CRANE CONTROL OF AN AUTOMATIC STORAGE & RETRIEVAL SYSTEM

by

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(ABSTRACT)

The nature of how an Automatic Storage & Retrieval System stacker crane moves through the aisle, between picking and storing operations, is analyzed through a simulation model. A continuous SLAM model simulates the performance of a single aisle Automatic Storage & Retrieval System stacker crane under various control conditions. Crane speed, acceleration rate, job arrival rate, and discrete or continuous interrupt sensing are the variables examined within the model. The performance level of the system is observed while altering the control.

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Chapter I

INTRODUCTION

Warehousing has generally been regarded by many as of secondary importance to process machinery and other equipment in a manufacturing facility. Warehousing, however, has taken on a new imagine in the 1970's and 1980's. A warehouse, that critical buffer between the production line and the marketplace, has proven to be a significant factor in whether a manufacturing facility makes a profit. Indeed, the warehouse itself is now viewed by many as an integral part of a finely-tuned manufacturing and distribution machine designed and operated to maximize the return on investment in raw or finished " assets process "[21]. This concept has brought a new awareness to the importance of the material handling equipment within a warehouse.

1.1 TOWARD AUTOMATION

In the past, the classical workhorse for transporting materials between in-house inventory and the production floor in a factory has been the forklift truck. It has been the cornerstone for in-house transportation since their in-

ception. The forklift truck serves many purposes in a factory. However, none of these functions are performed with utmost efficiency, due to the limitations imposed on its flexibility as a transportation vehicle. Some of the forklift truck's limitations are:

1) reaches a height of no more than 55 ft. [10],

2) carries only a single unit load,

3) requires the constant supervision of an operator, and

4) requires asile space of 5 ft. or more.

"Material handling is concerned with motion, time, quantity and space" [6]. In order for a factory to operate more efficiently, some of the above limitations will have to be erased.

The growth, diversity and economics of electronics during the last decade has had a greater impact upon the development and composition of the United States material handling industry than any other single factor [21]. It has lead to the birth of automation. Low cost circuitry, solid state electonics and the continuing lowering cost of memory in digital computers have given impetus to the development of a whole new type of material handling system. Types of such systems includes:

1. Automatic Storage and Retrieval System (ASR System),

2. Controllable Power Conveyors, and

3. Automatic Guided Vechicles System (AGVS).

All of the above have proven a significant benefit to modern day warehousing.

ASR System's are automated warehouses with storage and retrieval performed automatically by machines. The storage area is made up of cubicals (called cells) for storing parts. Each system may consists of hundreds, possibly thousands, of such cells. A computered controlled crane drives through an aisle and performs the task of either storing or removing parts. Some of these cranes can move up to a height of 100 feet or more, while occupying less aisle space than conventional forklift trucks [1]. Compared to a conventional warehouse where forklift trucks are used, space utilization in an ASR System warehouse is dramatically increased. In addition, the use of the ASR System has led to much tighter inventory control. Every time an item is taken into, or removed from, the storage area, a local processor that controls the crane sends a message to a host computer, which immediately updates the inventory on hand. The system also reduces errors of picking the wrong item for a specific order. One user claims that with an ASR System the percentage of wrong items being picked approaches zero [45]. All these features have made ASR Systems more attractive investments than conventional warehouse systems.

Conveyor system technology has advanced tremendously in the last decade[1]. Photoelectric sensors, bar-coded readers as well as other sensing devices have revolutionized conveyor capabilities. There are as many as 240 different types of conveyors on the market today, and more are being invented [6]. Conveyors which automatically sort products are availiable. Using a network of conveyors, different items can be transferred to different points in the conveyor system. Line shaft conveyor and conveyors with the capability to make a 90 degree turn are playing an important role in live roller technology [7]. Conveyors carry a continuous stream of parts to different loactions in a production facility; whereas, forklift trucks are capable of only unit load transportation.

The Automatic Guided Vehicle System (AGVS) is the newest and most sophiscated type of material handling system. Following a directed path, the automatic guided vechicle brings the load from one place to another without human interference. Similar in concept to a forklift truck, the AGVS vehicle does not need the constant attention of an operator. Routes are programmed into the system guiding the vehicle to its destination instead of an operator driving the vehicle. A change in the vehicle's route is usually accomplished by keying in certain commands. The design of such a system is

very complex especially when dealing with multiple carts arriving to an intersection at the same time. Therefore, extensive testing must be performed before the system is actually implemented. Although the initial overhead for installing such system is high, dramatic savings in labor cost can quickly offset the expenses.

With the many new innovations in material handling, few developments have had the impact of the Automatic Storage and Retrieval System [21]. It has revolutionized the whole concept of warehousing. Instead of a building being depreciated, the ASR System (building and crane inclusive) is eligible for depreciation at the same rate as capital equipment. With its ability to keep track of large amounts of inventory, distribution centers around the nation are quickly replaced by larger and more efficient ASR Systems. The U.S. Navy has replaced several existing warehouse and distribution centers with four newly built ASR Systems [45]. The size and capacity of the ASR System has more than doubled since those built in the early 70's. The number of storage bins (over 10,000) has double previous capacities, while the majority of racks were under 50 ft. tall then, they now average between 50-69 ft. tall [1]. The number of orders to built an ASR Systems has also increased exponentially [1]. Following this trend, soon most of the large warehouses

in this country will employ an ASR System. However, the combination of a sophisticated computer system and ostensible racks on the production floor do not make a complete ASR System. It is together with a well designed control strategy, capable of transporting the parts to and from the storage area in an optimum or near optimum fashion, that makes the system complete.

