distribution. Sample is 44 observations.

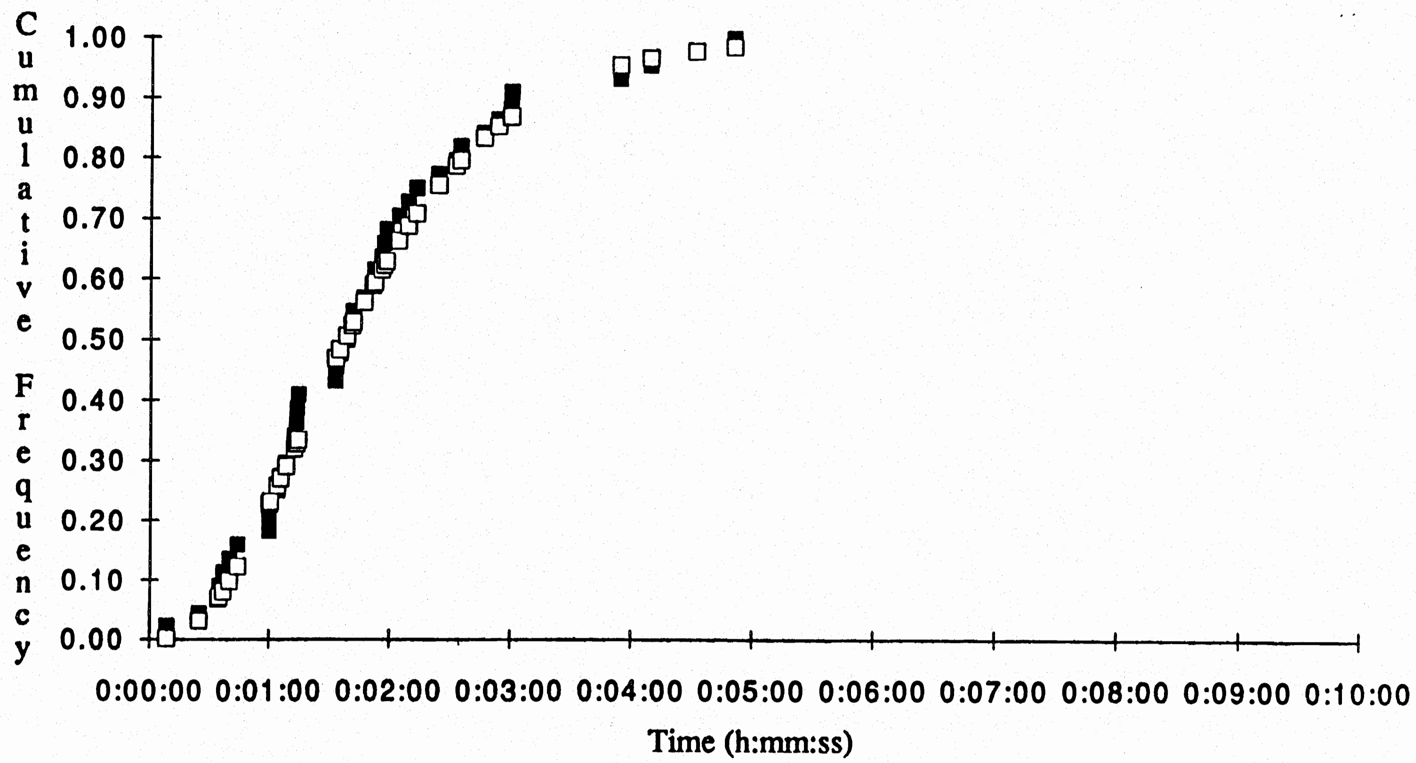


Figure B.9 - Cumulative frequency of backcycle times for Feb11a.1 data file. Best fit is the Erlang(6) distribution. Sample is 34 observations.

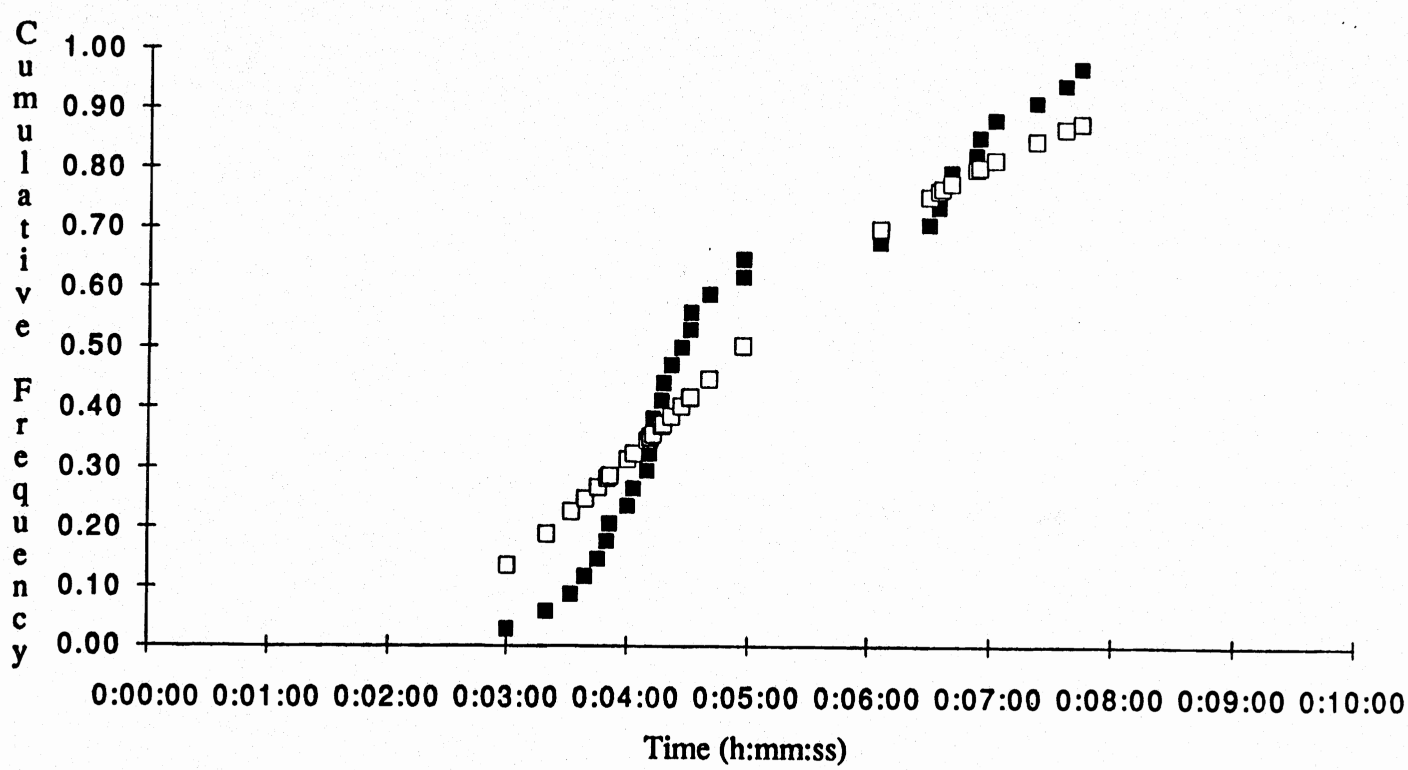


Figure B.10 - Cumulative frequency of service times for Feb11a.2 data file. Best fit is the Erlang(4) distribution. Sample is 37 observations.

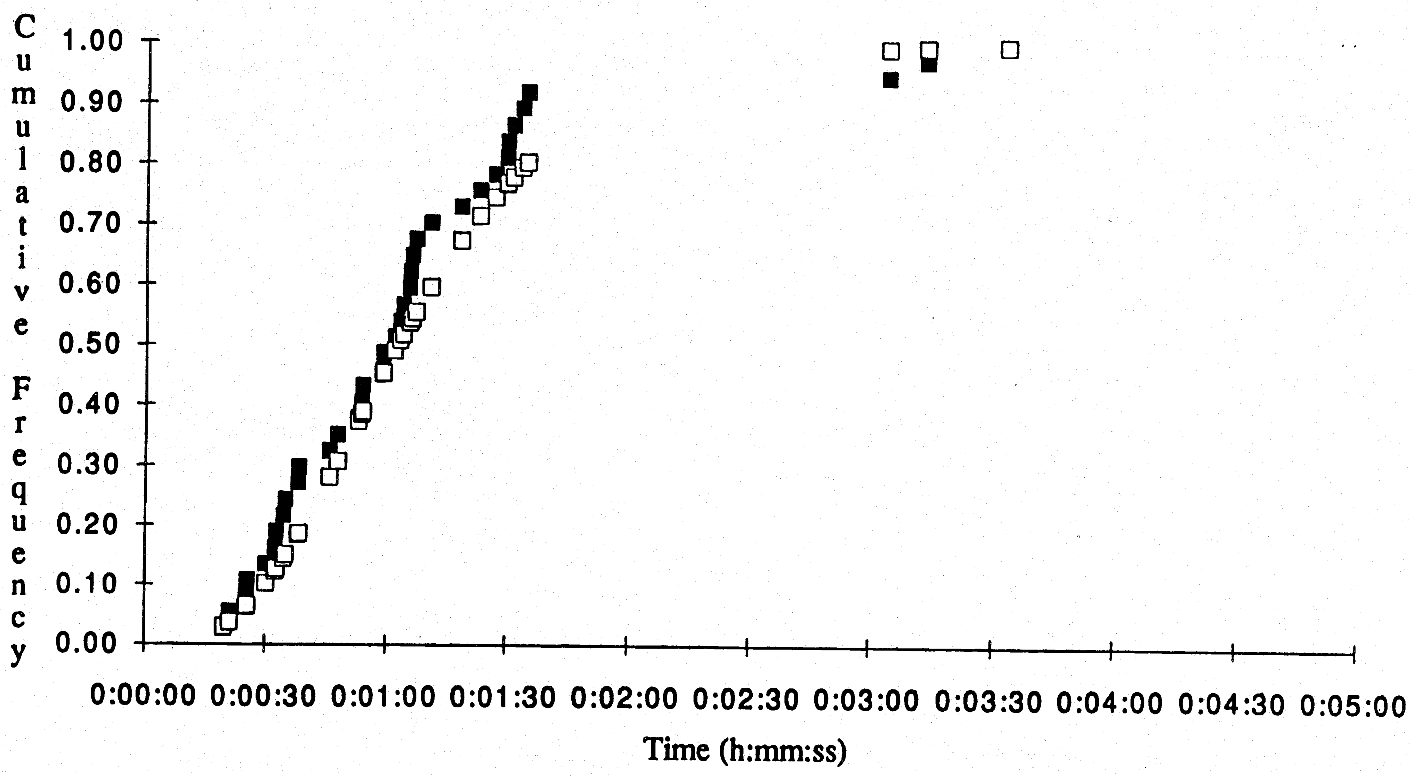


Figure B.11 - Cumulative frequency of interarrival times for Feb11a.2 data file. Best fit is the Erlang(3) distribution. Sample is 38 observations.

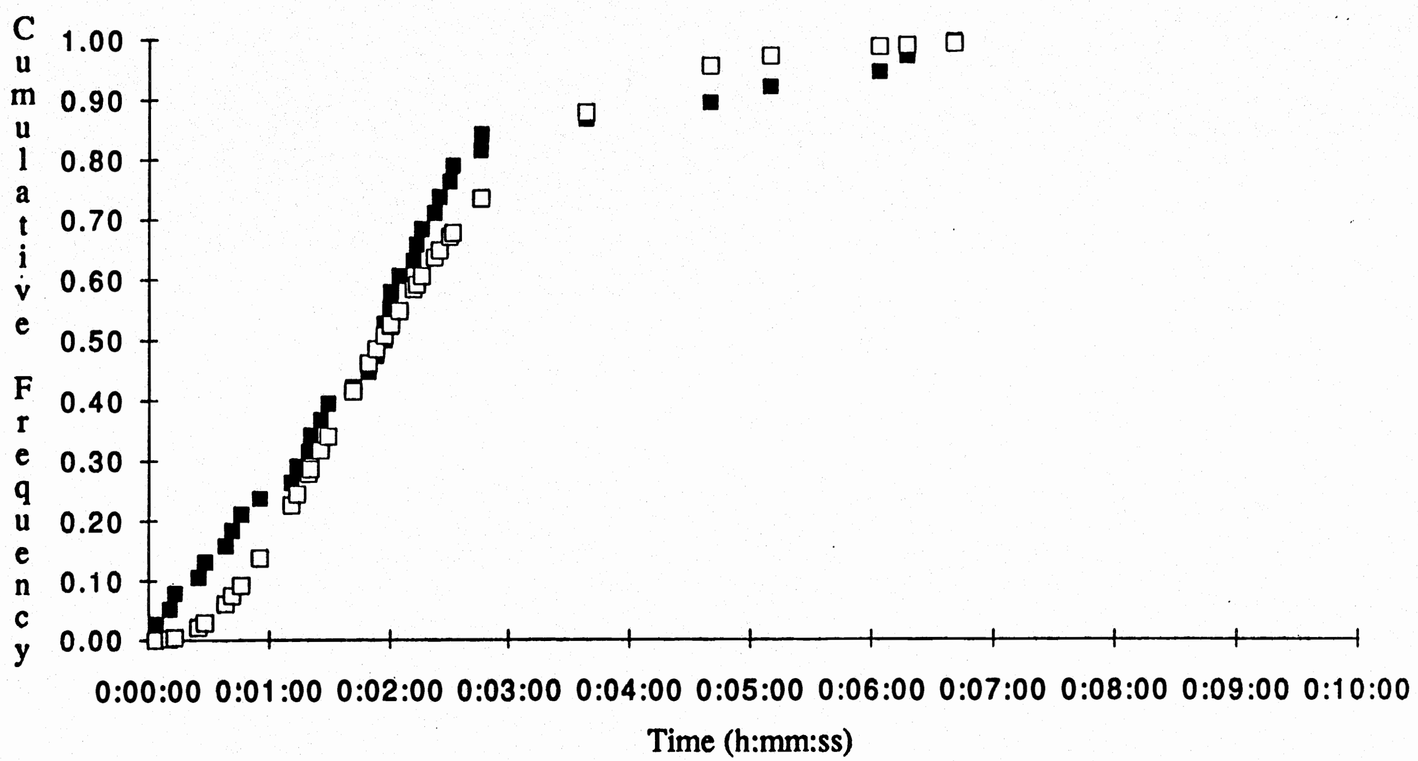


Figure B.12 - Cumulative frequency of backcycle times for Feb11a.2 data file. Best fit is the exponential distribution. Sample is 21 observations.

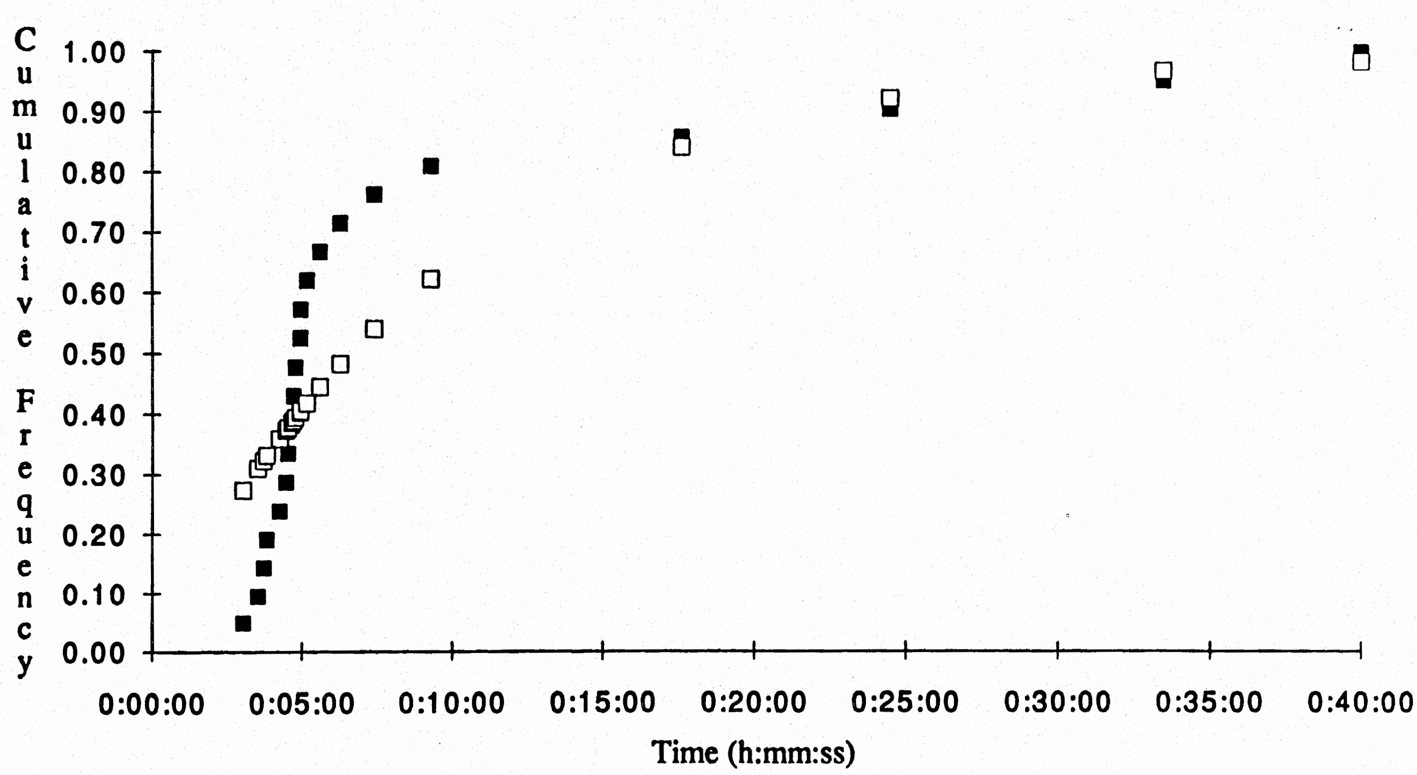


Figure B.13 - Cumulative frequency of service times for Feb11p.1 data file. Best fit is the Erlang(2) distribution. Sample is 74 observations.

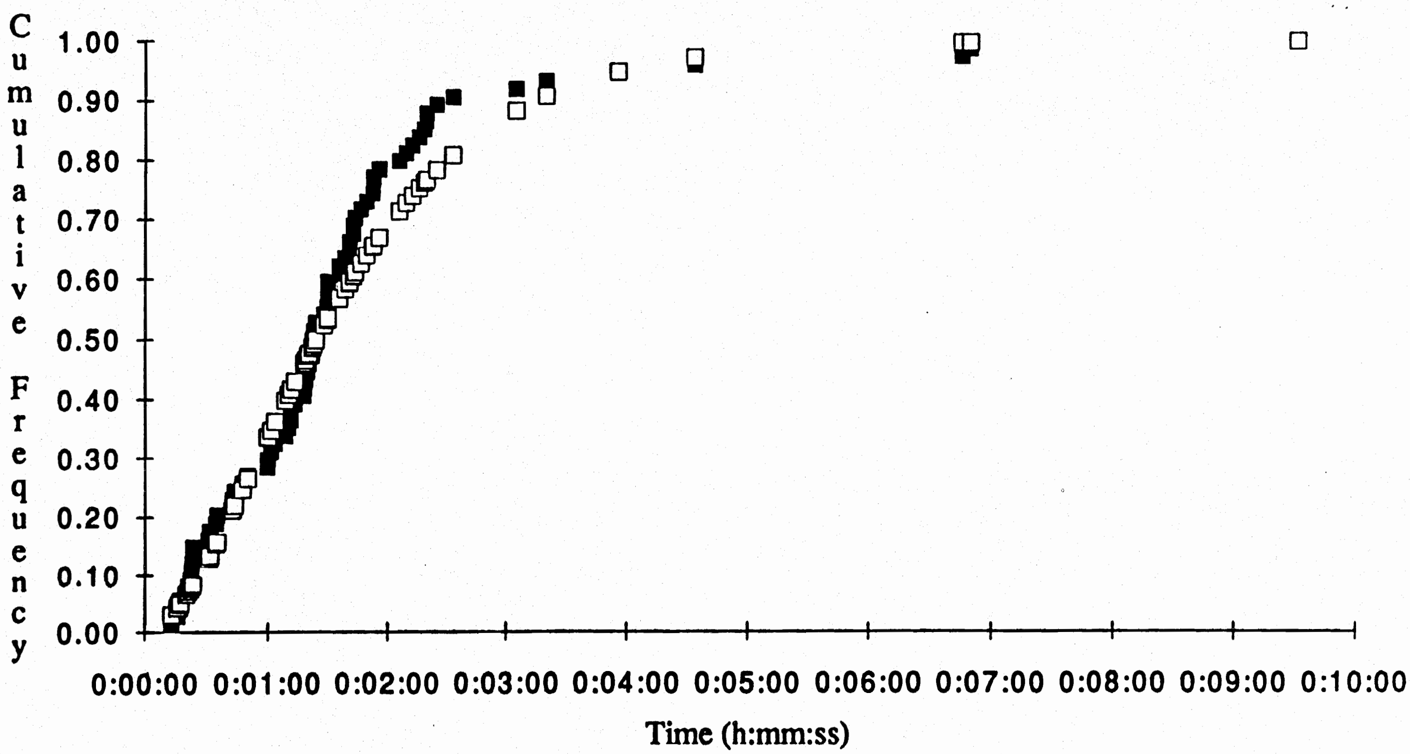


Figure B.14 - Cumulative frequency of interarrival times for Feb11p.1 data file. Best fit is the Erlang(2) distribution. Sample is 74 observations.