1.2 TYPES OF S/R MACHINES

Storage and retrieval machines of a rack storage system, other than the forklift trucks, can be classified into one of the following categories:

1. Man-ride Systems,
2. Semi-automatic Systems, and
3. Computer Controlled Systems [2].

Each of the above system classes may vary in complexity and the specialized skills required to design, build, test and operate.

The man-ride system is the most fundamental since all of the control is performed manually. In these systems, a storage/retrieve (S/R) machine is manually positioned by an on-board operator. The operator is housed inside the machine during the entire operation guiding it to the desired

location. Installation is performed in non-precise racks. These system are typically the least expensive of the three.

A semi-automatic system contains storage/retrieval machines with automatic positioning along with a remote control console. The crane is directed via the console by an operator outside the S/R machine (to the desired location), a phenomenon which is evident in a computer control system , if the computer fails. A system such as this requires racks erected to tight tolerances. It also requires a precision floor track to assure accurate positioning of the S/R machine.

The computer controlled system is the most expensive and complex system among the three. The S/R machines store and retrieve motions are controlled by a computer. Aside from the racks and the S/R machines, the system includes a computer, which controls the operation and maintains an inventory record. In addition, a conveyor system usually directs parts, which are retrieved from the S/R machines, to different unload stations or from different load stations back to the storage system. Capital investment in such system is high, but the benefits are usually an increase in system throughput [2], and a better control of existing inventory.

1.3 ADVANCES IN ASR SYSTEMS

Through the 70's and into the 80's, the rate of ASR System erection has climbed exponentially [1]. Advances in technology and computer control have made these systems more realiable and efficient. The mini- or micro-computer that controls these systems now operates much faster and communicates with a host computer that plans production or warehousing activity in order to maintain inventory balances more efficiently. An increase in diagnostic information is thus availiable. The machine now can talk back if abnormal conditions occur and performs error checking if necessary [7]. ASR Systems now include unit load AS/R machines, mini-load AS/R machines, car-in-lane systems and automatic trucks [7]. All of these systems can transfer materials automatically to or from automated transportation stations. There are also rail riding S/R machines, which travel out of the rack area into the process area [7]. These machines, called shuttle trolleys, deliver parts and assemblies to process stations and also take work from in-process into temporary storage. In addition, new concepts have sprung with the use of ASR Systems in the 80's. Vertical Integrated Production Systems (VIPS) where processing operations such as knitting, assembly and testing takes place at mezzanines

around the perimeter of an ARS System. If properly designed this concept can save up to 40 percent of the plant floor space [7].

1.4 PLANNING FOR CONTROL OF AN AUTOMATED WAREHOUSING SYSTEM

The basic concept of a computer-integrated warehousing system is to link planning and scheduling with warehousing functions [7]. The ability to control the physical movement of materials is the basis for the ASR System. However, to move the materials efficiently so as to maximize throughput requires a well developed control strategy to control the movement of the crane. Techniques used in the control of these systems seldom appear in the literature [16,20,40] . It is very important that the proper techniques be chosen and used correctly to minimize travel time.

1.4.1 Continuous Analytical Model

Analytical models are concerned with storage assignment rules for automatic warehousing includes interleaving; that is, the sequencing of storage and retrieve requests. Expected crane travel time is found and compared with other types

of storage assignment and interleaving rules. From these analytical results, the best rule for a particular system can be found. Graves, Hausmin and Schwarz [16] analyze the ASR System employing this technique.

1.4.2 Simulation

Simulation is the most common tool used in the analysis of actual performance of the system before implementation. Although simulation cannot guarantee optimality, the best practical solution is often found. Simulation can be categorized into two groups:

1. Computer Simulation, and
2. Physical Simulation.

Computer simulation utilizes a computer program to analyze the system under different configurations and constraints. The data output from the simulation indicates how the system performed and perhaps what can be done to improve it. SLAM, GPSS and GASP IV are a few examples of the simulation languages developed especially for such purposes. Extreme caution must be excerized to ensure that the program is simulating the actual system. Often the program is not simulating the actual environment, due to unforeseen variables.

Physical simulation is usually performed on a scaled model of the actual system. System performance is tested on different control strategies in search of an optimum. Although the computer simulation is reliable, inconceivable variables often cause a designer to turn to physical modeling. The study of waves acting upon a ship for instance has always been studied on a physical model because the waves cannot be quantified easily.

Computer simulation is more flexible than physical simulation and changes to the configuration can be easily implemented. It is normally less expensive and less time consuming to experiment with computer simulation than the full scale system. Systems that used simulation during the development of their control strategies have been documented in the literature [12,30,42]. According to Maxwell [31] "Simulation has been and will continue to be a prime approach to the problems an industral engineer, involving in material handling, confronts".

1.5 ORGANIZATION OF RESEARCH

In this chapter, a brief introduction of what an ASR System is and the benefits of using one such system is discussed. Different types of storage/retrieve (S/R) machines

used in today's automated warehousing systems are also mentioned. However, the basis of this chapter is to inform the reader the importance of a well developed cart movement control strategy and the ways in which one would find it.

Chapter 2 outlines the thesis objective and the problems associated with the control nature of an ASR System. By solving these problems, the objective of this thesis is accomplished.

Chapter 3 is a survey of the current literature involved with the control of an ASR System. It begins by addressing articles related to the characteristics of industrial motors; what obstacles are perceived from using them. Next, the types of feedback signal that can be used for the system is addressed. This includes how the accuracy of the signals can be improved. Finally, articles related to the types of interleaving rules are addressed--types that will enhance better throughput.

Chapter 4 investigates the methodology used to create a better control. Computer simulation is chosen as the tool used to analyze the system. The results from the simulation model are analyzed in Chapter 5.

Chapter 6 concludes the thesis and provides ideas for futher research.

Chapter II

PROBLEM STATEMENT AND OBJECTIVE

2.1 PROBLEM STATEMENT

Since the birth of ASR Systems, research contributions in this area have been scarce. Analytical or simulated results, appearing in the literature, deal primarily with the subject of storage assignment and interleaving, but little is related to the physical control of the craneis presented. Time-speed profiles (Figure 1) of the physical movement of the crane are seldom addressed, as well as real time tracking of the location of the crane. For a single-aisle stacker storage system (Figure 2), the problem of the combinational levels of the rate of acceleration and velocity necessary to drive the crane to its desired position, in the most efficient manner is discussed. The type of feedback signal is also important for the crane control of the ASR System.

Queue length and time (performance) is dependent on both acceleration and velocity. However, the question remains is that; will the shortening of queue length be directly proportional to the speed of the crane, or does it have a diminishing return effect after it has passed certain limits.

Since the service time is directly proportional to both the acceleration rate and velocity, an increase in either should improve the overall system performance. However, the effects in queue length of an increase of either one is unknown. Other issues that relate to the crane control evolve around feedback. The feedback signal that the processor (computer) receives is the only means by which it knows if the crane is performing according to requirements. The feedback signal gives the processor information on where the crane is and how fast it is moving. Feedback can often be classified into two categories: 1)discrete feedback, and 2) continuous (analog) feedback. Benefits of continuous versus discrete feedback are that decisions or corrective actions can be made by the continuous system at any point along the track, and not necessary at certain fixed points. How then will the implementation of either have an effect on system performance is unknown. The following are a list of control parameters and/or assumption that the results of this research are based upon:

1) The rate of store and retrieve jobs are evenly distributed at all times.

2) The rate of acceleration and deceleration are equivalent.

3) The time required to load and unload a part is the same.

4) Changes made to either speed or acceleration involves changing both components (horizontal & vertical).

5) No processing time is required to determine whether interrupts are possible.

6) Distance travelled is the only criteria which determines if an interrupt can occur.

7) FIFO discipline rule is applied to both the store and retrieve queues.

2.2 OBJECTIVE

The objective of this thesis is to determine the control requirements and resultant system performance characteristics for the control of an ASR System cart. Two performances are measured in determining how each control variables affects the system. They are: 1) queue length and 2) crane utilization. The following are issues covered by this thesis.