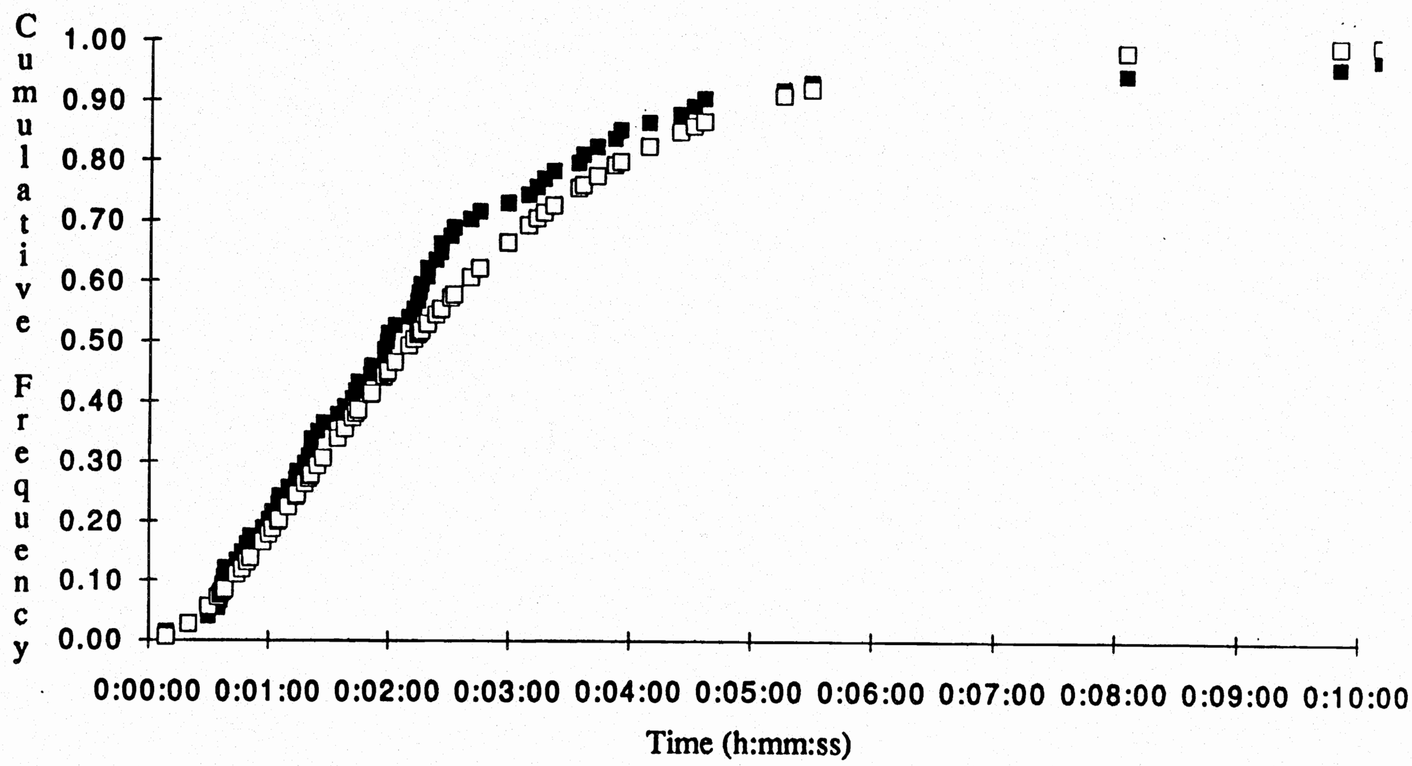


Figure B.15 - Cumulative frequency of backcycle times for Feb11p.1 data file. Best fit is the Erlang(2) distribution. Sample is 62 observations.

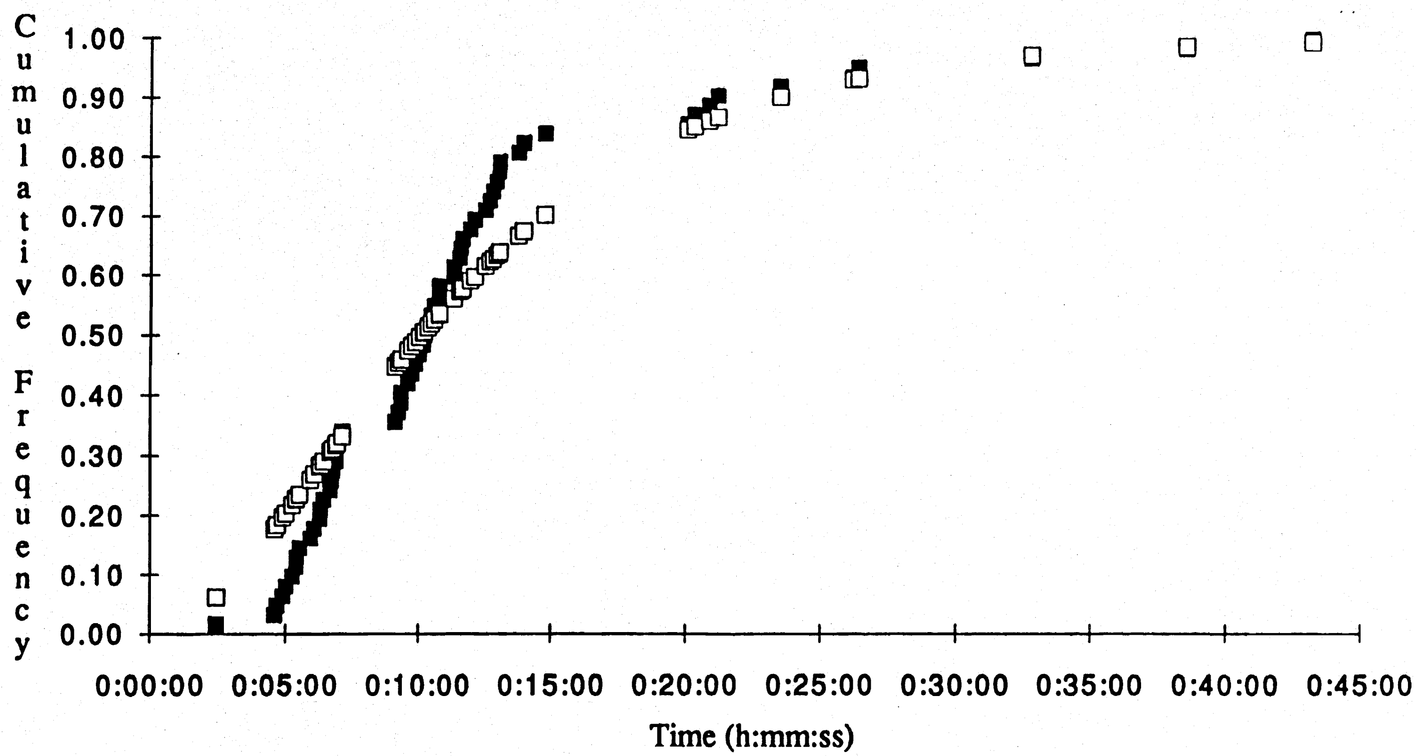


Figure B.16 - Cumulative frequency of service times for Feb12a.1 data file. Best fit is the Erlang(2) distribution. Sample is 27 observations.

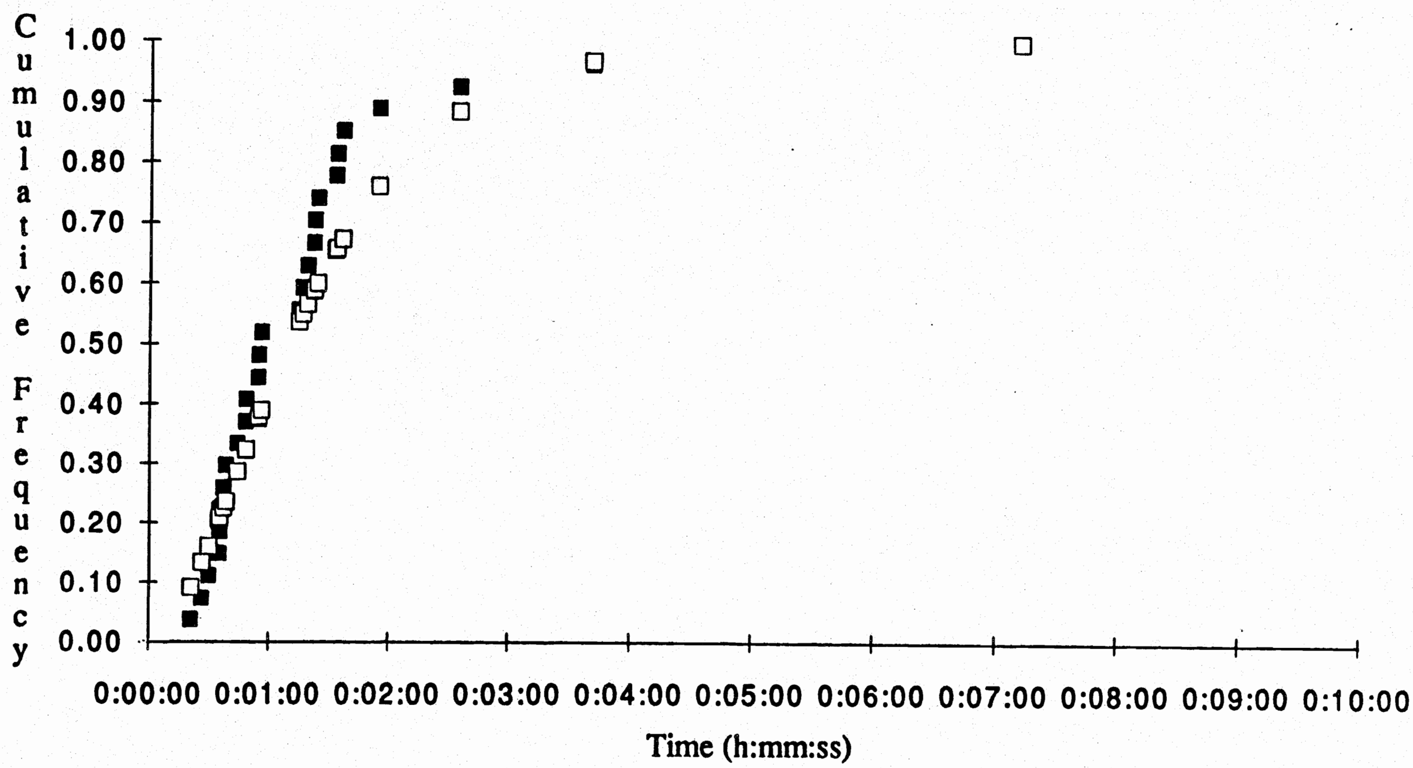


Figure B.17 - Cumulative frequency of interarrival times for Feb12a.1 data file. Best fit is the Erlang(2) distribution. Sample is 29 observations.

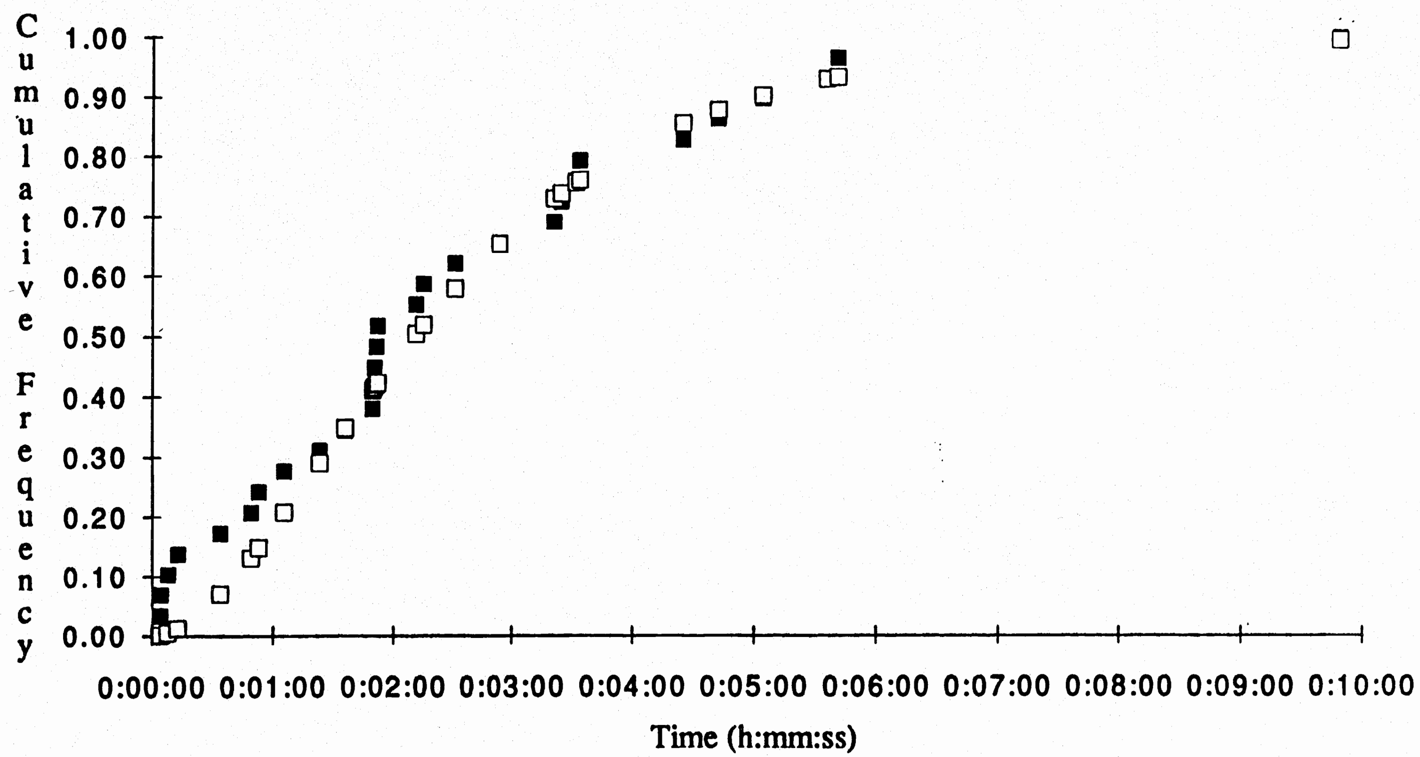


Figure B.18 - Cumulative frequency of backcycle times for Feb12a.2 data file. Best fit is the Erlang(2) distribution. Sample is 15observations.

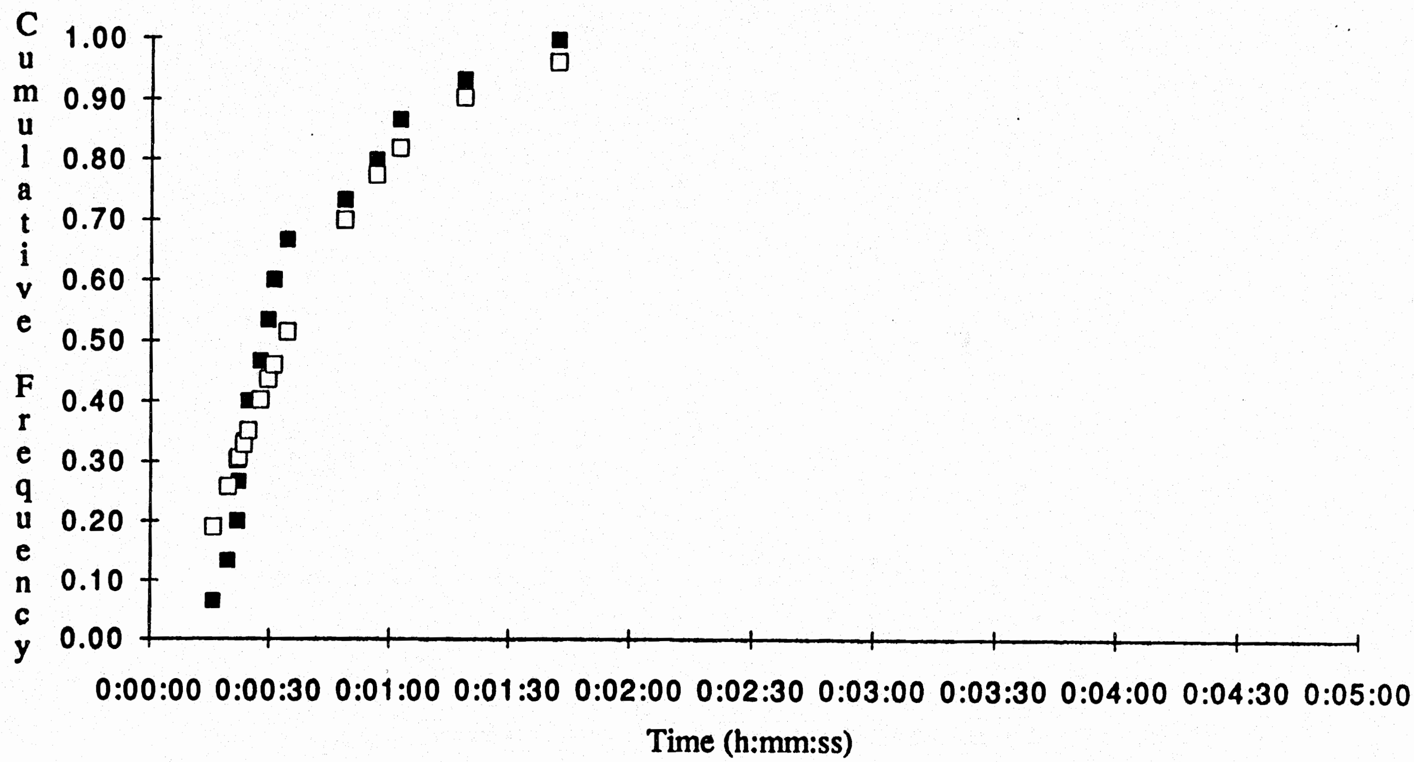


Figure B.19 - Cumulative frequency of interarrival times for Feb12a.2 data file. Best fit is the exponential distribution. Sample is 16 observations.

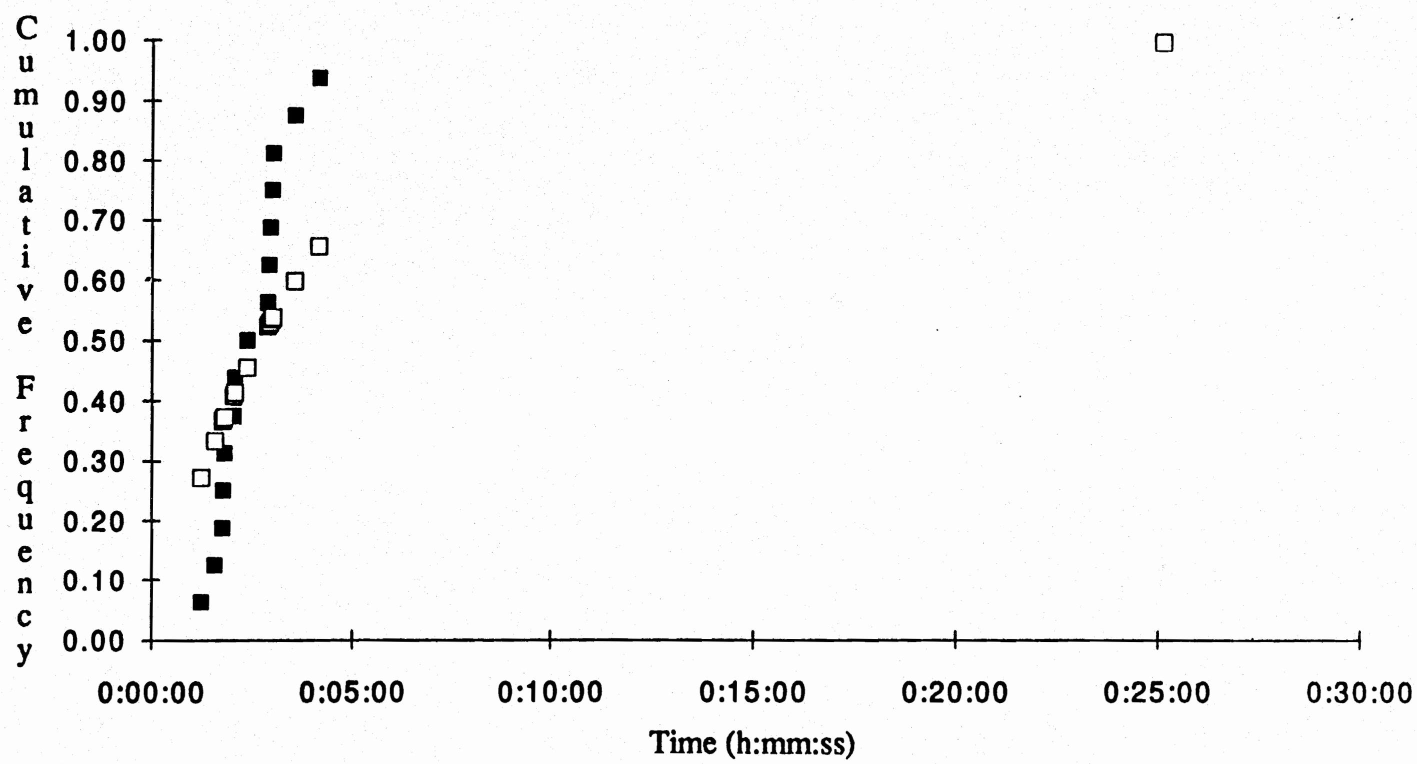


Figure B.20 - Cumulative frequency of service times for Feb12a.3 data file. Best fit is the Erlang(7) distribution. Sample is 22 observations.