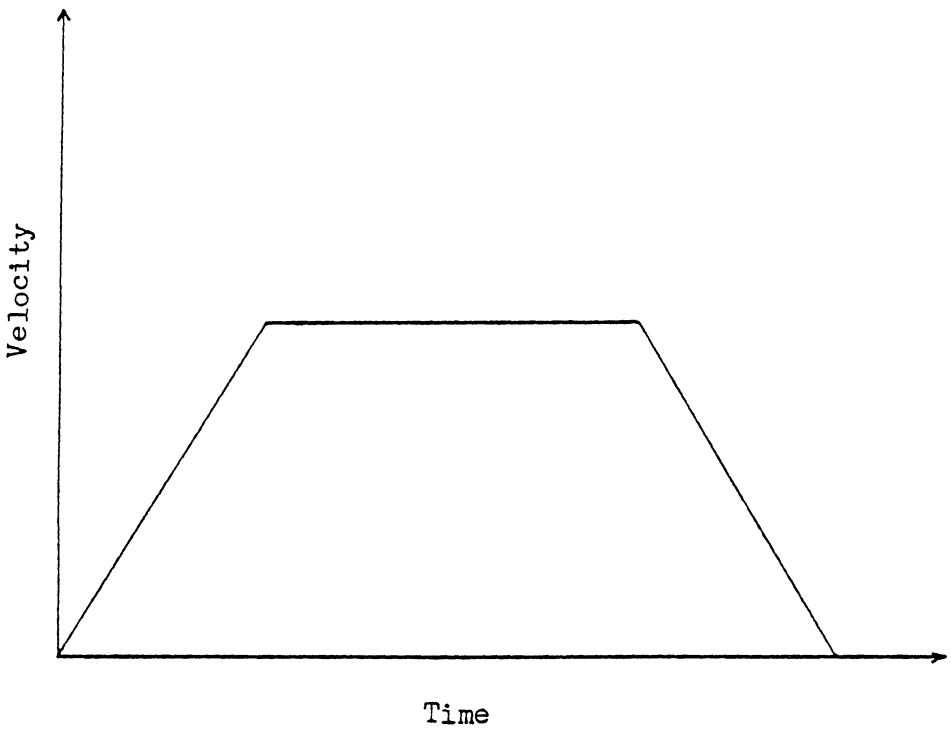

Figure 1: TIME-SPEED PROFILE OF A CRANE

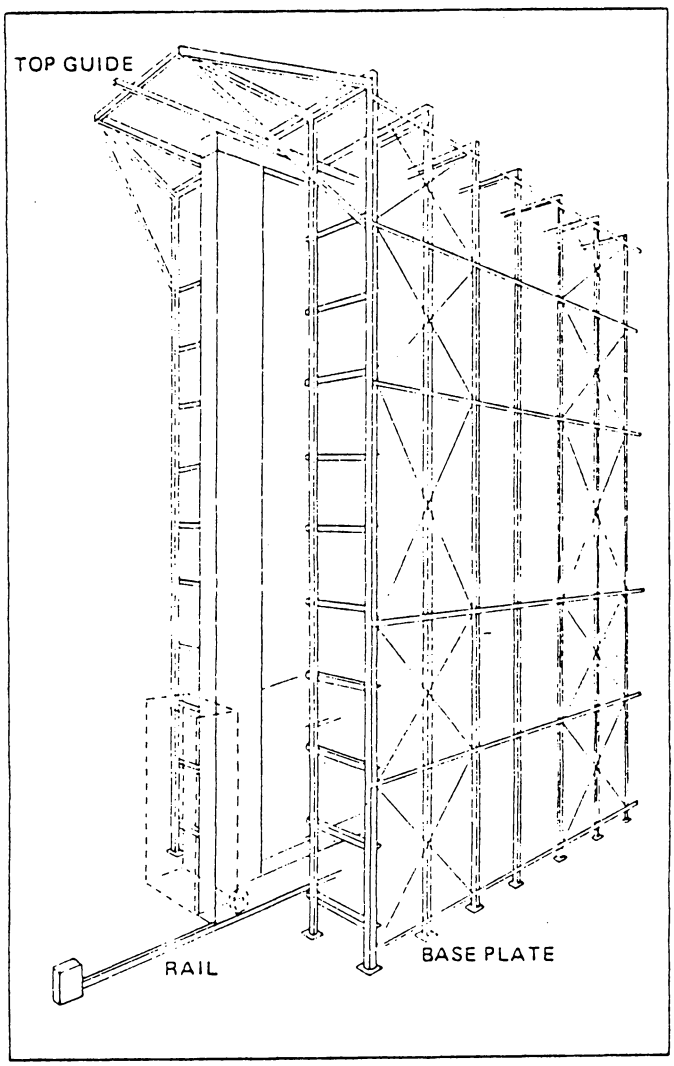

Figure 2: A SINGLE AISLE STACKER STORAGE SYSTEM

1) Desired level of the time-speed profile

The maximum acceleration that can be attained is constrained by both the mechanical stability of the crane and the load being able to secure itself on the fork. Variables affecting the desired level of acceleration includes the mass of the load it is carrying, the crane mass, the crane center of gravity, horsepower of the motor, etc. On the other hand, the only dependant variable affecting crane velocity is the frictional force between the crane and its track. It is obvious that system performance can be easily improved by changing the velocity, which involves correcting a single variable -- the motor. Contrary to an increase in velocity, an increase in acceleration means the redesign of the crane and many other factors have to be changed as well (detailed in chapter 4). The best combination between a given acceleration and velocity is unknown, for which any additional increase in velocity produces less effect in reducing queue length than an increase in acceleration.

2) Interrupt

An interrupt occurance, interrupting the handling of a lesser efficient move for a more efficient one (detailed in chapter 4), is peceived to shorten both queue length as well as lowering crane utilization. Since the control in-

volving a system with interrupt is much more complicated, justification has to be made to determine if the effects of interrupt significantly affects the system.

3) Interrupt on continuous versus discrete feedback

Intuitively it can be preceived that in the case when an interrupt occurs, the use of analog feedback may respond more quickly than discrete feedback, since decisions can take place at any point along the track and not necessarily at specific points. However, in terms of system performance, the degree of improvement derived from the use of continuous (analog) over discrete signal sensing is unknown.

This thesis will investigate the above three points, in order to determine how sensitive the effect each has on system performance. Through this thesis, the author wishes to design the process control of an ASR System in order to maximize throughput and minimize average delay time.

2.3 CHAPTER SUMMARY

This chapter points out the problem associated with the control of the ASR System. A number of assumptions for the control of the system are listed. Finally, the objective of the research are stated.

Chapter III

LITERATURE REVIEW

The design and implemenation of the process control of an ASR System is a very complex process. Nearly every aspect of the ASR System must be considered. This includes the motors and types of feedback signal (analog or discrete) as well as methods used to store and retrieve a part. This chapter gives a brief overview of some of the characteristics of industrial motors types of feedback signals available, and research contributions in the systems control in ASR Systems. The chapter is divided into two major areas:

1. Crane/Local control, and
2. System control

Under these two areas, the total picture of process control of the ASR System is presented.

3.1 CRANE/LOCAL CONTROL

The crane/local control deals with the crane operation. Given a certain motor, a maximum speed/acceleration can be attained, delivering the necessary torque to drive the crane. Voltage drop, vibration, horsepower, and acceleration

time of the motor all have an impact on the performance of the machine(equipment). Several considerations which must be made when dealing with motors will be presented in the following paragraphs.

William and Griffith [48] analyzed the effects of industrial motors during starting. With the aid of computers, studies aimed at reducing the amount of inrush current to the motor and associated voltage dip ,during starting, in an effort to increase starting torque, was discussed. However, tradeoffs at increasing the time required to reach synchronous speed must be made. The authors also presented a formula whereby the time to reach 95 percent of synchronous speed can be calculated.

Albright [5] concentrated his effort on highlighting on the problem areas of motor starting/acceleration, torsional vibration, lateral vibration, coupling, excitation control, and surge protection. The paper is intended to give the user a better understanding of industrial motors, and any application should be given special attention and extreme caution to these problem areas. Several motors were compared in determining the pros and cons.