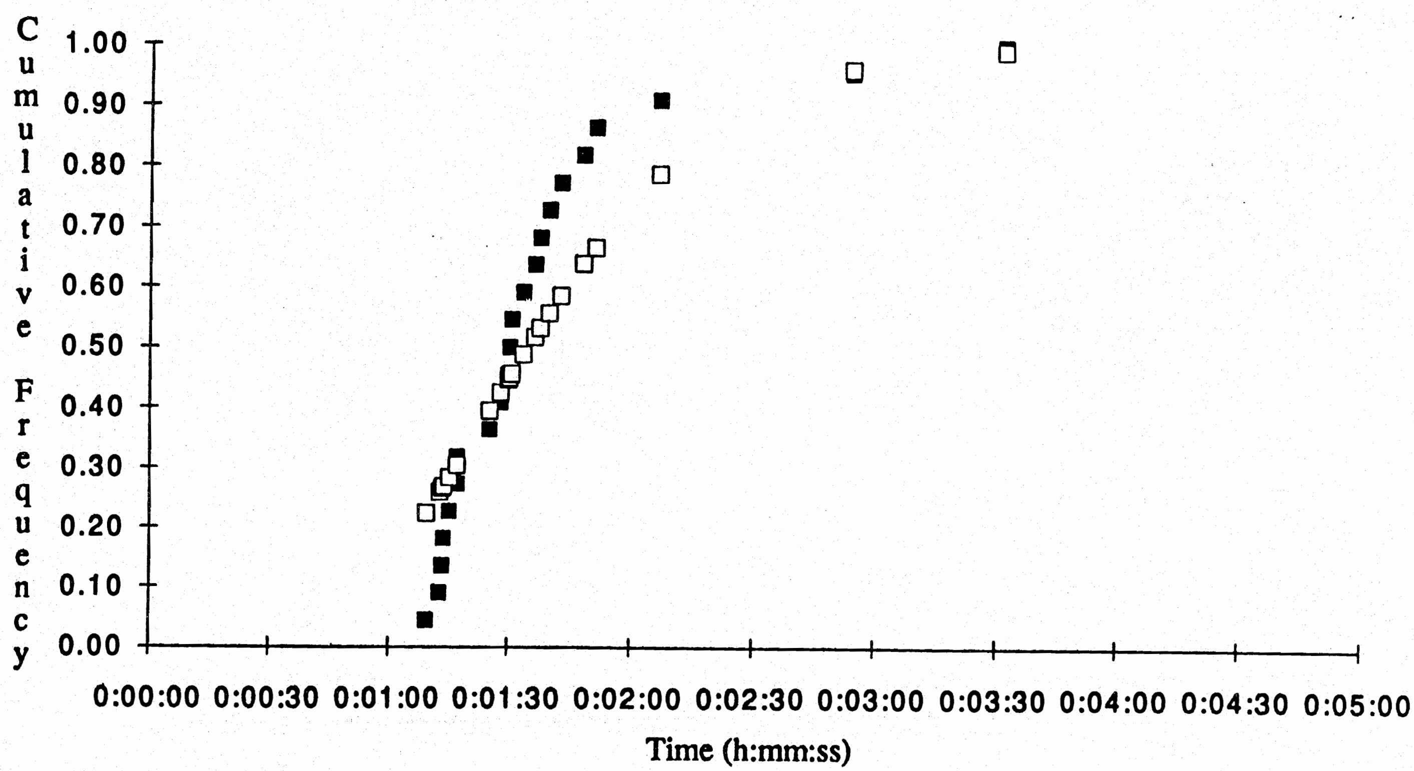


Figure B.21 - Cumulative frequency of interarrival times for Feb12a.3 data files. Best fit is the Erlang(2) distribution. Sample is 22 observations.

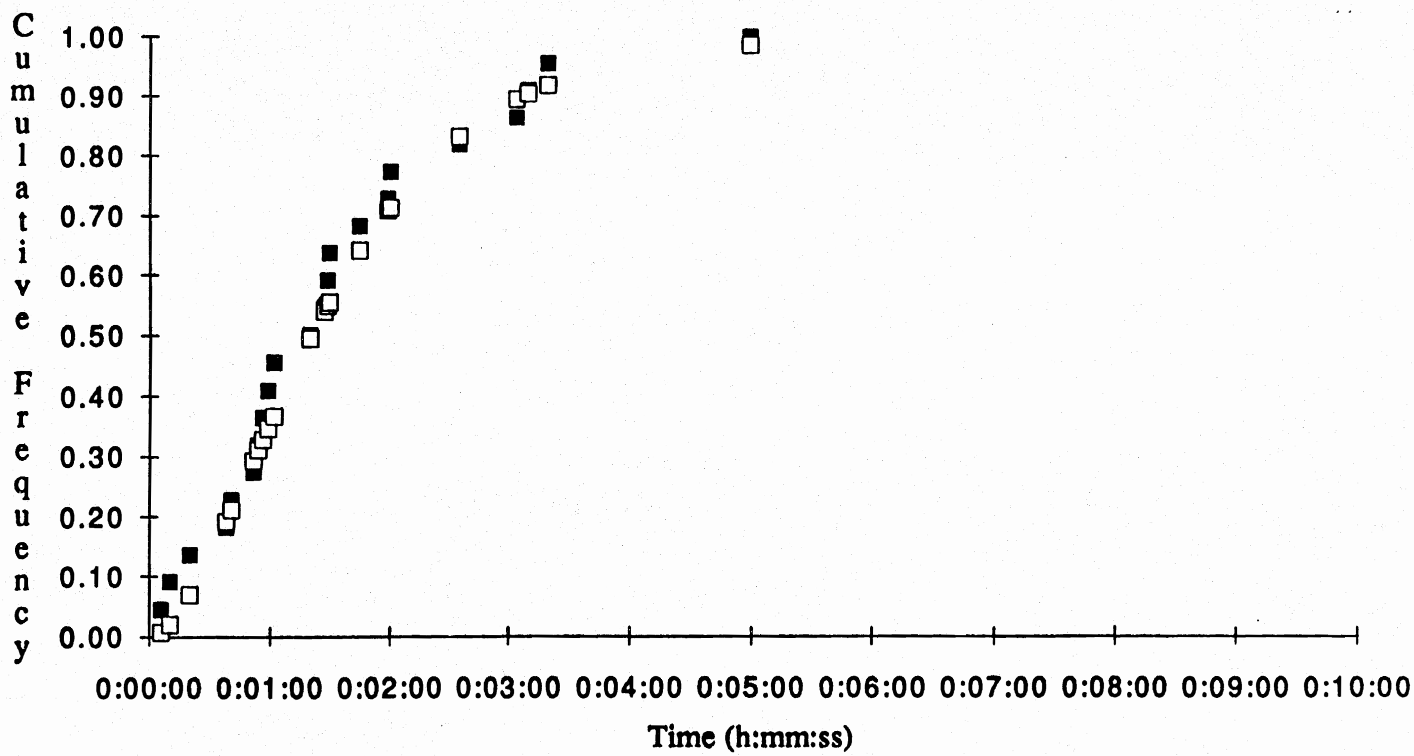


Figure B.22 - Cumulative frequency of backcycle times for Feb12a.3 data file. Best fit is the Erlang(7) distribution. Sample is 16 observations.

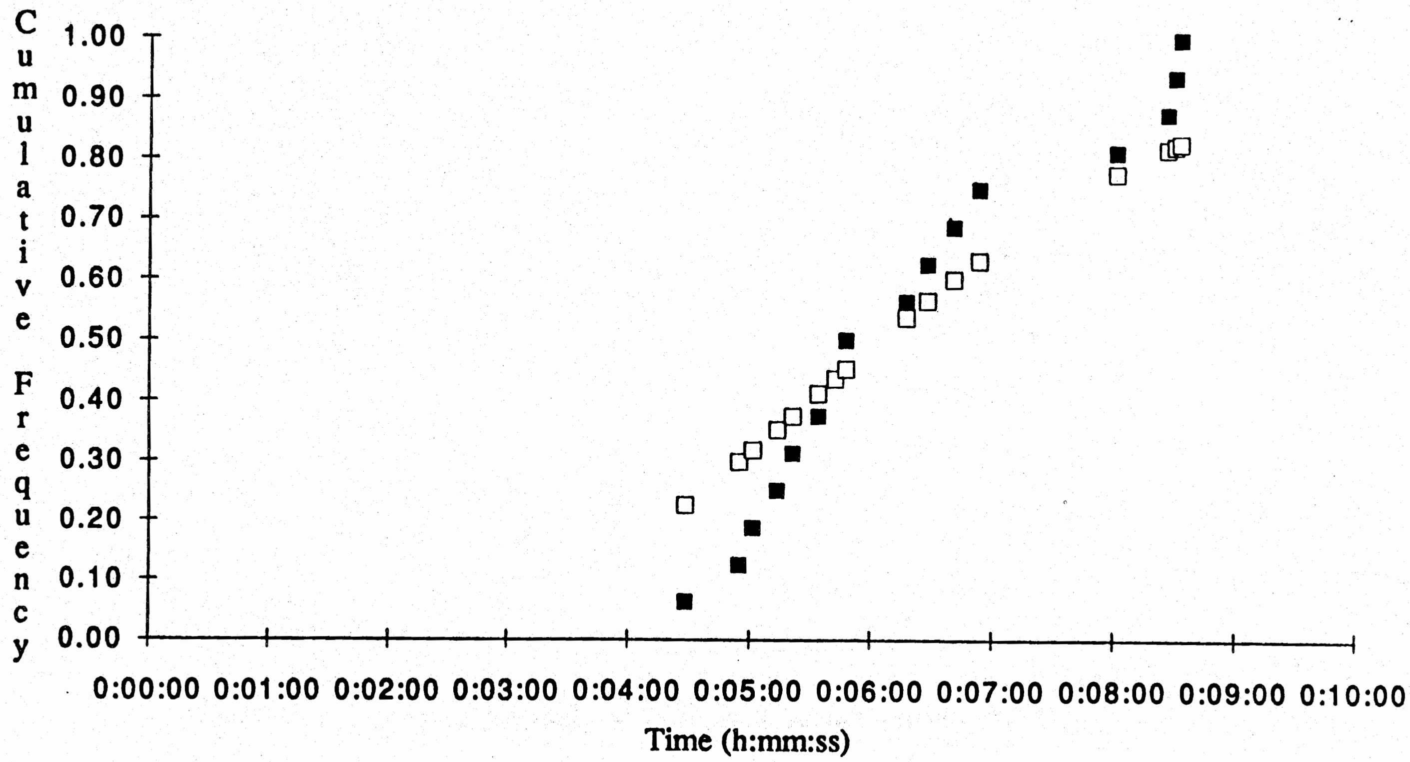


Figure B.23 - Cumulative frequency of service times for Feb12p.1 data file. No distribution tested significant to the field data. The Erlang(7) distribution is shown. Sample is 53 observations.

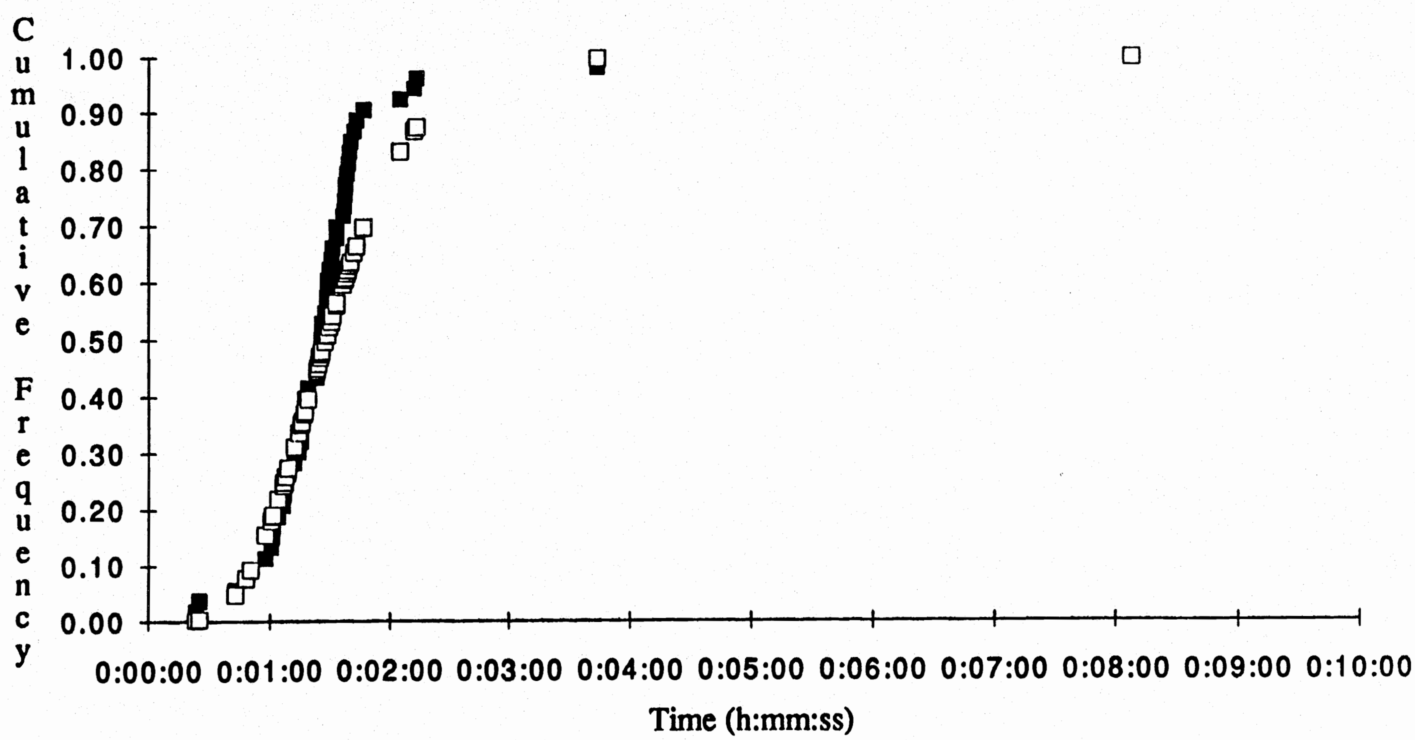


Figure B.24 - Cumulative frequency of interarrival times for Feb12p.1 data file. Best fit is the exponential distribution. Sample is 48 observations.

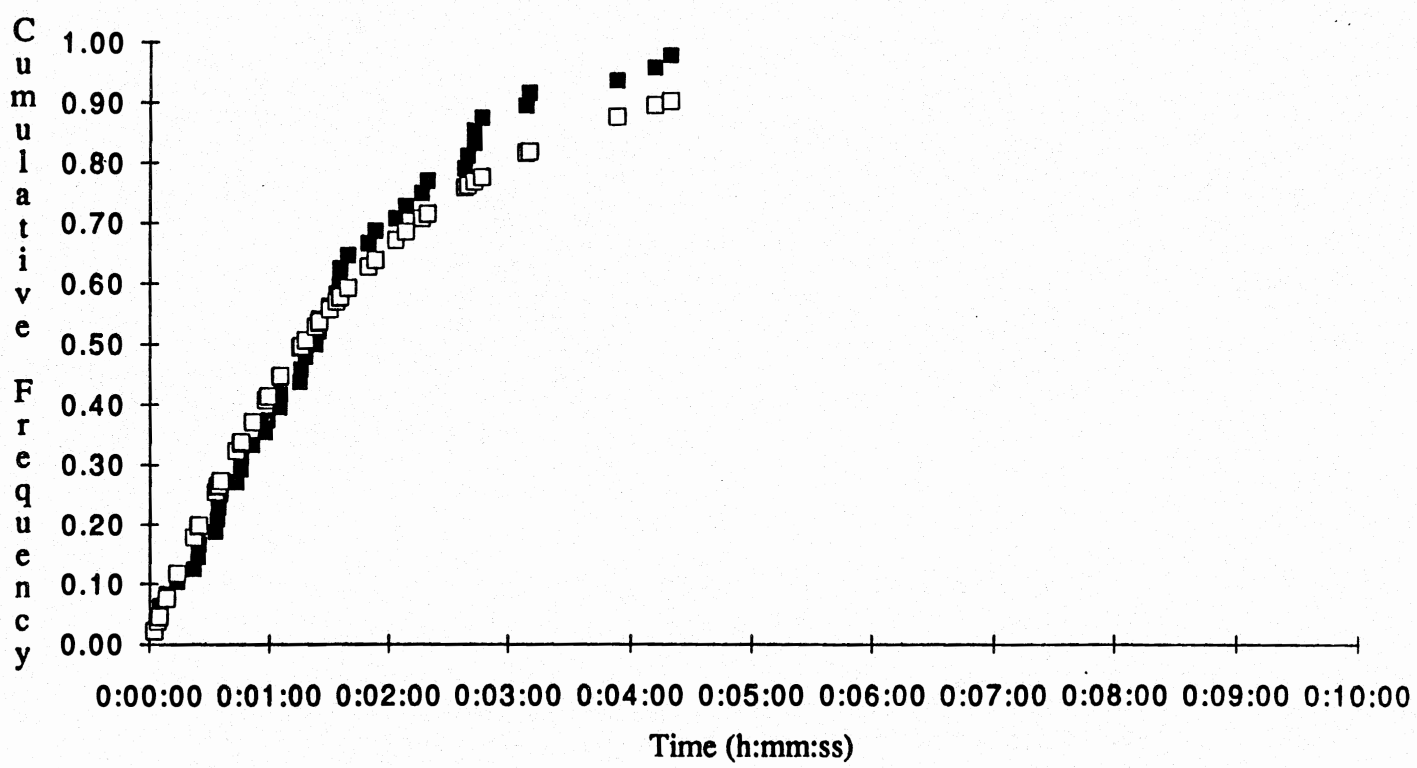


Figure B.25 - Cumulative frequency of backcycle times for Feb12p.1 data file. Best fit is the Erlang(7) distribution. Sample is 39 observations.