Eis [14] concentrated on the aspect of torsional and lateral vibration of industrial motors. He discussed the effects of resonant speed acting on the lateral vibration of

motors, and how vibration levels could be kept to within acceptable limits. The same diagnostic applies when considering the effects of torsional vibration on motors. Ideas on how to cure the effect are also discussed in the paper.

Finally ,Plunkett and Plette [34] did a comparsion on the two basic type of A.C. motors; synchronous and induction. By presenting a chart(table), they compared the reliability, maintainability, cost, efficiency, etc., of the two types of motors. The authors also discussed the characteristics of each type of motor under the same application. One important distinction between synchronous and induction motors is that the former has a brake feature and the latter does not.

Other factors effecting crane/local control include different types of feedback. Feedback is the means by which the processor(computer) identifies the crane's position during its operation, so that required actions can be taken. Feedback signals can be classified as,

1. discrete feedback signal, and
2. continuous analog feddback signal.

Discrete feedback signals deals with strategically placing sensors at various points along the crane's path. Sensors of such type are usually photoelectric sensors which turn on as soon as a light source comes in contact with it

(sensor). Mcvey and Chen [28] presented a method which will improve the position detecting accuracy of optical signals. The output of each sensor is assumed to be 1 if illuminated by an amount equal to or greater than some threshold, and 0 otherwise. The speed of the moving object across the sensors, the spacings in between sensors, and the frequency and amplitude of the signals all have an impact of whether the siganl is received properly. Aylor, Parish and Cook [8] further extended the work so that optimum setting of the amplitude of the signal is achieved in an effort to improve the accuracy.

Analog feedback signals continuously update the relative position of the crane on the track. It is analogous to having a infinite array of discrete sensors situated side by side along the path. Dewan and Forsythe [13] presented an inducton method which will locate the position of a rotating shaft. An analog decoding scheme for determining explicitly the shaft's positon within a 360 degree range was discussed. Conditions necessary for the generation of shaft position information were stated and several error sources were introduced. However, error analysis was not included. The accuracy of this method will increase proportionally to cost and complexity of the system. With this method, linear position of the crane's position can be determined. Another

analog scheme used a potentiometer for measurement. Linear distance is converted into voltages, ranging in a certain value. The value is then transferred via an Analog to Digital Converter(ADC) and are immediately sent into the process controller. The accuracy depends on the ADC more so than any other devices.

Crane/local control evolves around both the characteristics of the motors and the types of feedback signals. The ability to successfully control the crane depends on the understanding of the problem areas, so that the best control for the crane can be achieved.

3.2 SYSTEM CONTROL

Since the birth of the ASR System, which dates back to the late 1950's, little published research has been done on the topic until the 1970's when material handling people realized the benefits that can be derived from it. Only then did papers dealing with the control and configuration of the ASR System began to surface.

With the advances in computer technology, more and better control can be achieved from the use of ASR System. Unit-load picking uses a computer controlled crane to store

or retrieve one unit-part into and out of the ASR System. With this development comes the analysis of the best possible ways to control the crane. Graves, Hausman, and Schwarz [16,20] analyzed the problem using a continuous analytical model on storage assignment rules for automated warehousing system that includes interleaving; the sequencing of storage and retrieve requests. In their paper, three assignment rules and two interleaving rules were studied. The three assignment rule includes: 1) Random Storage Assignment--every part has an equal chance of being stored in each open locations, 2) Class-based Storage Assignment--storage racks are partitioned into a small number of classes, with the highest turnover class closest to the I/O point, 3) Full Turnover-Based Storage Assignment --the highest turnover pallet is assigned to the location closest to the I/O point. The two interleaving rules include the Mandatory Interleaving Rule with FCFS discipline of retrieves and Mandatory Interleaving Rule with selection queue of K retrieves-where retrieves need not be FCFS with the first K retrieves. Results using combinations of the above rule were studied by the authors to develop the best rule for such a system. To prove the authenticity of the model, the authors [40] used a GASP IV simulation to compare the analytical results with that of the simulation. The result from the simulation proved that it

was not significantly different from that of the analytical result.

Witt [49] studies revealed that mandatory interleaving on FCFS was unpractical, when the storage location is very close to the I/O point and the retrieve part is far away from it. In the above case, if a FCFS rule is to be used, the author found it to be more pratical to return to the I/O point and start another store action, rather than retrieving that particular part.

Karason, Nakayama and Dohi [25] used a non-linear mixed integer program to arrive at an optimal solution which minimized the cost of the system with the highest efficiency of the function. The decision variables are the number of cranes, and the length and height of the system. From the model, the configuration and the number of cranes required for the system under certain input conditions can be found. The authors stress that the capability of the warehouse completely depends upon both the number of cranes and their speed. Therefore, more consideration should be made when deciding how many cranes of certain speed is required.

3.3 CHAPTER SUMMARY

The chapter illustrated two different areas of research contributed by researchers. The first deals with motor control, power, torque and feedback sensing. The second area deals with the system control such as the storage and retrieve of parts, the number fo cranes, etc.

Chapter IV

METHODOLOGY

Crane control of an ASR System includes a variety of different control variables. The obvious control variables include the crane speed and acceleration. Obviously, by increasing the levels of these variables, the crane performance will increase. The higher the level is, the better is the performance. However, on most occasions, these control variables are constrained by the horsepower within the motor and other constraints imposed by the design of the crane.