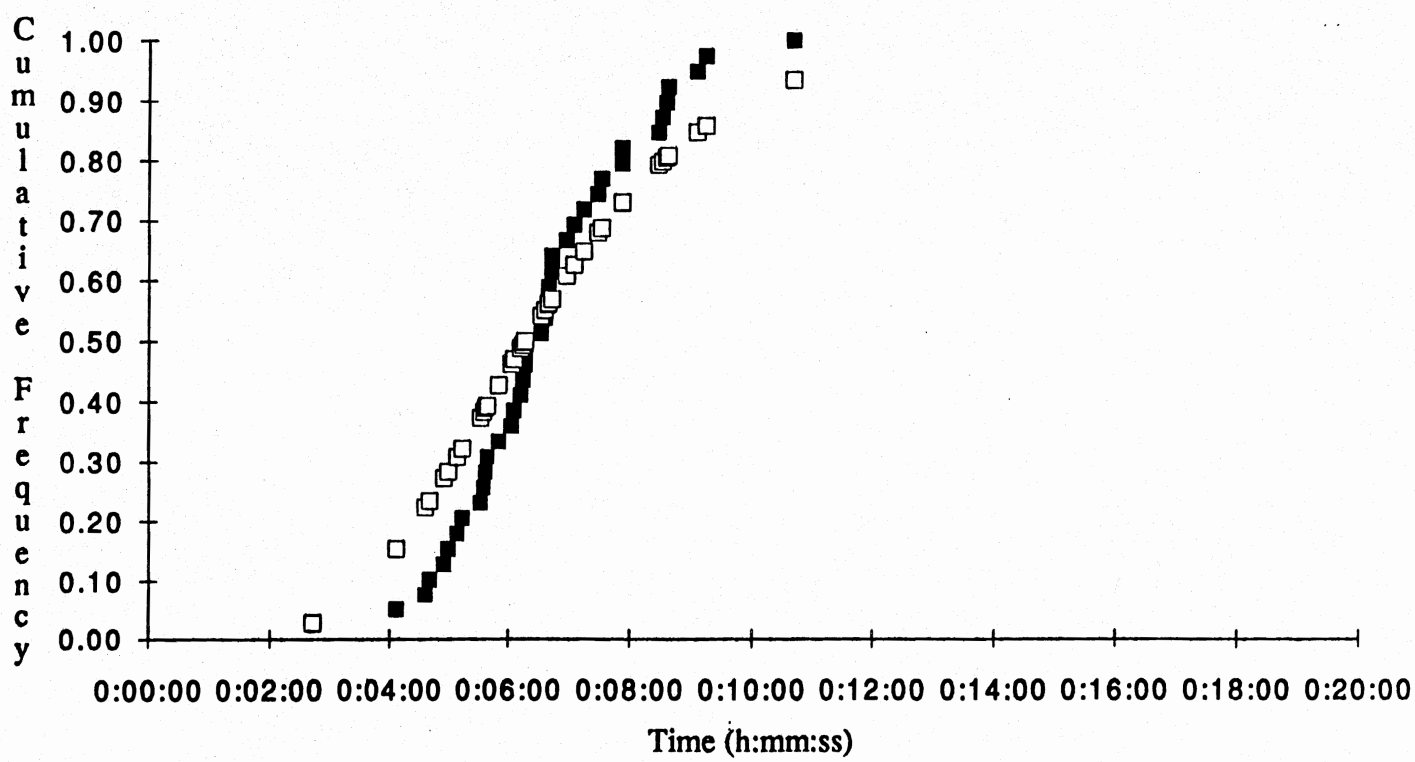


Figure B.26 - Cumulative frequency of service times for Mar7p.1 data file. Best fit is the Erlang(6) distribution. Sample is 30 observations.

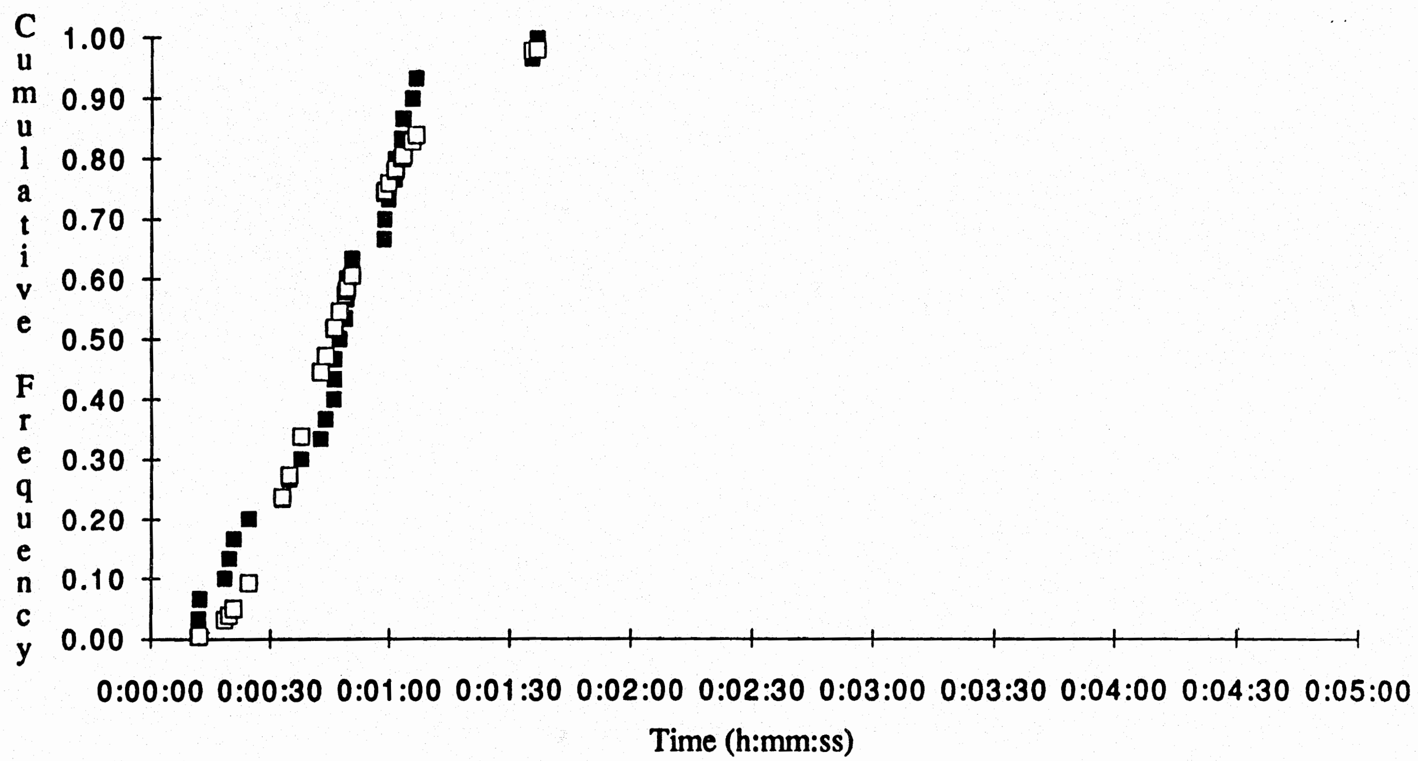


Figure B.27 - Cumulative frequency of interarrival times for Mar7p.1 data file. Best fit is the exponential distribution. Sample is 27 observations.

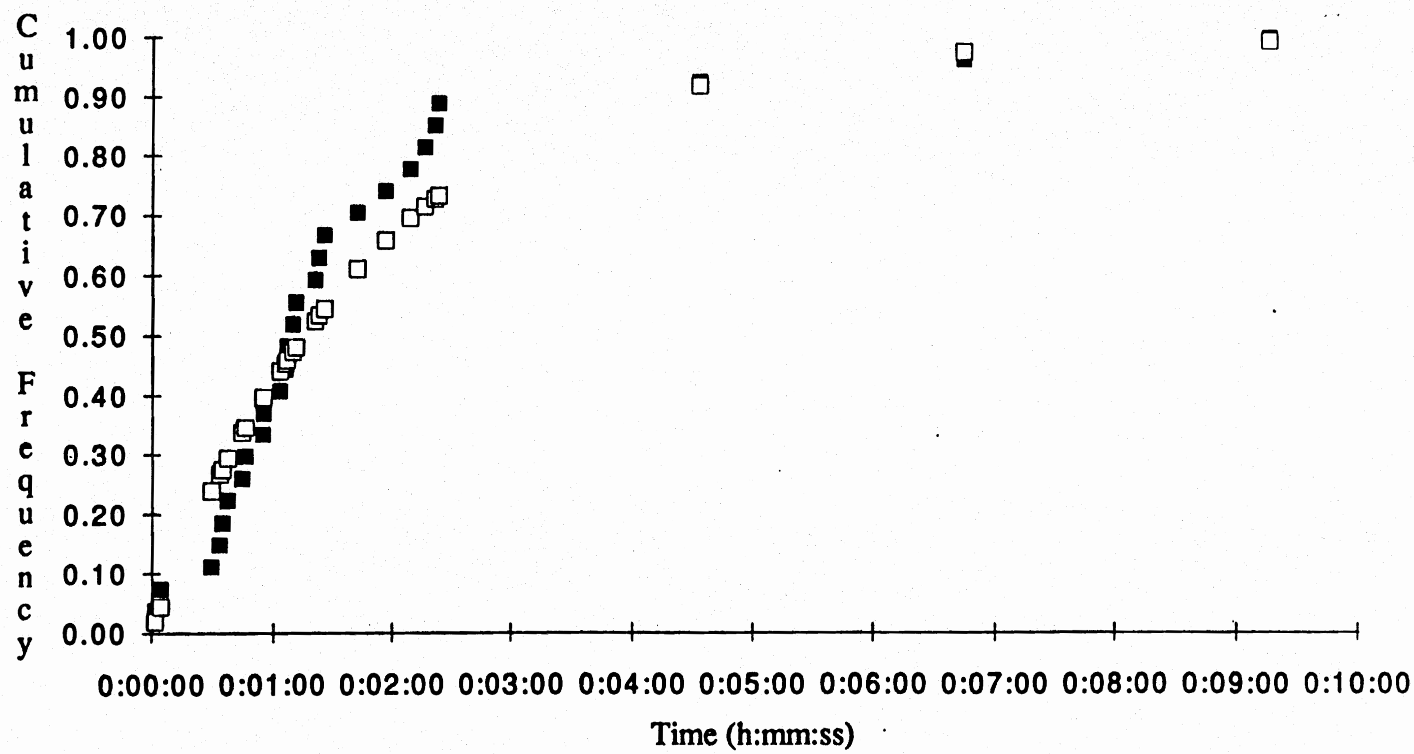


Figure B.28 - Cumulative frequency of backcycle times for Mar7p.1 data file. Best fit is the Erlang(2) distribution. Sample is 17 observations.

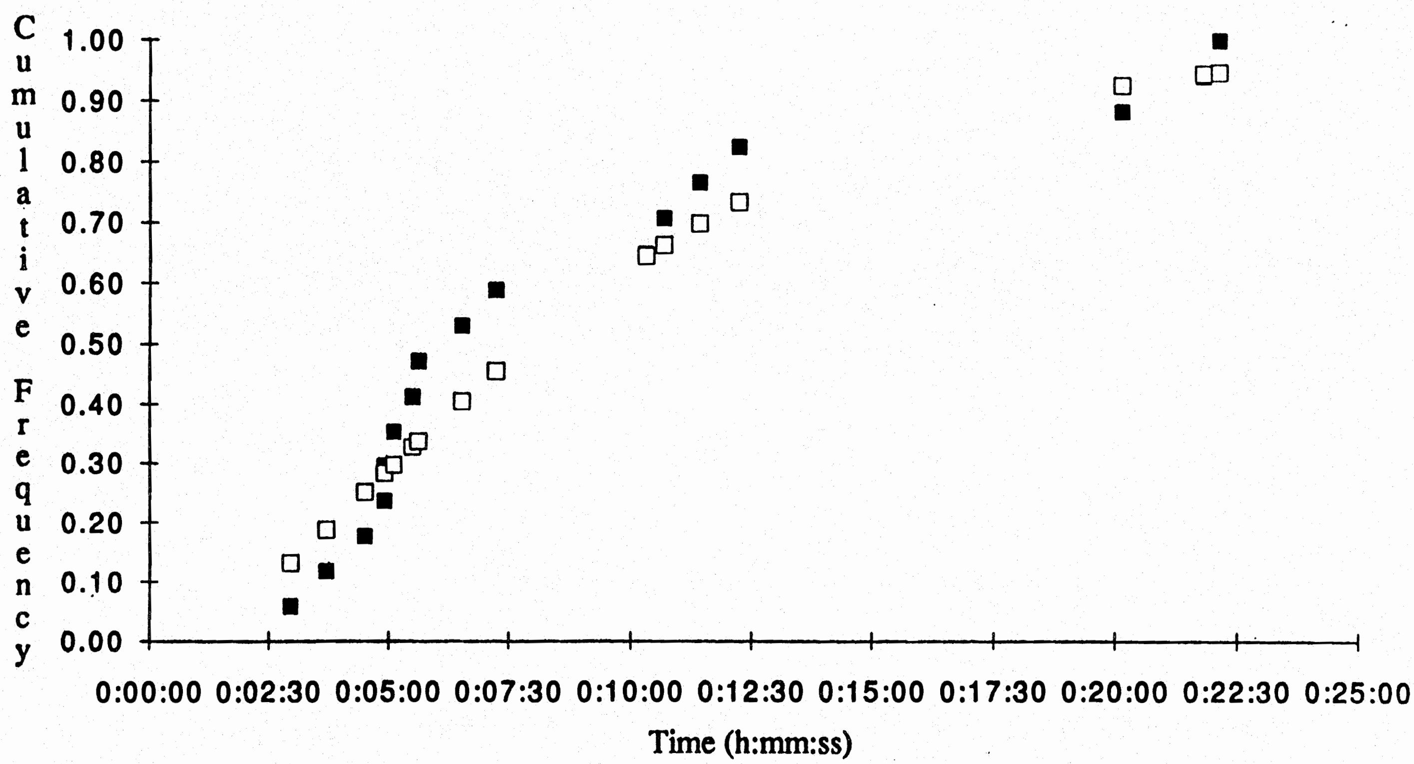


Figure B.29 - Cumulative frequency of service times for Mar7p.2 data file. Best fit is the Erlang(7) distribution. Sample is 47 observations.

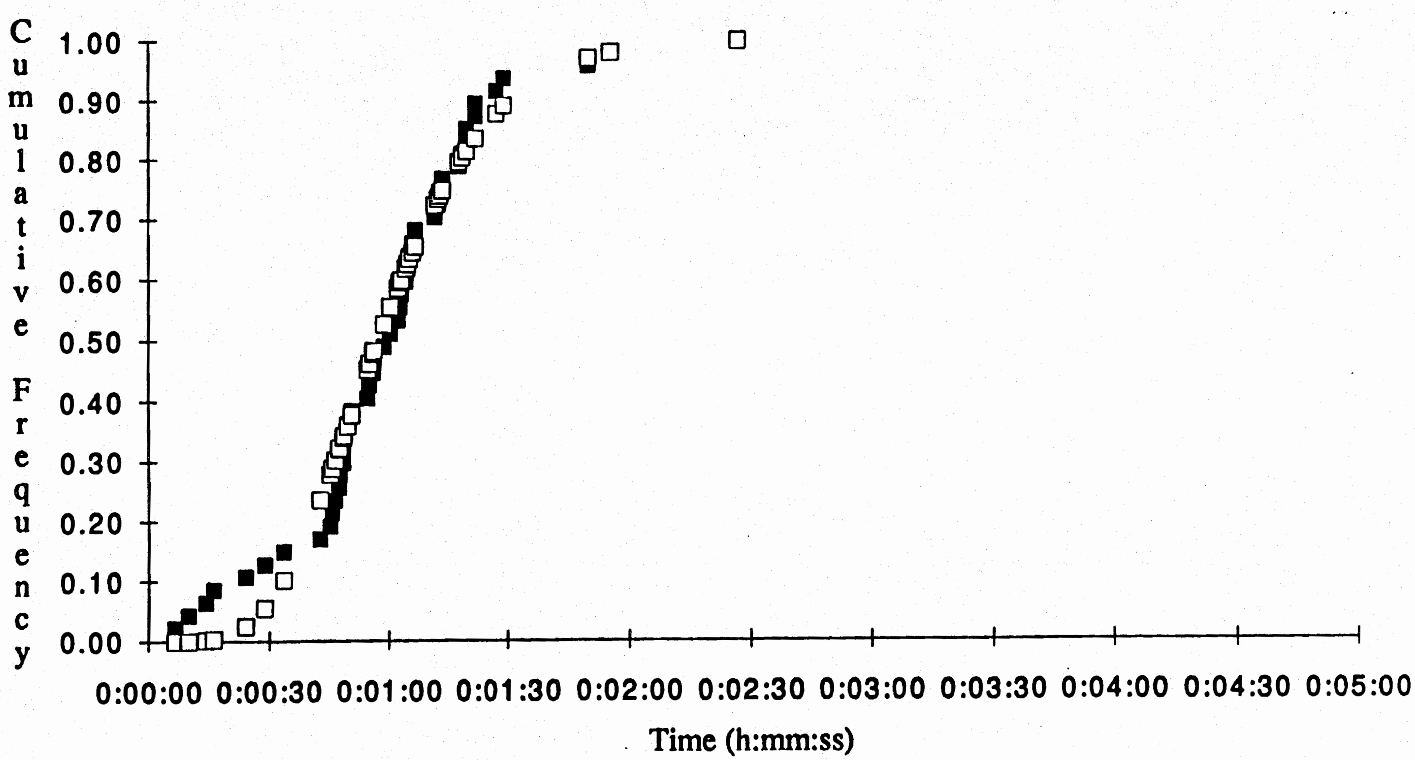


Figure B.30 - Cumulative frequency of interarrival times for Mar7p.2 data file. No distribution tested statistically similar to the field data. The exponential distribution is shown below with 38 observations.

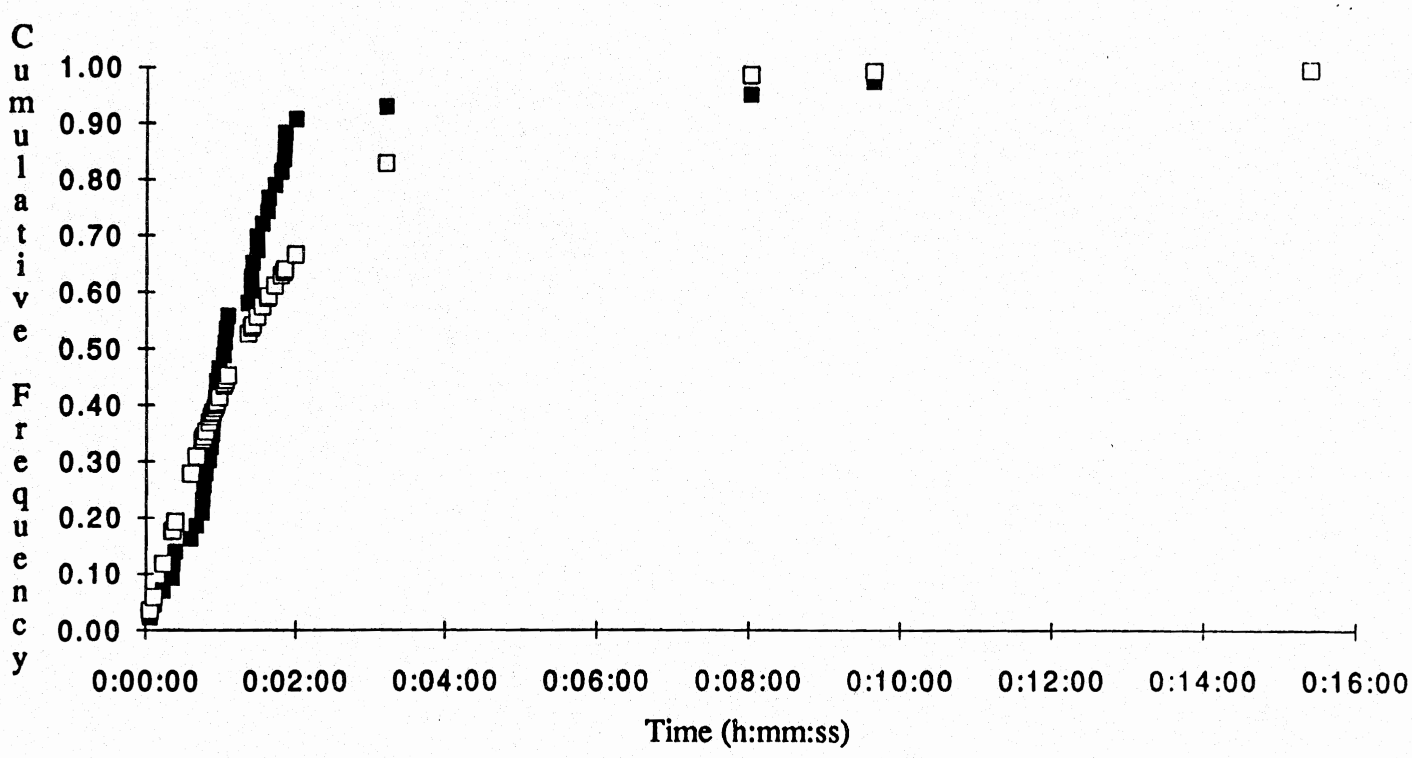


Figure B.31 - Cumulative frequency of backcycle times for Mar7p.2 data file. No distribution tested statistically significant to the field data. The Erlang(3) distribution is shown below. Sample is 43 observations.

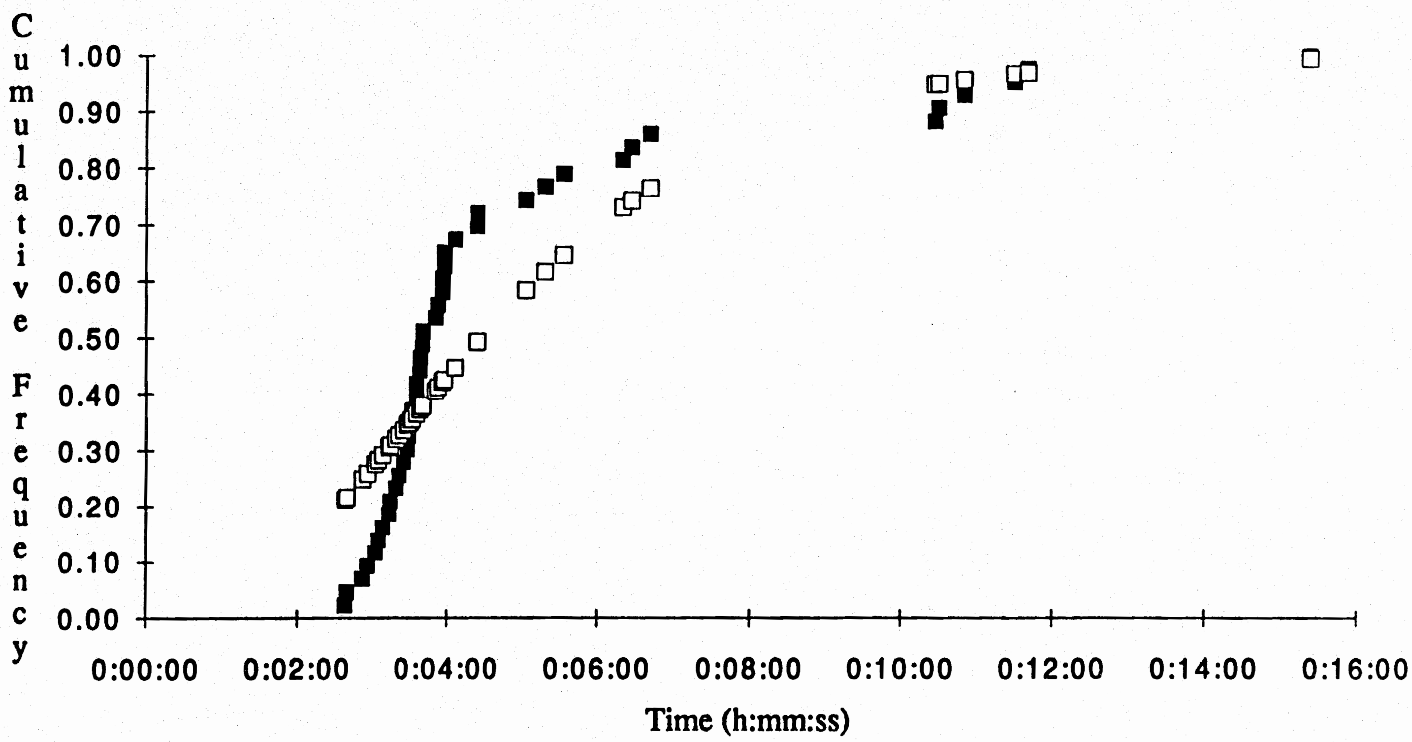


Figure B.32 - Cumulative frequency of service times for Mar8a.1 data file. Best fit is the Erlang(3) distribution. Sample is 25 observations.

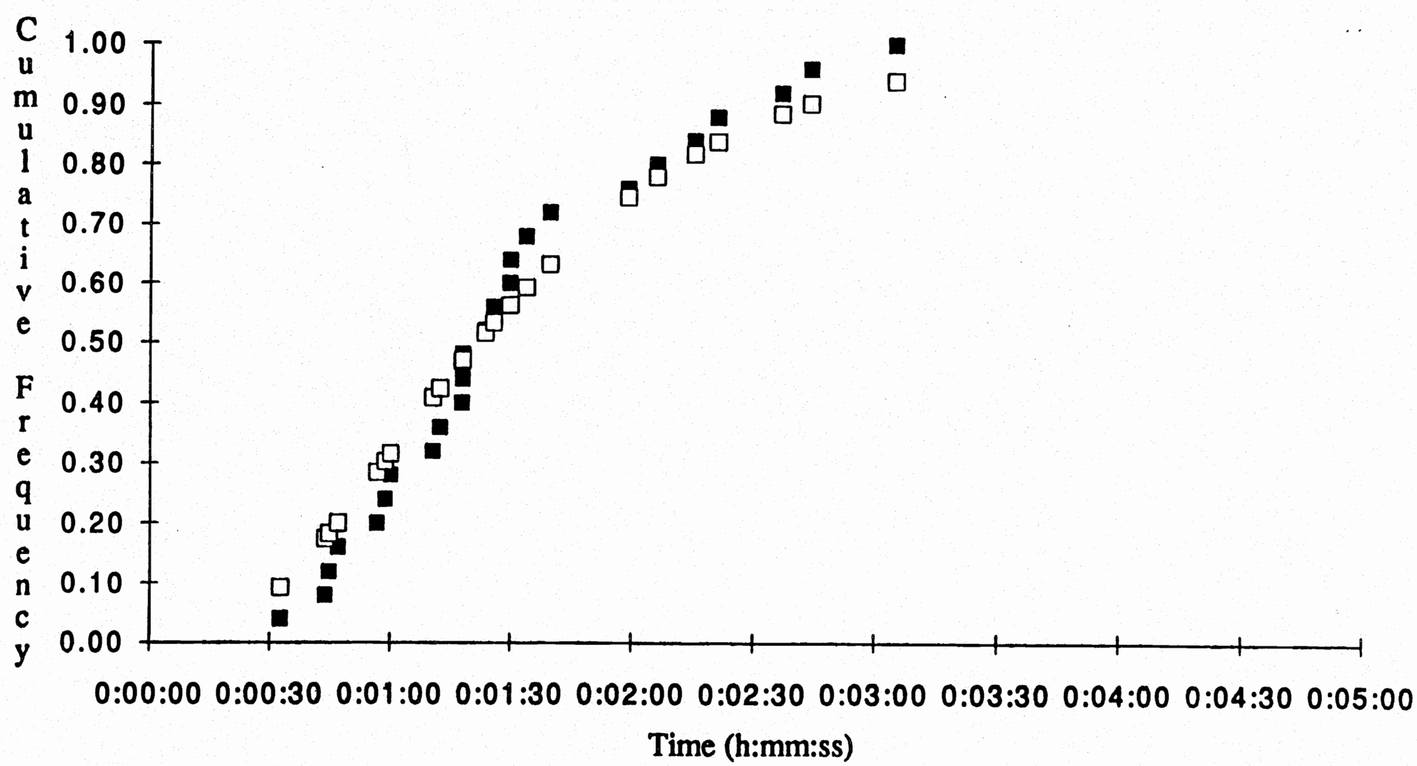


Figure B.33 - Cumulative frequency of interarrival times for Mar8a.1 data file. Best fit is the Erlang(2) distribution. Sample is 21 observations.

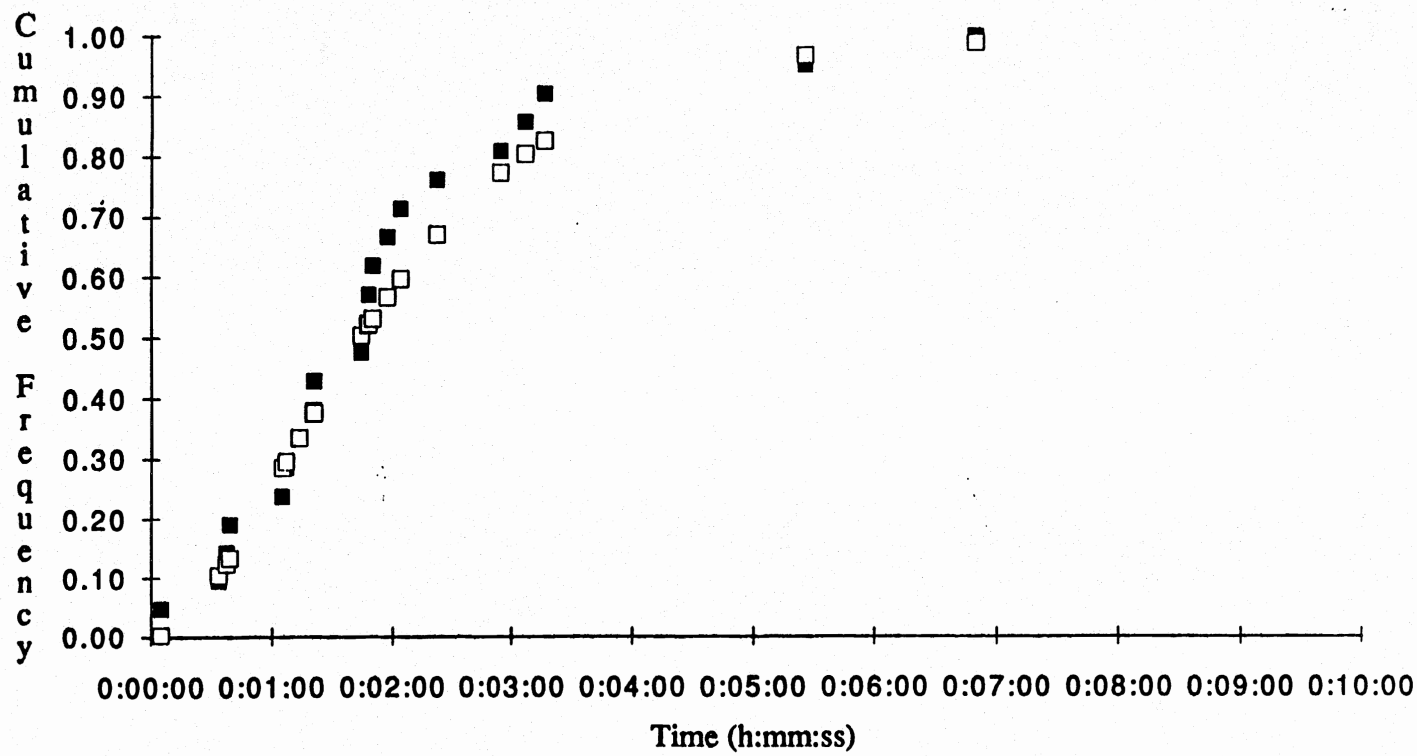


Figure B.34 - Cumulative frequency of backcycle times for Mar8a.1 data file. Best fit is the Erlang(2) distribution. Sample is 21 observations.

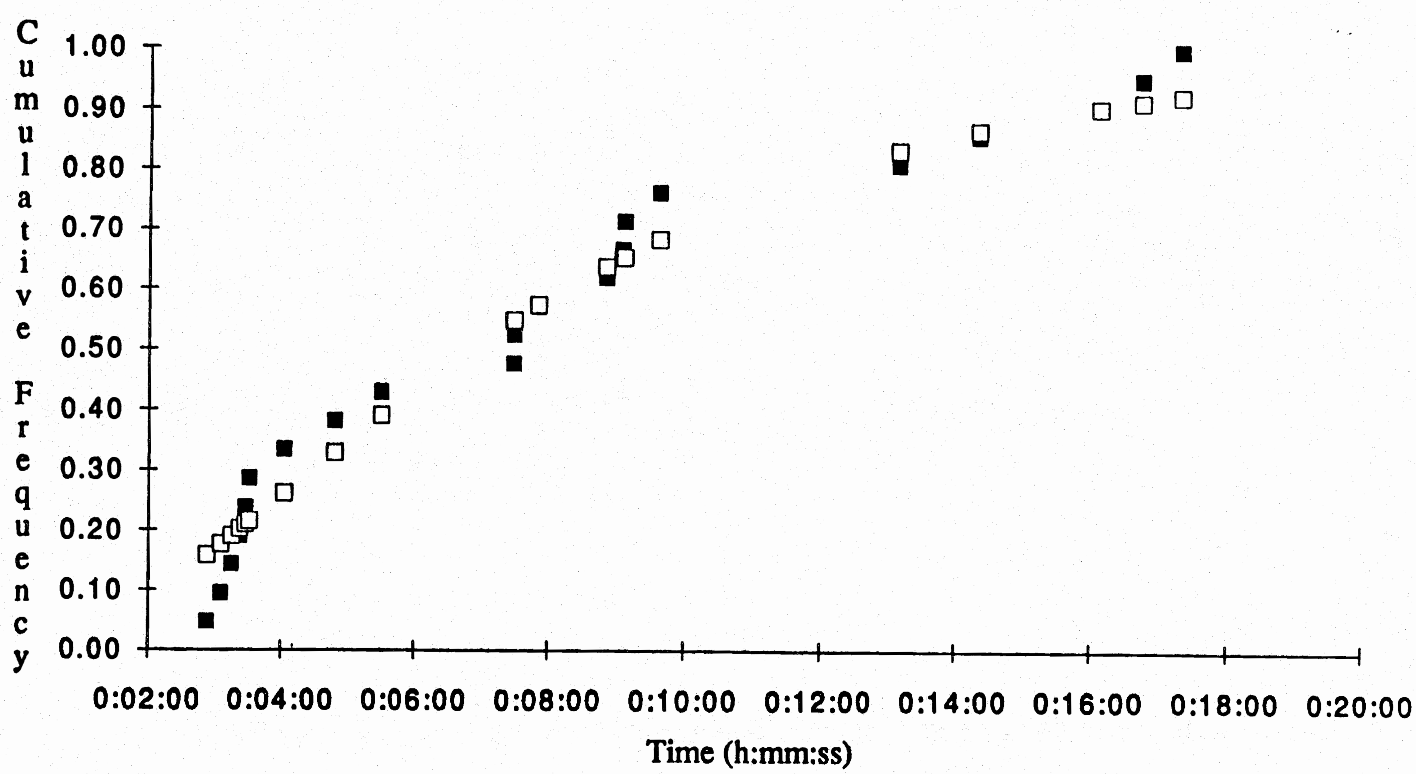


Figure B.35 - Cumulative frequency of service times for Mar8a.2 data file. Best fit is the Erlang(7) distribution. Sample is 17 observations.

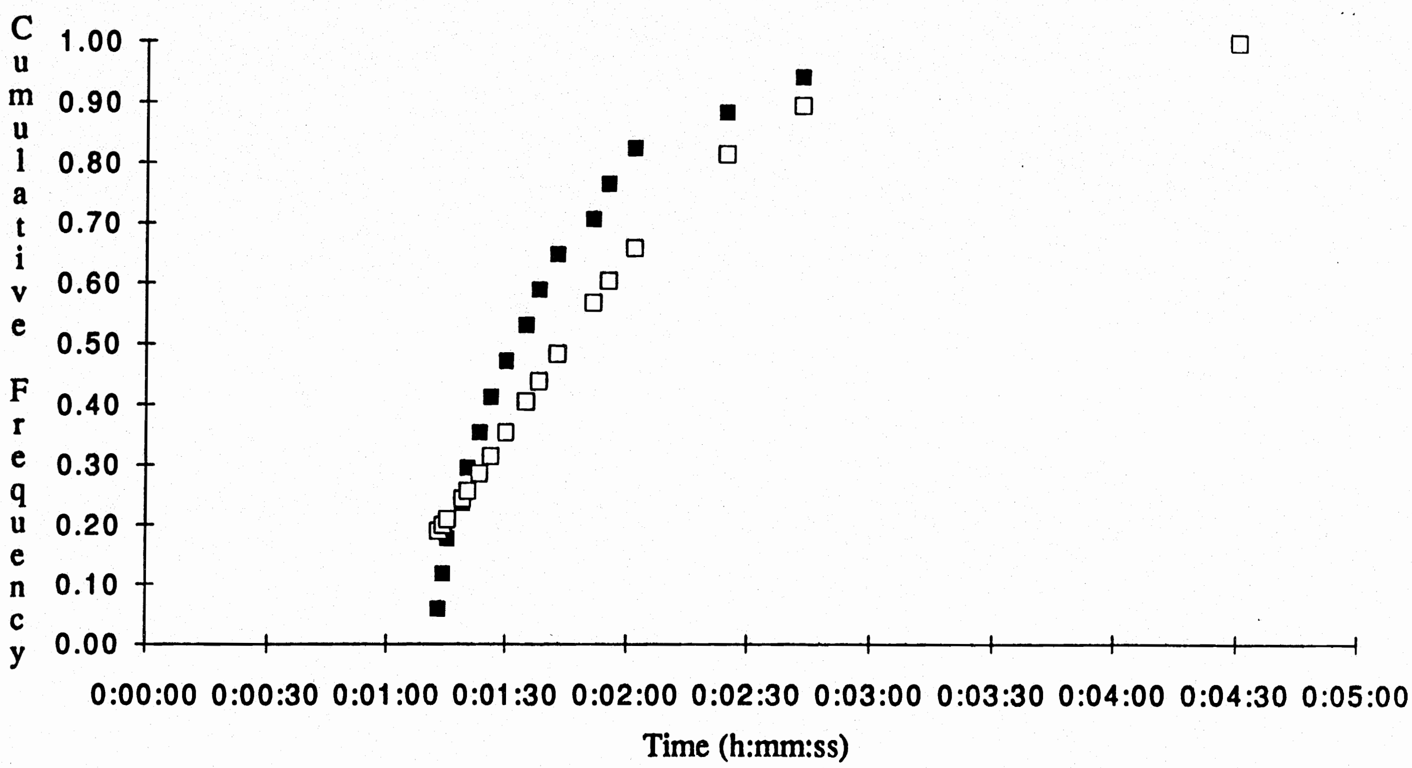


Figure B.36 - Cumulative frequency of interarrival times for Mar8a.2 data file. Best fit is the Erlang(2) distribution. Sample is 14 observations.

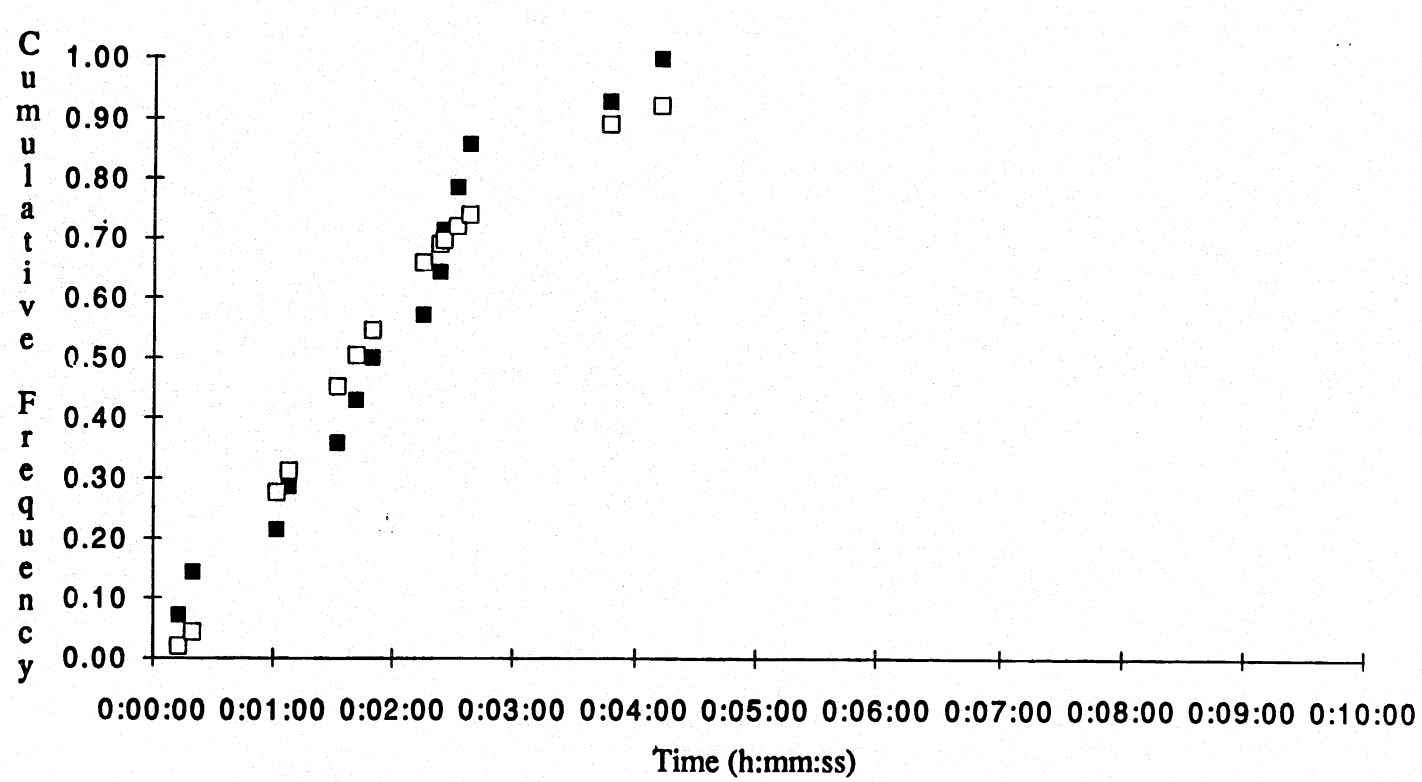


Figure B.37 - Cumulative frequency of backcycle times for Mar8a.2 data file. Best fit is the Erlang(7) distribution. Sample is 14 observations.