Everytime the crane carries out a task, travelling from one bin to another, work is performed. The amount of force used to drive the crane is directly related to the horsepower generated from the motor. The larger the horsepower in the motor, the greater the force exerted on the crane, thus shortening the acceleration time before a constant speed can be attained. However, the amount of force that can be exerted on the horizontal component of an stacker cart is constrained by two factors:

1) toppling (or instability) of the crane, and

2) friction between the fork and the load.

The only constraint acting on the vertical component of the stacker crane is the weight of the load and the fork it is resting on. Provided that the horsepower of the drive is large enough, the acceleration can go from 0 to g ($9.18 m/s^2$), without affecting the stability of the load on the fork.

The following paragraphs present a prototype example of a crane that can be used for such an operation. The limitations set forth are derived based on the design of this crane. However, these restrictions are evident on almost all all types of crane, and depending on the design may have some or little effect on the overall system.

4.1 TOPPLING OF THE CRANE

The movement of the crane along the horizontal component is generally controlled by a motor driving it. The crane could be driven directly by a motor and a collection of gears attached to the crane or be driven by a chain-drive mechanism. Either attachment will put the crane in a state of instability if it is to accelerate at a high rate. In this example, a motor sits at the end of the aisle, a gear is attached to the motor and resting on the gear is a chain with the other end of it mounted onto the base of the crane. By rotating the motor in either direction, the crane is

pulled along the horizontal component. In Figure 3, a schematic of the type of crane used for the model is shown where:

g = acceleration due to gravity

F = force pulling the crane in the positive direction

m = mass of the crane plus load

P = force pulling the crane in the negative direction

c = the center of gravity

a = constant acceleration of the crane

By having the moment about B and P=0,

$$mgd = Fh$$

Since,

$$F = ma$$

$$mgd = mah$$

$$a = gd/h$$

If F=0 and the moment is at A,

$$a = gb/h$$

Since b > d, F=mgd/h is the maximum force that can be exerted on the crane before it becomes unstable(tips).

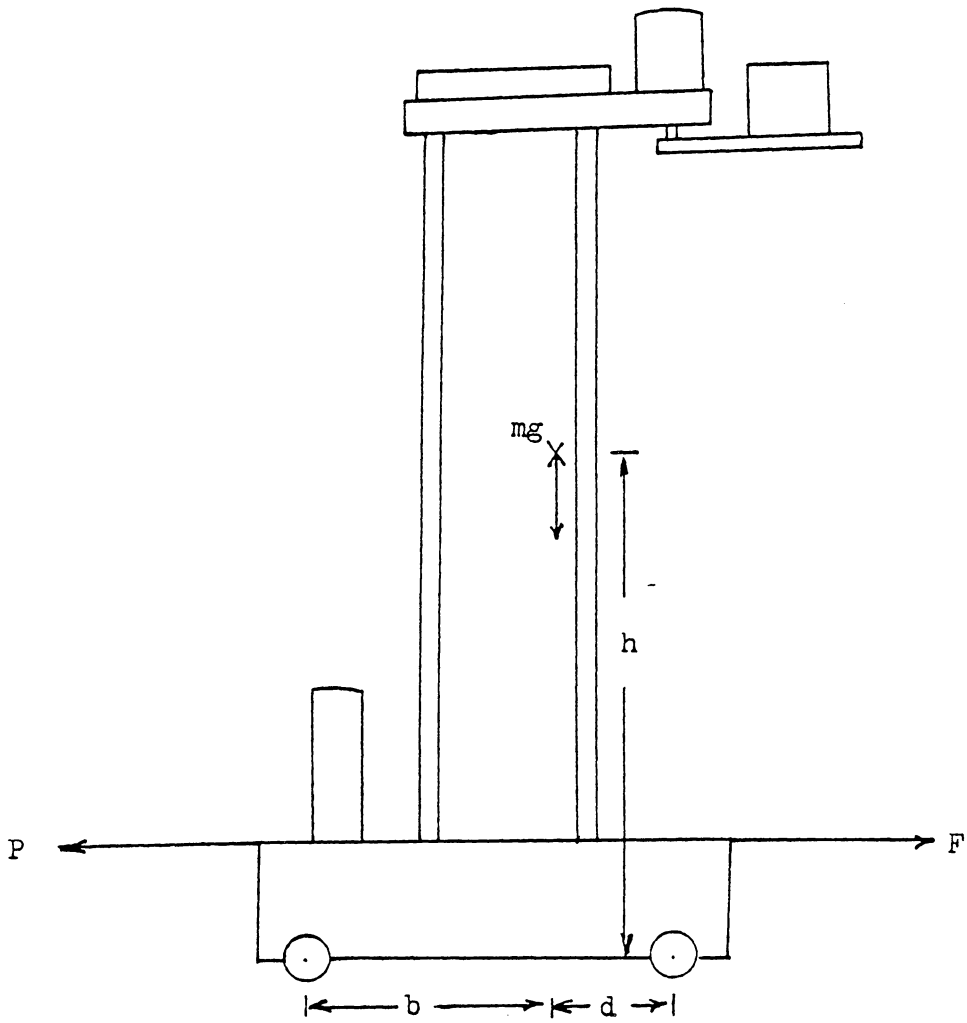

Figure 3: ASRS CRANE

4.2 FRICTION BETWEEN THE FORK AND THE LOAD

It is assumed that the load is not fastened to the fork by any fixtures other than by the weight of the load itself resting on the fork. Therefore, in order for the load to stay securely on the fork, the crane must be accelerating and decelerating at a rate such that,

$$a < Ug$$

where,

a = constant acceleration of the crane

U = coefficient of friction between fork and load

g = acceleration due to gravity

The minimum of the two accelerations is the active constraint for the force applied to the horizontal component motor during acceleration or deceleration. Since, power is equivalent to work done per unit time, the larger the power, the greater the force, and thus the acceleration rate. Conversly, motors of different horsepower can be placed on the vertical component to determine the correlation between acceleration and queue length.