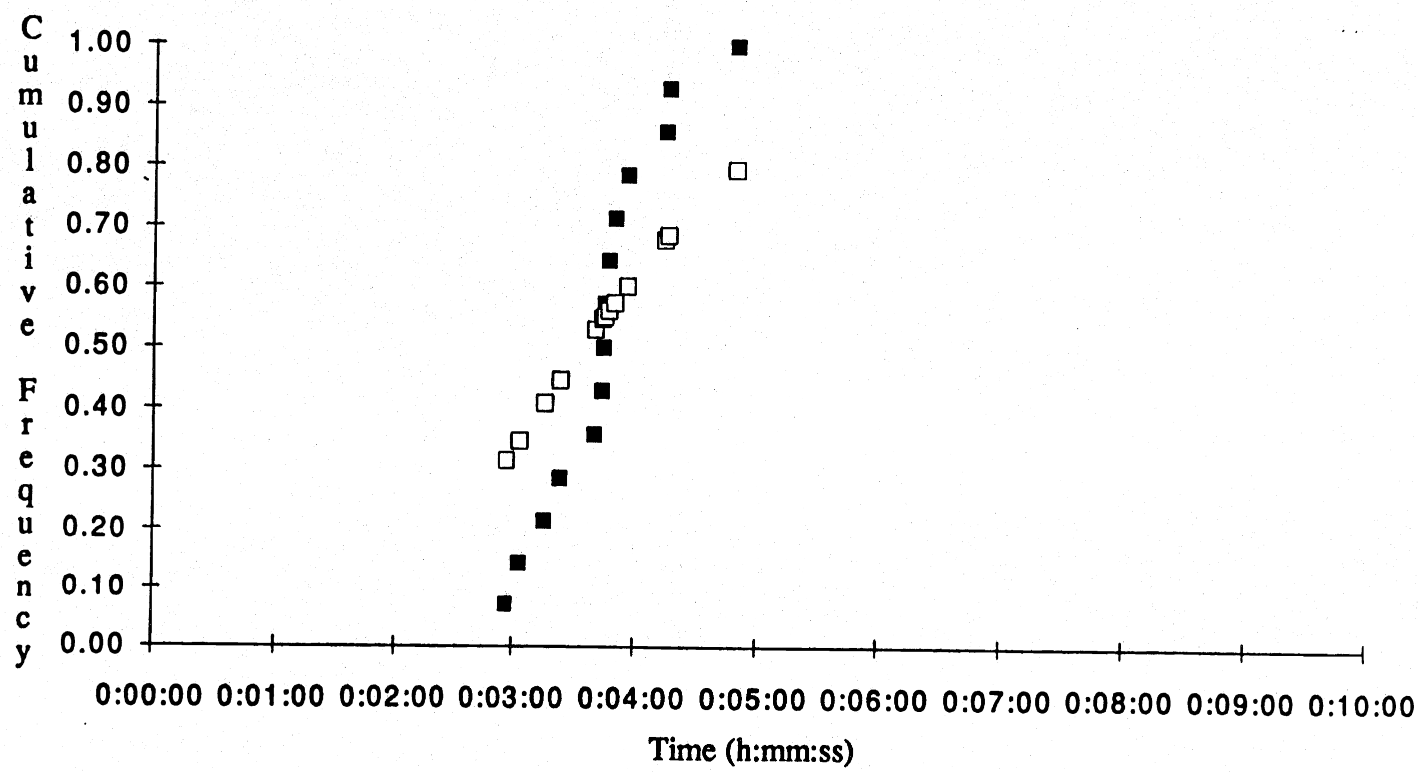


Figure B.38 - Cumulative frequency of service times for Mar8p.1 data file. Best fit is the Erlang(2) distribution. Sample is 61 observations.

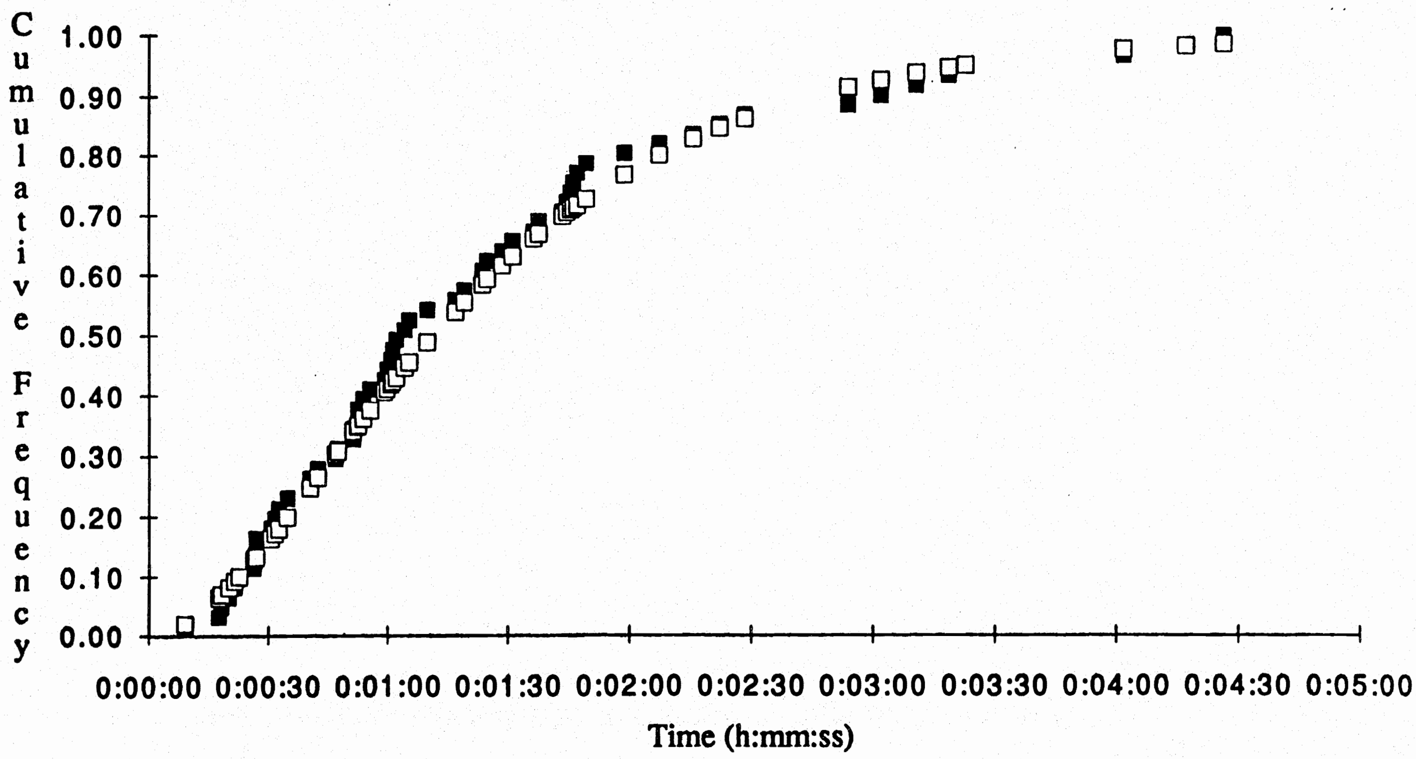


Figure B.39 - Cumulative frequency of interarrival times for Mar8p.1 data file. Best fit is the exponential distribution. Sample is 65 observations.

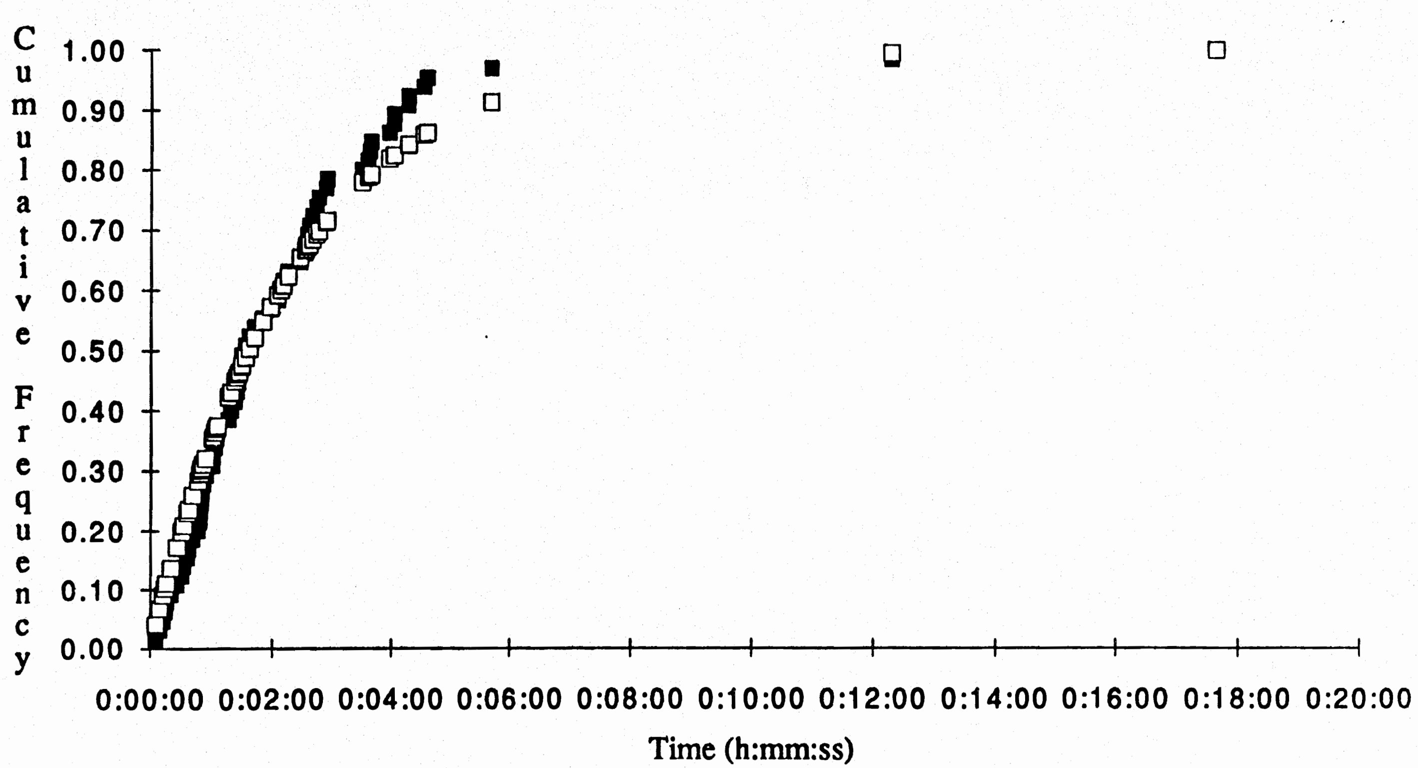


Figure B.40 - Cumulative frequency of backcycle times for Mar8p.1 data file. Best fit is the Erlang(2) distribution. Sample is 47 observations.

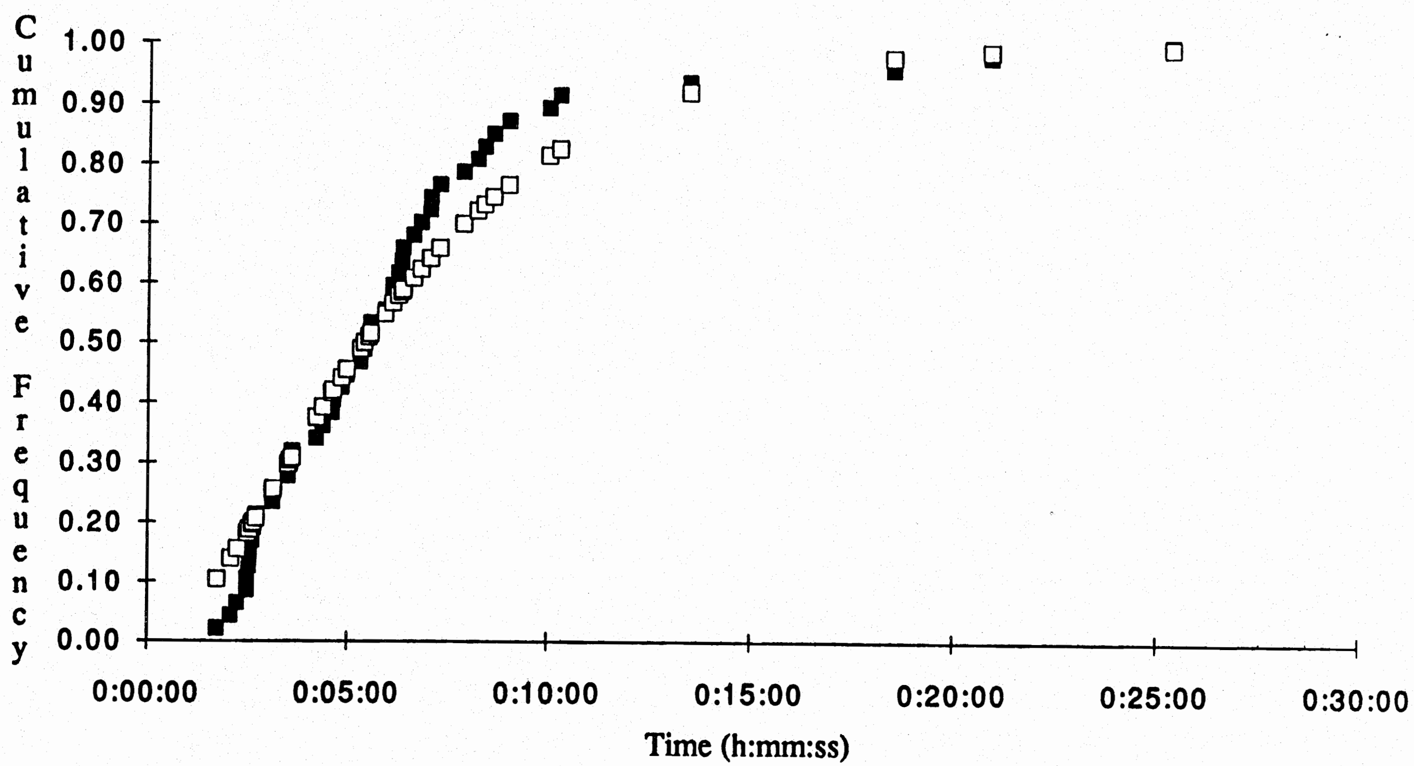


Figure B.41 - Cumulative frequency of service times for Mar9p.1 data file. No distribution tested significantly similar to the field data. The Erlang(4) distribution is shown below. Sample is 38 observations.

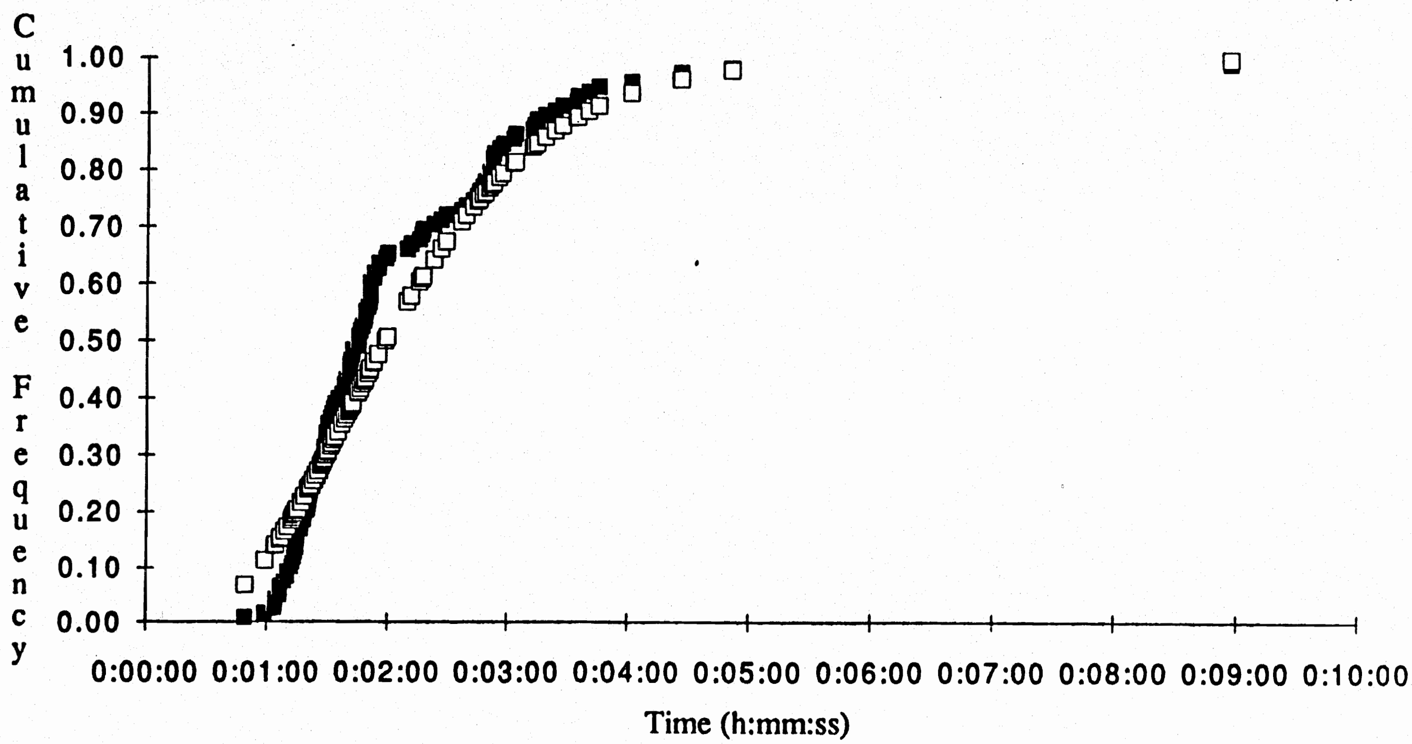


Figure B.42 - Cumulative frequency of single move service times for Mar9p.1 data file. No distribution tested statistically similar to the field data. The Erlang(3) distribution is shown with 38 observations.

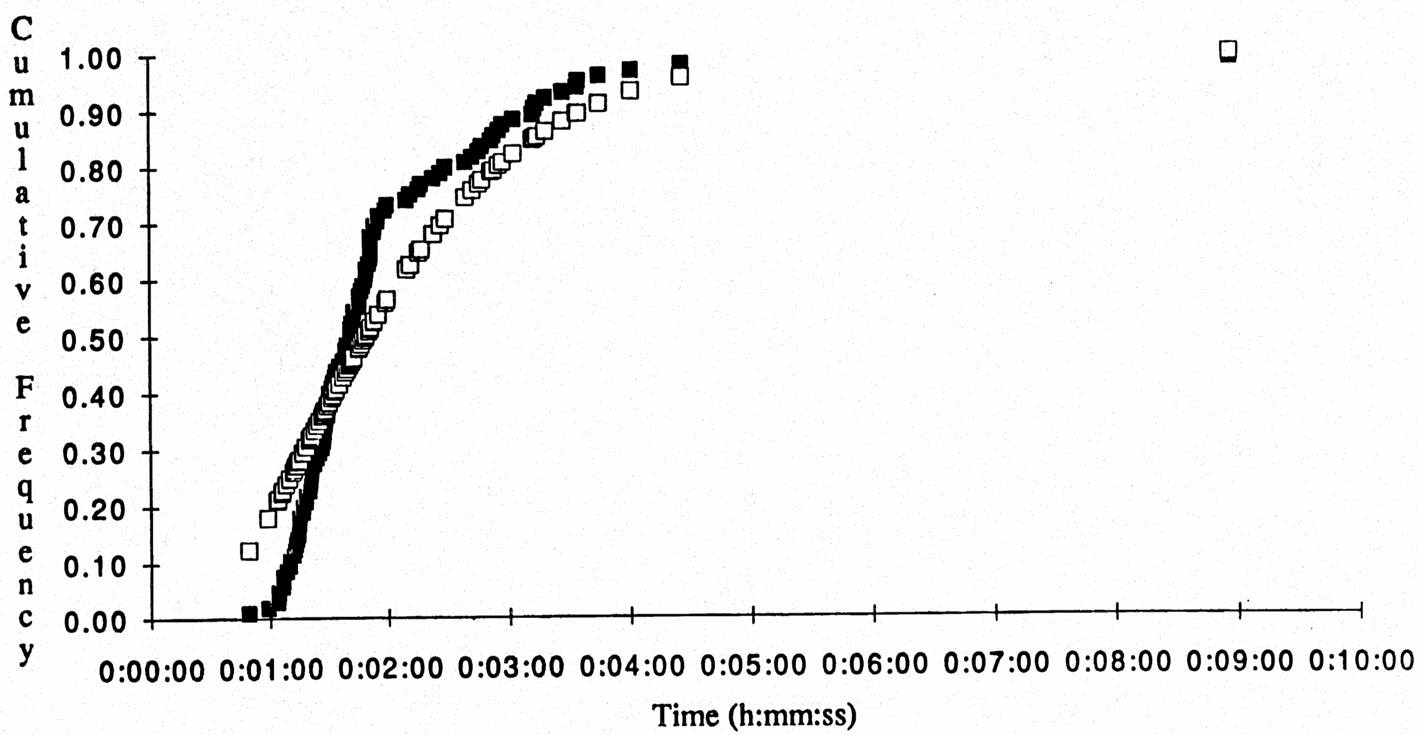


Figure B.43 - Cumulative frequency of interarrival times for Mar9p.1 data file. Best fit is the Erlang(2) distribution. Sample is 97 observations.

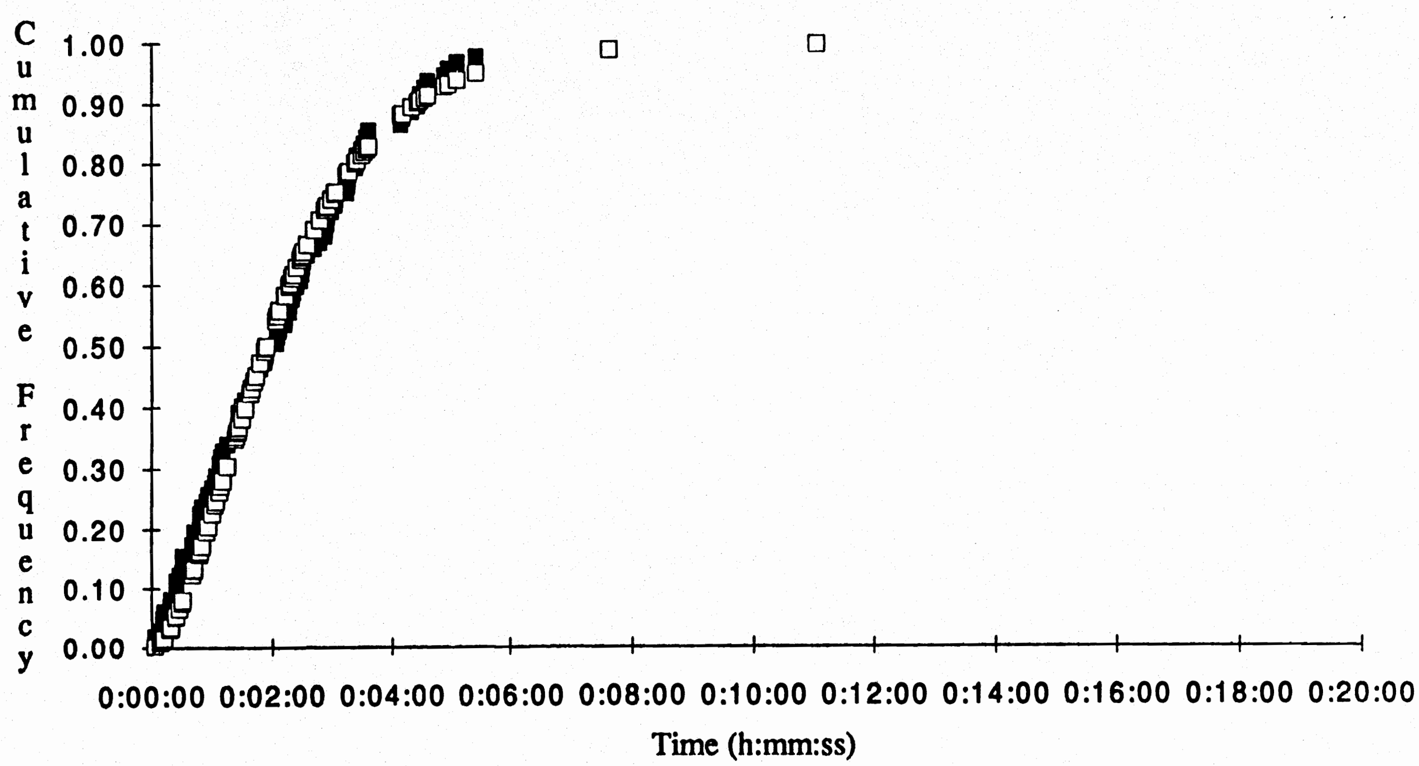


Figure B.44 - Cumulative frequency of single move interarrival times for Mar9p.1 data file. Best fit is the Erlang(2) distribution. Sample is 80 observations.

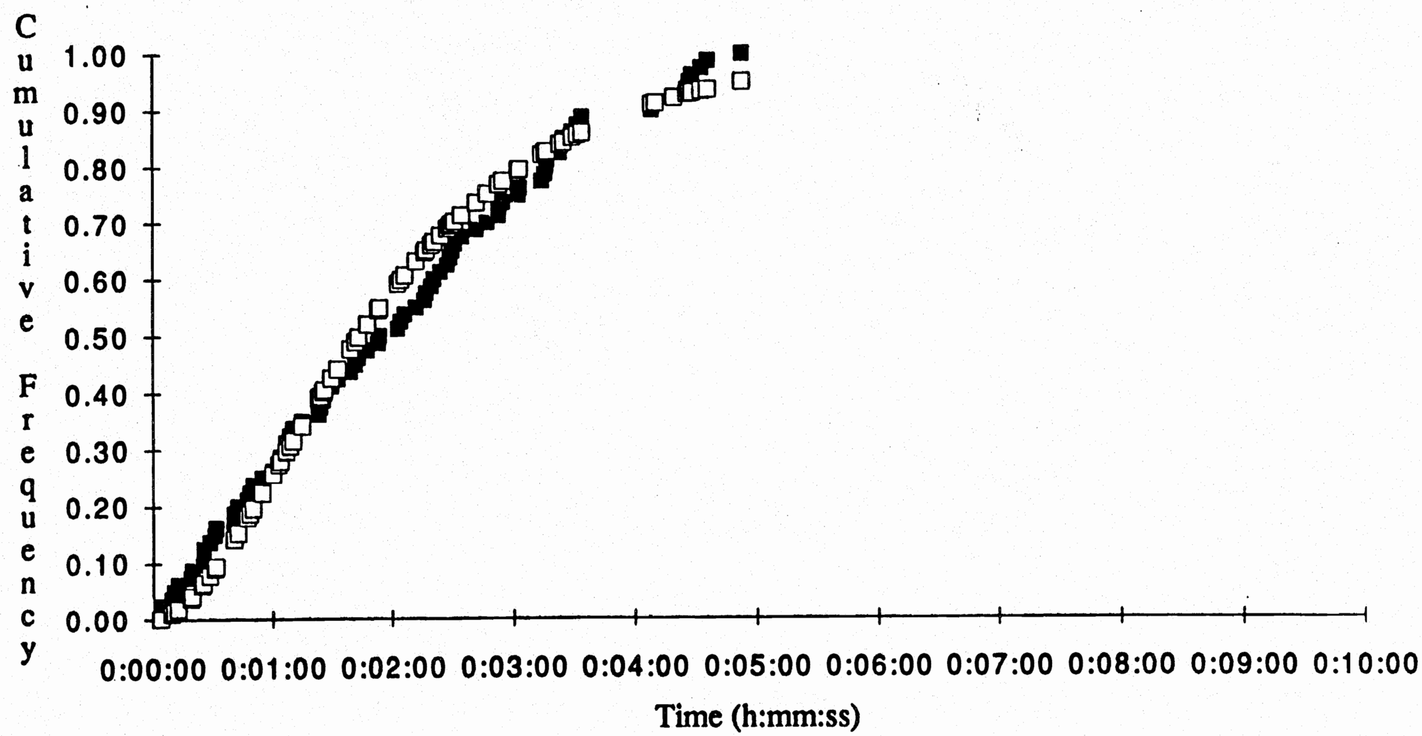


Figure B.45 - Cumulative frequency of backcycle times for Mar9p.1 data file. No distribution tested statistically similar to field data. The Erlang(7) distribution is shown below with 89 observations.

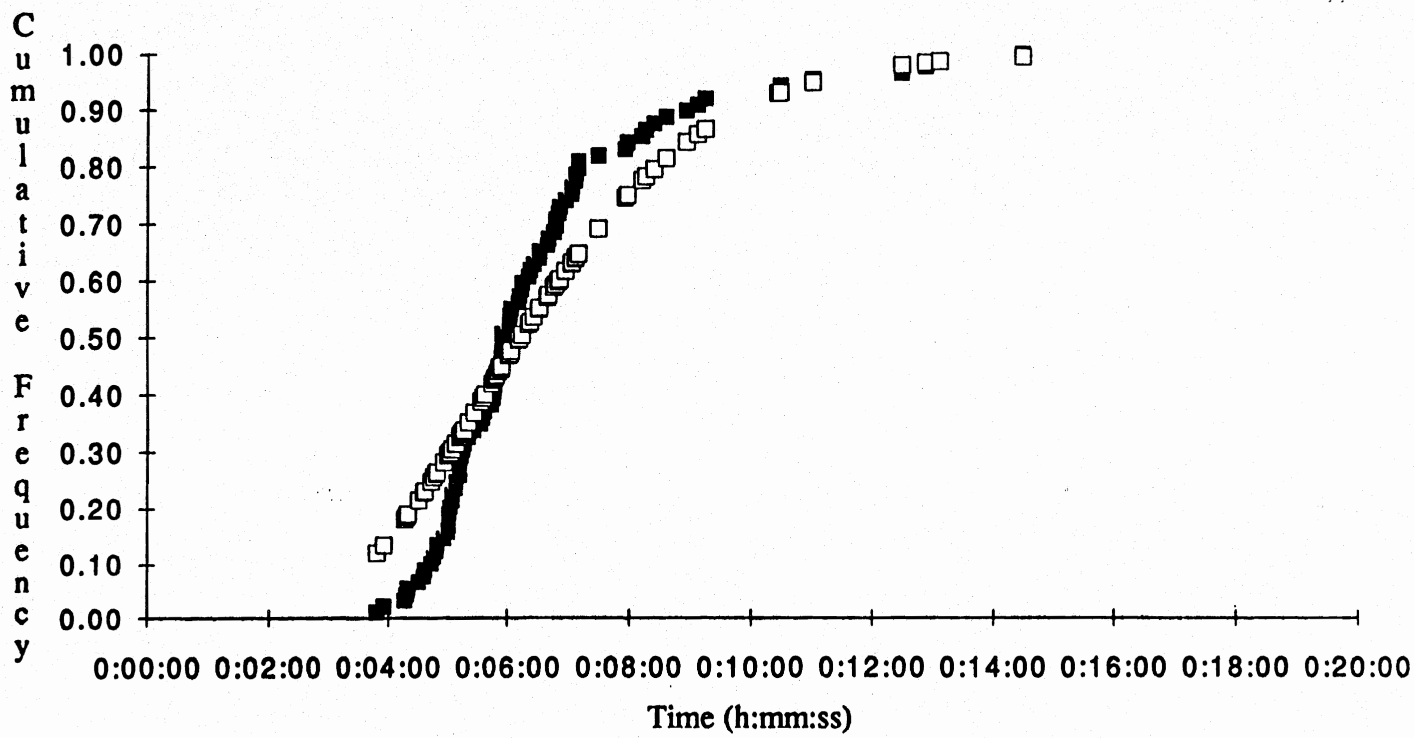


Figure B.46 - Cumulative frequency of service times for Mar9p.2 data file. Best fit is the Erlang(2) distribution. Sample is 128 observations.

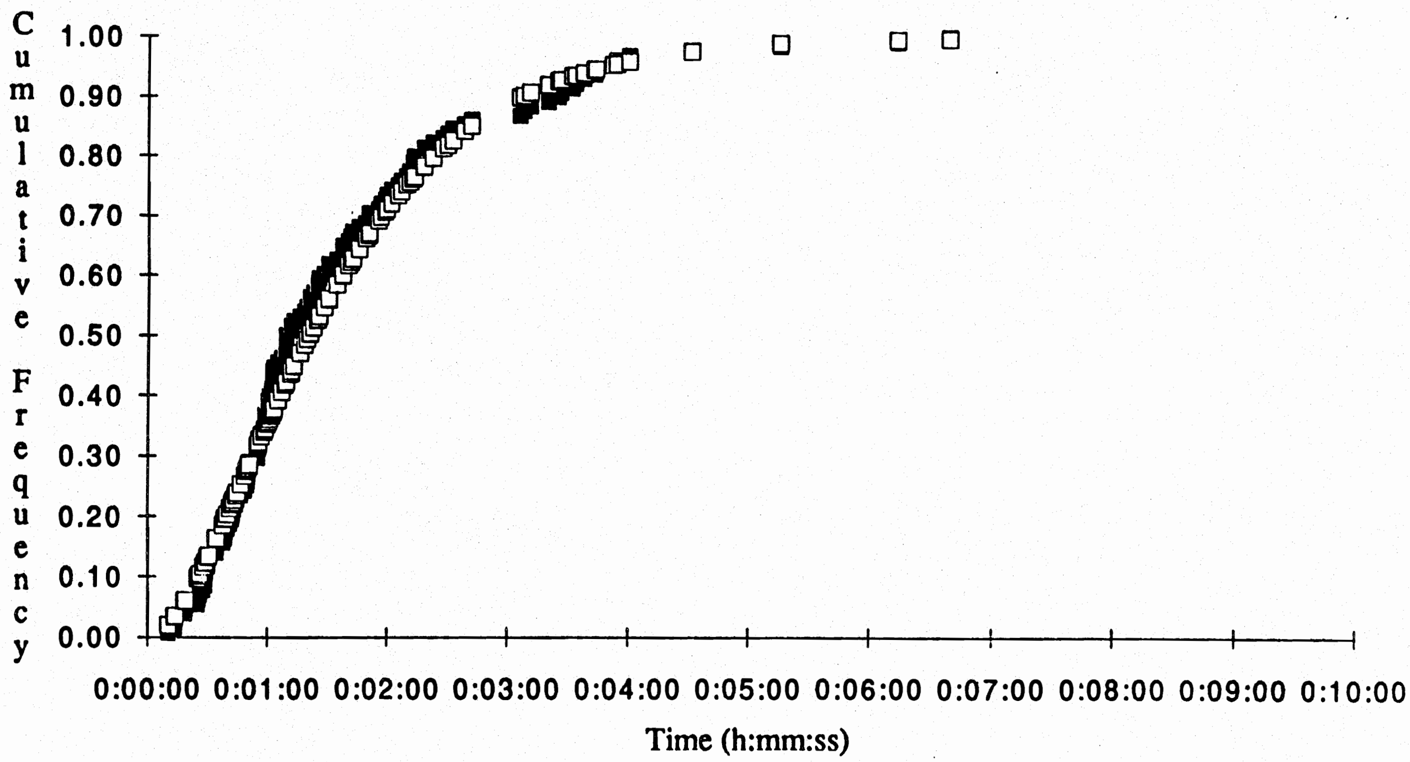


Figure B.47 - Cumulative frequency of single move service times for Mar9p.2 data file. Best fit is the Erlang(2) distribution. Sample is 99 observations.

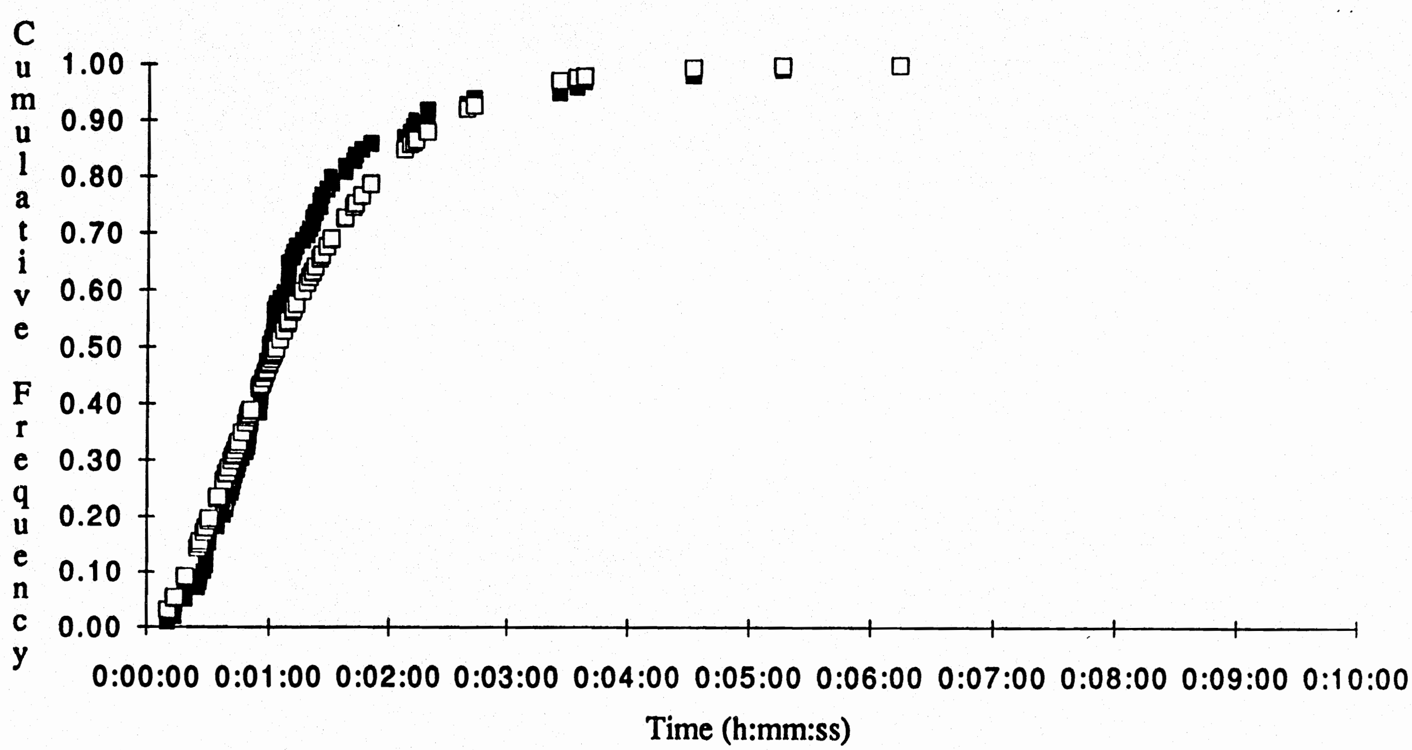


Figure B.48 - Cumulative frequency of interarrival times for Mar9p.2 data file. Best fit is the exponential distribution. Sample is 136 observations.

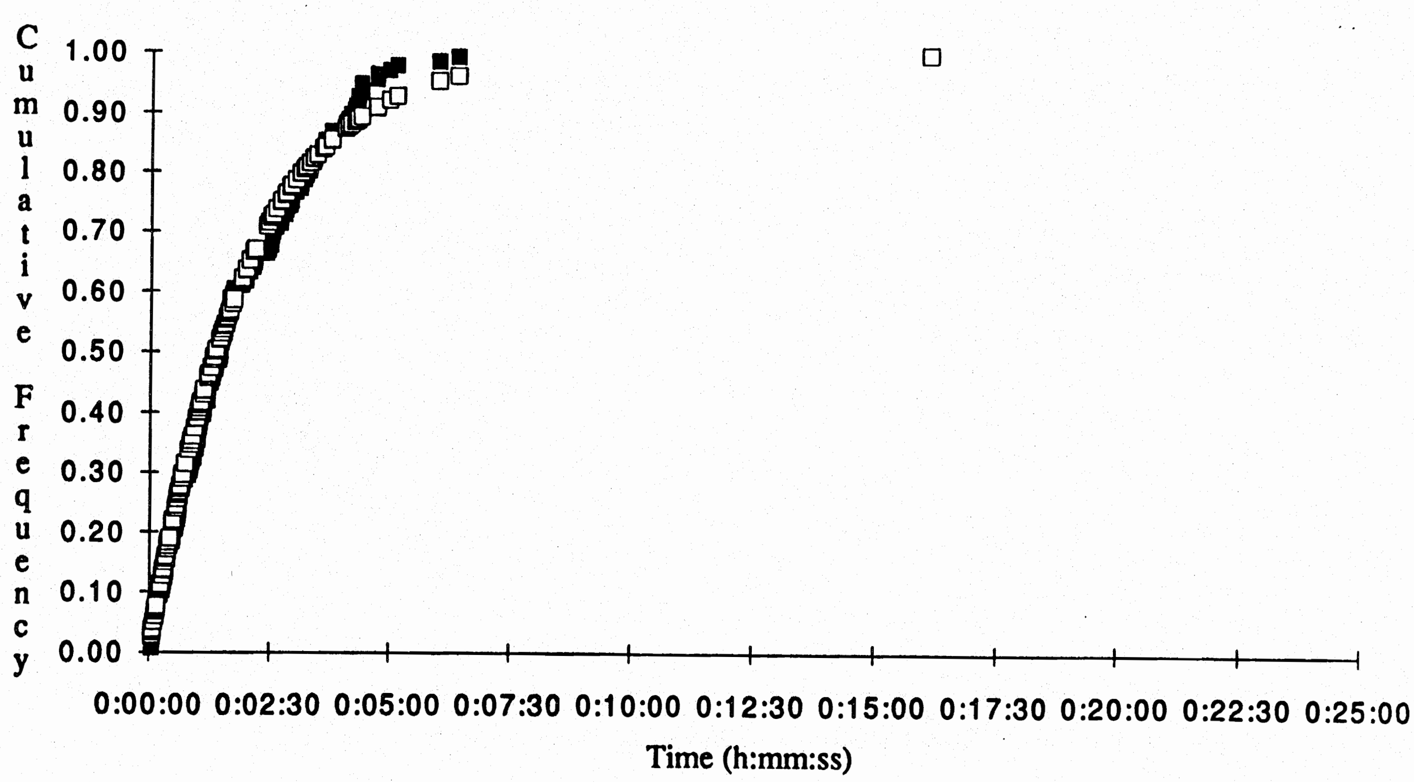


Figure B.49 - Cumulative frequency of single move interarrival times for Mar9p.2 data file. Best fit is the exponential distribution. Sample is 108 observations.