4.3 DESIRED MAXIMUM VELOCITY

It is assumed that the crane will not continue to accelerate once it has attained a critical speed. From Newton's first law, the only force acting on the crane during this time is the frictional force between the crane and its track. Here,

$$F = mUg$$

and,

$$P = F.v$$

where,

F = force pulling the crane during constant speed

m = mass of crane and load

U = coefficient of friction of crane/track

g = acceleration due to gravity

P = power of the motor

With the amount of force required to drive the crane known, the maximum velocity of the crane becomes proportional to the horsepower of the motor. Thus the larger the horsepower

in the motor, the faster the crane can travel. However the effects of a higher maximum speed level and throughput may not affect the performance of the system as one might expect. Determining whether a critical speed exists where an increase in the speed level has little effect in reducing queue length needs to be investigated.

4.4 FEEDBACK

Feedback signals are essential for the dynamic control of the ASR System. However, the types of feedback signal that one may use raises the question as to which is superior. In the previous chapter, two types of feedback signals were discussed: 1) discrete feedback, and 2) continuous (analog) feedback. It is evident that by placing sensors at strategic points along the rack, a discrete sensing system, whose the operations would be less complex and less expensive, could be configured. However, this implies that deceleration and interrupt can only take place at discrete points along the track, whereas, such actions can take place at any point along the track for continuous sensing. In this respect, continuous sensing has an advantage over discrete sensing since it does not require waiting until a signal point is reached before decision(s) can be made. This im-

plies that the response to interrupt is quicker and therefore may have a performance edge over the discrete sensing system.

For the simulation model, three discrete sensors A, B and C are mounted at strategic locations in every bin. Since the accelerating and decelerating rate are the same, the sensors serve as a decision point where the motor should begin to decelerate. Figure 4, 5 and 6 shows how each discrete signal can serve as a decision point for the motor to decelerate so that it does not overshoot the bin. Figure 4 shows how signal B is employed for decelerating the crane for a one bin move. Figure 5 shows how signal A is employed for decelerating the crane for a two bin move. Finally, Figure 6 shows how signal C becomes a decision point for decelerating the crane once a constant velocity is reached. Given the constant speed of the crane, the position of signal C is calculated by the equations:

$$v^2 = u^2+2ax$$

Here,

v = 0 (final velocity of the crane)