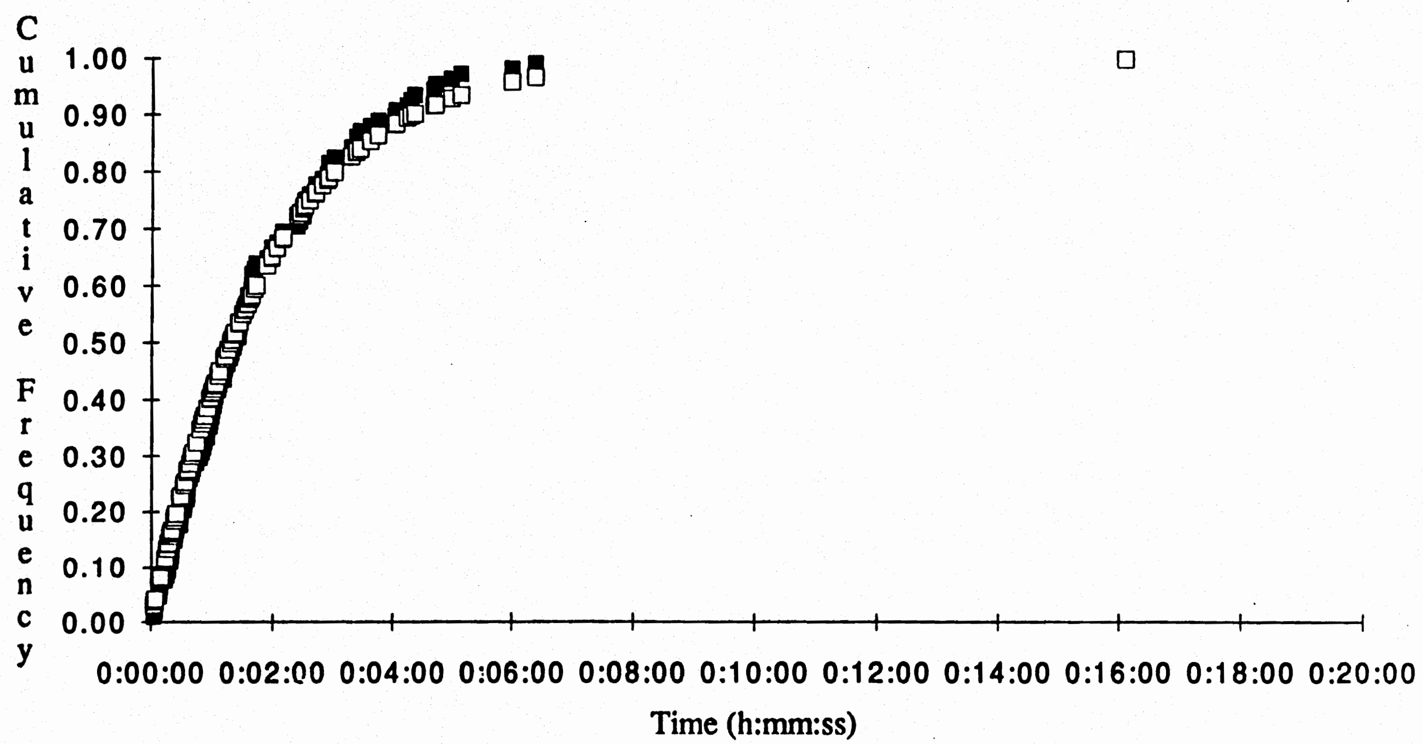


Figure B.50 - Cumulative frequency of double move interarrival times for Mar9p.2 data file. Best fit is the exponential distribution with 28 observations.

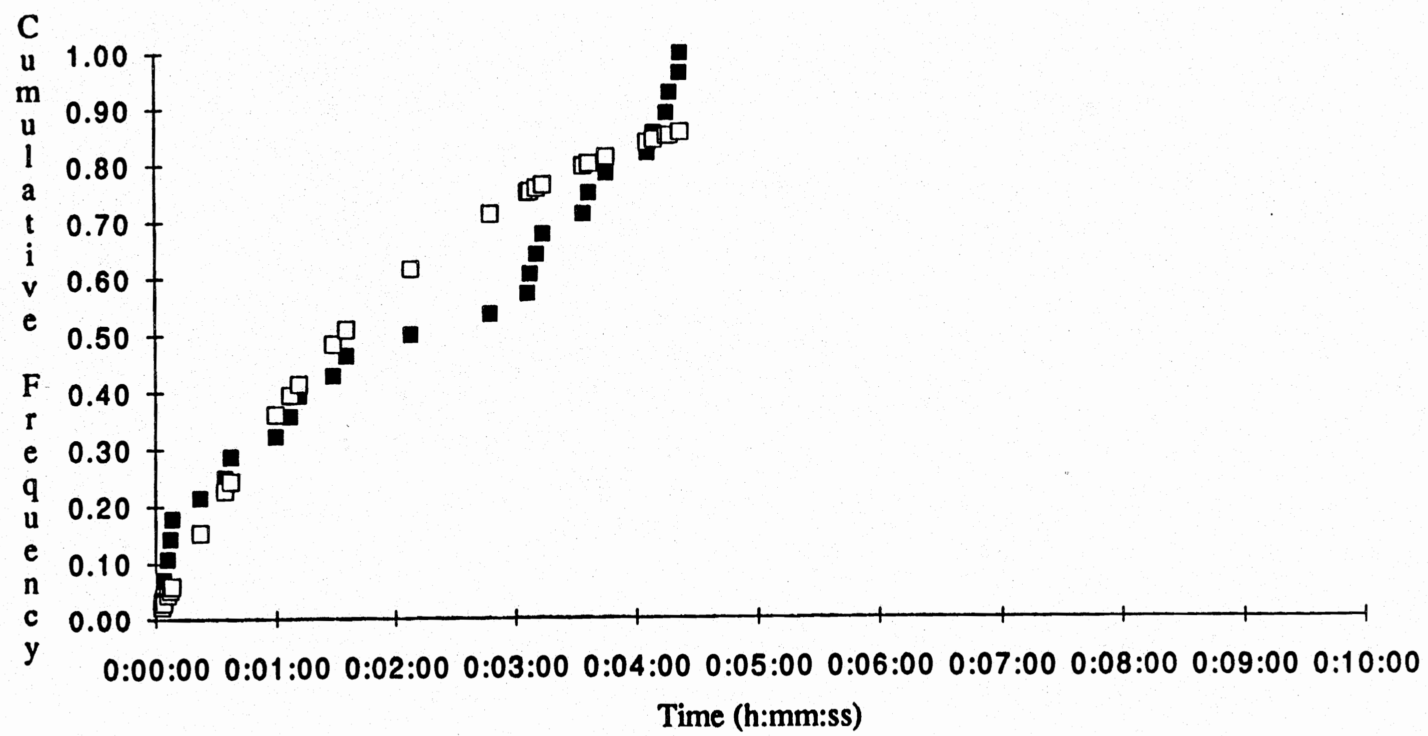
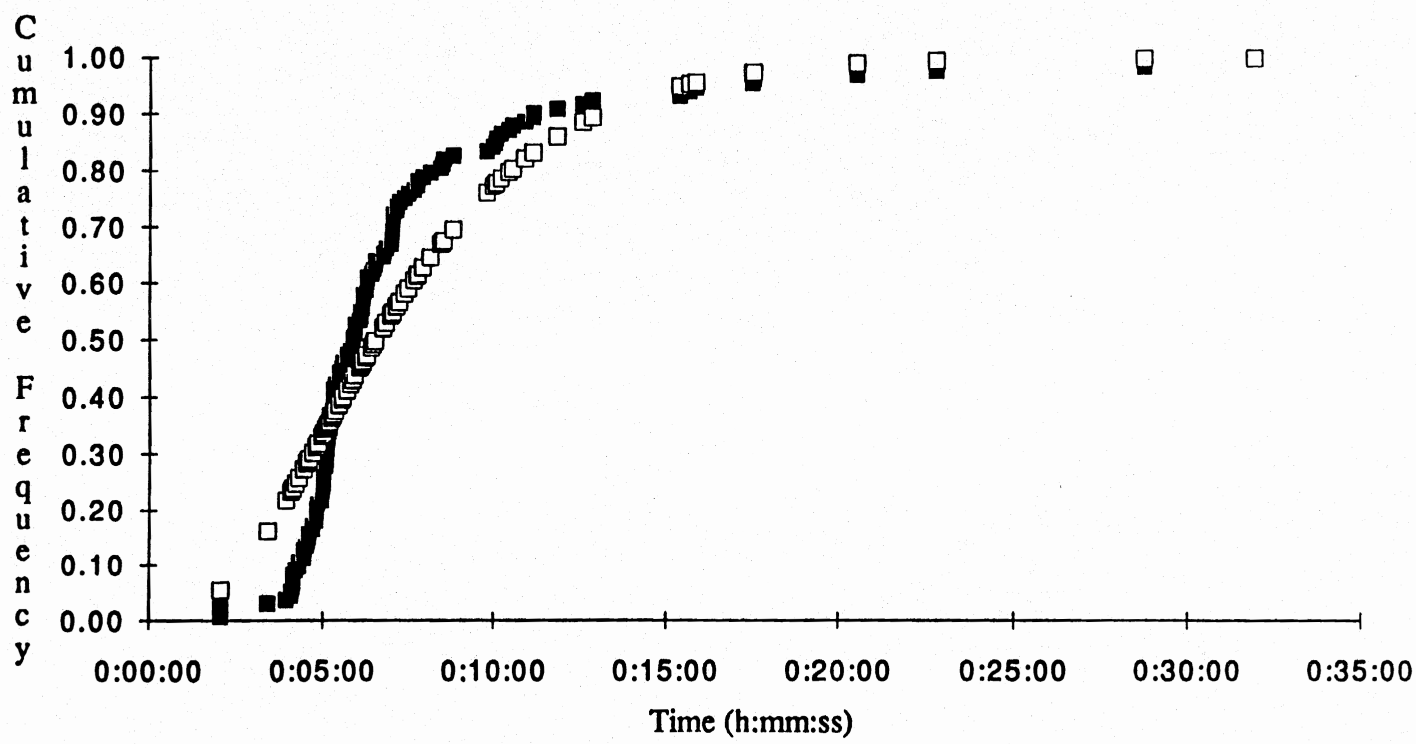


Figure B.51 - Cumulative frequency of backcycle times for Mar9p.2 data file. No distribution tested statistically similar to the field data. The Erlang(3) distribution is shown below with 133 observations.



REFERENCES

1. Whittaker, J.R. Containerization. Washington: Hemishpere Publishing Company, 1975, 1-2.

2. Whittaker, J.R. Containerization. Washington: Hemishpere Publishing Company, 1975, 3.

3. Gilman, Sidney. Container Logistics and Terminal Design. Washington: International Bank for Reconstruction and Development, 1982, 1.

4. Strom, Harold K. "Containerization: A Pandora's Box in Reverse?" Transportation Journal v12 n2 (Winter 1972): 46. In reference to Meyers, Harold B. "The Maritime Industry's Expensive New Box." Fortune. November 1967, 152.

5. Gilman, Sidney. Container Logistics and Terminal Design. Washington: International Bank for Reconstruction and Development, 1982, 1.

6. Taleb-Ibahimi, Mounira, Bernardo de Castilho, and Carlos F. Daganzo. "Storage Space Versus Handling Work in Container Terminals." University of California at Berkeley, November 5, 1990, 2.

7. U.S. Department of Transportation, Maritime Administration. Containerized Cargo Statistics. [Washington, D.C.]: U.S. Department of Transportation, Maritime Administration, 1970-1983.
Note that the container cargo statistics were only published for the years 1970-1983.

8. Data analyzed and represented throughout this report were obtained from each of the two ports.

9. U.S. Department of Transportation, Maritime Administration. Containerized Cargo Statistics. [Washington, D.C.]: U.S. Department of Transportation, Maritime Administration, 1970-1983.

10. Port of Houston Authority. 1990 Annual Report.

11. U.S. Department of Transportation, Maritime Administration. Containerized Cargo Statistics. [Washington, D.C.]: U.S. Department of Transportation, Maritime Administration, 1970-1983.

12. Statistics provided by the Port of New Orleans, June 30, 1991.

13. Murphy, Paul, Douglas Dalenberg, and James Daley. "A Comtemporary Perspective of International Port Operations." Transportation Journal v28 n2 (Winter 1988): 24.

14. Oram, Robert Bruce, and Christopher Charles Robert Baker. The Efficient Port. New York: Pergamon Press Inc., 1971, 2.

15. Oram, Robert Bruce, and Christopher Charles Robert Baker. The Efficient Port. New York: Pergamon Press Inc., 1971.

16. Whittaker, J.R. Containerization. Washington: Hemishpere Publishing Company, 1975.

17. Gilman, Sidney. Container Logistics and Terminal Design. Washington: International Bank for Reconstruction and Development, 1982.

18. Frankel, Ernst G. Management and Operations of American Shippping. Boston: Auburn House Publishing Company, 1982.

19. Atkins, Captain Warren H. Modern Marine Terminal Operations and Management. San Francisco: The Compage Company, 1983.

20. Land constraints have forced many container ports, carriers and rail yards to employ the grounded (stacked) container storage method. The most notable exception is Sea-Land, Inc.

21. Corbett, Jr., Scott S. "Handling and Storage of Empty Chassis." Transportation Research Record 907 (1983).

22. Marcus, Henry S. "Improving Port Productivity: Research Trends and Issues." Transportation Research Forum v25 n1 (October 22-24, 1984).

23. Daganzo, Carlos F. "Crane Productivity and Ship Delay in Ports." Transportation Research Record 1251 (1990): 1-9.

24. Peterofsky, Roy I. "SCULL: A Computer Program for the Scheduling of Cargo Unloading and Loading." Masters thesis, University of California at Berkeley, 1987.

25. Daganzo, Carlos F. "The Crane Scheduling Problem." Transportation Research v23B n3 (1989): 159-175.

26. Peterofsky, Roy I. and Carlos F. Daganzo. "A Branch and Bound Solution Method for the Crane Scheduling Problem." Transportation Research v24B n3 (1990): 159-172.

27. Easa, Said M. "Analysis of Traffic Operations in Harbor Terminals." Ph.D. dissertation, University of California at Berkeley, 1981.

28. Sabria, Federico. "Analysis of Potential Improvements in Port Operations." Ph.D. dissertation, University of California at Berkeley, 1986.

29. Daganzo, Carlos F. "The Productivity of Multipurpose Seaport Terminals." Transportation Science v24 n3 (August 1990).

30. Nehrling, Bruce C. "Container Ship Loading and Unloading Simulation." The University of Michigan. Paper presented at The Society of Naval Architects and Marine Engineers, Hawaii, August 11, 1970.

31. Hammesfahr, R.D. Jack, and Edward R. Clayton. "A Computer Simulation to Assist Intermodal Terminal Managers in Operations Analysis." Transportation Journal v22 n4 (Summer 1983).

32. Taleb-Ibahimi, Mounira, Bernardo de Castilho, and Carlos F. Daganzo. "Storage Space Versus Handling Work in Container Terminals." University of California at Berkeley, November 5, 1990.

33. Koenigsberg, Earnest. "Twenty Five Years of Cyclic Queues and Closed Queue Networks: A Review." Journal of the Operational Research Society v33 (1982): 605-619.

34. Burke, Paul J. "The Output of a Queueing System." Operations Research v4 n6 (December 1956): 699-704.

35. Jackson, James R. "Networks of Waiting Lines." Operations Research v5 n4 (August 1957): 518-521.

36. Saaty, Thomas L. Elements of Queueing Theory With Applications. New York: Dover Publications, Inc., 1961.

37. Kleinrock, Leonard. Queueing Systems. New York: John Wiley and Sons, 1975.

38. Gross, Donald, and Carl M. Harris. Fundamentals of Queueing Theory. New York: John Wiley and Sons,1985.

39. Hunt, Gordon C. "Sequential Arrays of Waiting Lines." Operations Research v4 n6 (December 1956): 674-683.

40. Koenigsberg, Earnest. "Finite Queues and Cyclic Queues," Operations Research v8 n2 (March-April 1960): 246-253.

41. Kleinrock, Leonard. "Sequential Procesing Machines (S.P.M.) Analyzed With a Queueing Theory Model." Journal of the Association for Computing Machinery v13 n2 (April 1966): 179-193.

42. Gordon, William J., and Gordon F. Newell. "Closed Queueing Systems With Exponential Servers." Operations Research v5 n2 (March-April 1967): 266-277.

43. Gordon, William J., and Gordon F. Newell. "Cyclic Queueing Systems With Restricted Length Queues." Operations Research v5 n2 (March-April 1967): 266-277.

44. Maher, M.J., and J.G. Cabrera. "The Transient Behavior of a Cyclic Queue." Operational Research Quarterly v24 n4 (1974): 603-613.

45. Maher, M.J., and J.G. Cabrera. "A Multi-State Cyclic Queueing Model." International Journal of Production Research v13 n3 (1975): 255-264.

46. Posner, M., and B. Bernholtz. "Closed Finite Queueing Networks With Time Lags." Operations Research v16 n5 (1968): 962-976.

47. Posner, M., and B. Bernholtz. "Closed Finite Queueing Networks With Time Lags and With Several Classes of Units." Operations Research v16 n5 (1968): 977-985.

48. Daskin, Mark S., and C. Michael Walton. "An Approximate Analytical Model of Supertankering Lightering Operations." Transportation Research v17B n3 (1983): 201-219.

49. Carmichael, D.G. Engineering Queues in Construction and Mining. New York: John Wiley and Sons, 1987.

50. McNickle, Don C., and R.C. Woollons. "Analysis and Simulation of a Logging Weighbridge Installation." New Zealand Journal of Forestry Science (forthcoming).

51. U.S. Department of Commerce. Local Climatological Data - Monthly Summary. Washington, D.C.: GPO, 1989.

52. Winston, Wayne L. Operations Research: Applications and Algorithms. Boston: PWS-KENT Publishing Company, 1987.

53. Pritsker, A. Alan B. Introduction to Simulation and SLAM II. Indiana: Systems Publishing Corporation, 1986.

54. Pritsker, A. Alan B. Introduction to Simulation and SLAM II. Indiana: Systems Publishing Corporation, 1986, 308.

55. Larson, Richard C. "Perspectives on Queues: Social Justice and the Psychology of Queueing." Operations Research v35 n6 (Nov-Dec 1987): 895.

56. Maher, M.J., and J.G. Cabrera. "A Multi-State Cyclic Queueing Model." International Journal of Production Research v13 n3 (1975): 255-264.

57. Posner, M., and B. Bernholtz. "Closed Finite Queueing Networks With Time Lags." Operations Research v16 n5 (1968): 962-976.

58. Carmichael, D.G. Engineering Queues in Construction and Mining. New York: John Wiley and Sons, 1987.

59. Winston, Wayne L. Operations Research: Applications and Algorithms. Boston: PWS-KENT Publishing Company, 1987.

60. Burke, Paul J. "The Output of a Queueing System." Operations Research v4 n6 (December 1956): 699-704.

61. Gordon, William J., and Gordon F. Newell. "Closed Queueing Systems With Exponential Servers." Operations Research v5 n2 (March-April 1967): 254-265.

62. Carmichael, David G. "Erlang Loading Models in Earthmoving." Civil Engineering Systems v3 (September 1986): 118-124.