u = constant speed

a = decelerating rate

x = distance travelled travelled during deceleration

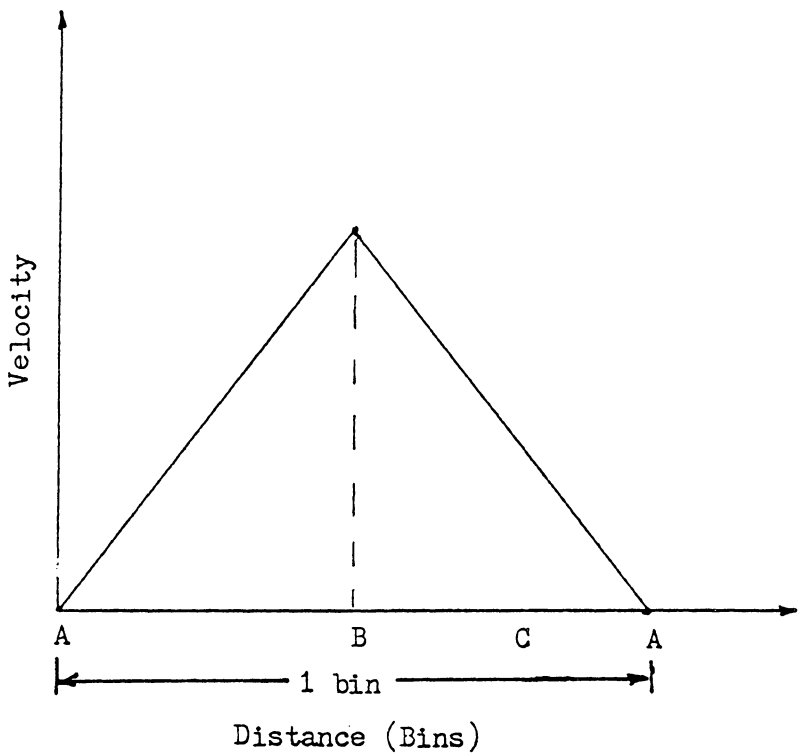

Figure 4: VELOCITY-DISTANCE PROFILE FOR ONE BIN DISTANCE

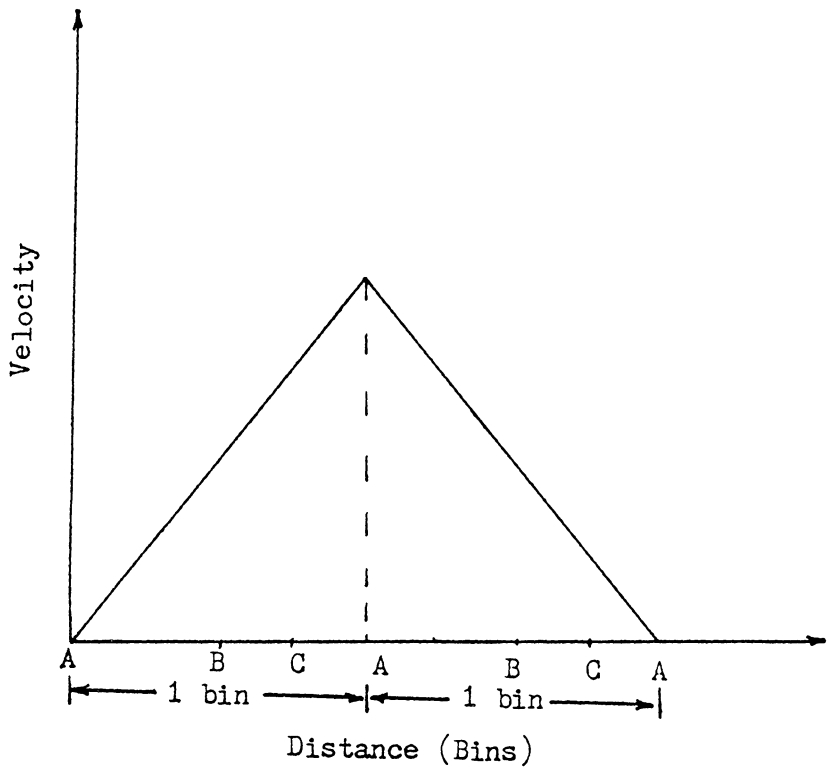

Figure 5: VELOCITY-DISTANCE PROFILE FOR TWO BIN DISTANCE

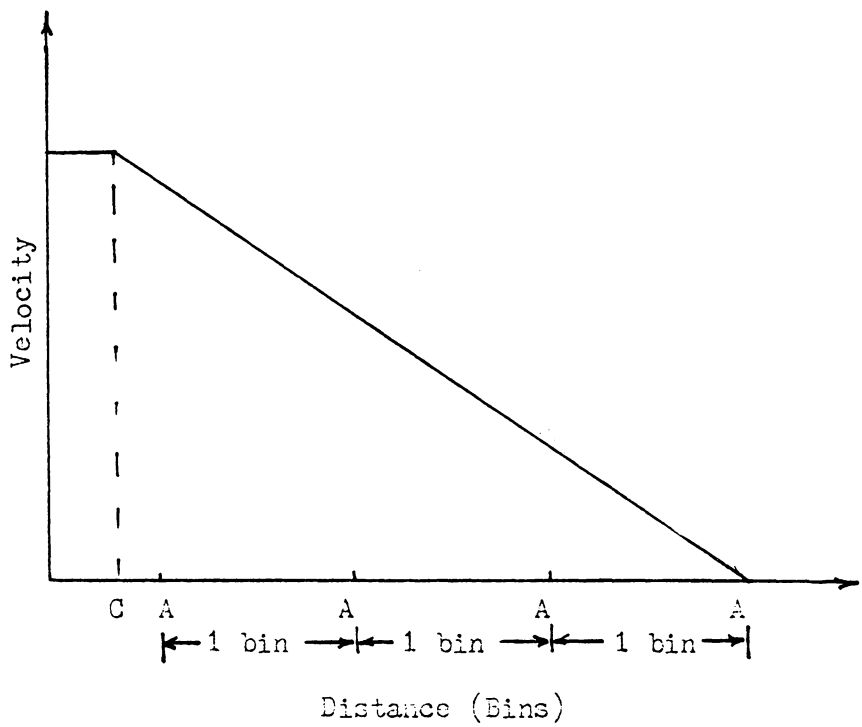

Figure 6: VELOCITY-DISTANCE PROFILE FOR THREE BIN DISTANCE

The position of signal C is found by moving back x units from where the desired stopping point is. It is possible to have only two sensors at each bin, provided that that the point to decelerate from a constant speed rest on signals A or B.

4.5 INTERRUPT

Interrupts are operations which have a higher priority over normal operations. In this model, interrupts are generated by the following conditions:

1) Type 1-The crane has just left the load/unload station to retrieve a part when a part arrives for storage.

2) Type 2-The crane is returning to the load/unload station preparing to store a part with its fork not carrying anything, when an order arrives for a part to be retrieved from the system.

Both these interrupt forces the crane to change its original command chain and switch to an interrupt command.

Normal operations will be interrupted only when there are no orders in the store file or the retrieve file. Fig-

ure 7 and 8 shows the velocity and distance-time context of two types of operation within a normal cycle where interrupts do not exist. In the figures,

L = loading time

S = travel to a bin to store a part

UL = unloading time

R1 = travel to a bin to retrieve a part

R2 = travel to the I/O point

Figure 7 shows the velocity and distance profiles of the crane storing a part in a bin. The crane then travels forward to another bin to retrieve another part. Once it has retrieved the part, the crane drives back to the load/unload station and drops the part off. Figure 8 shows the operation cycle when the retrieve part is on the opposite side of where a part is stored previously. Therefore, no movement is required by the crane other than rotating its fork to the other side of the aisle. Once the part is retrieved the crane automatically returns to the load/unload station where it unloads the part. For both occasions, the interrupts are not processed since there is always a part waiting to be stored and a part waiting to be retrieve in each file.

In type 1-interrupt, the time of arrival of the part must come when the crane has travelled less than 25 percent of the distance of the scheduled journey, before an inter-

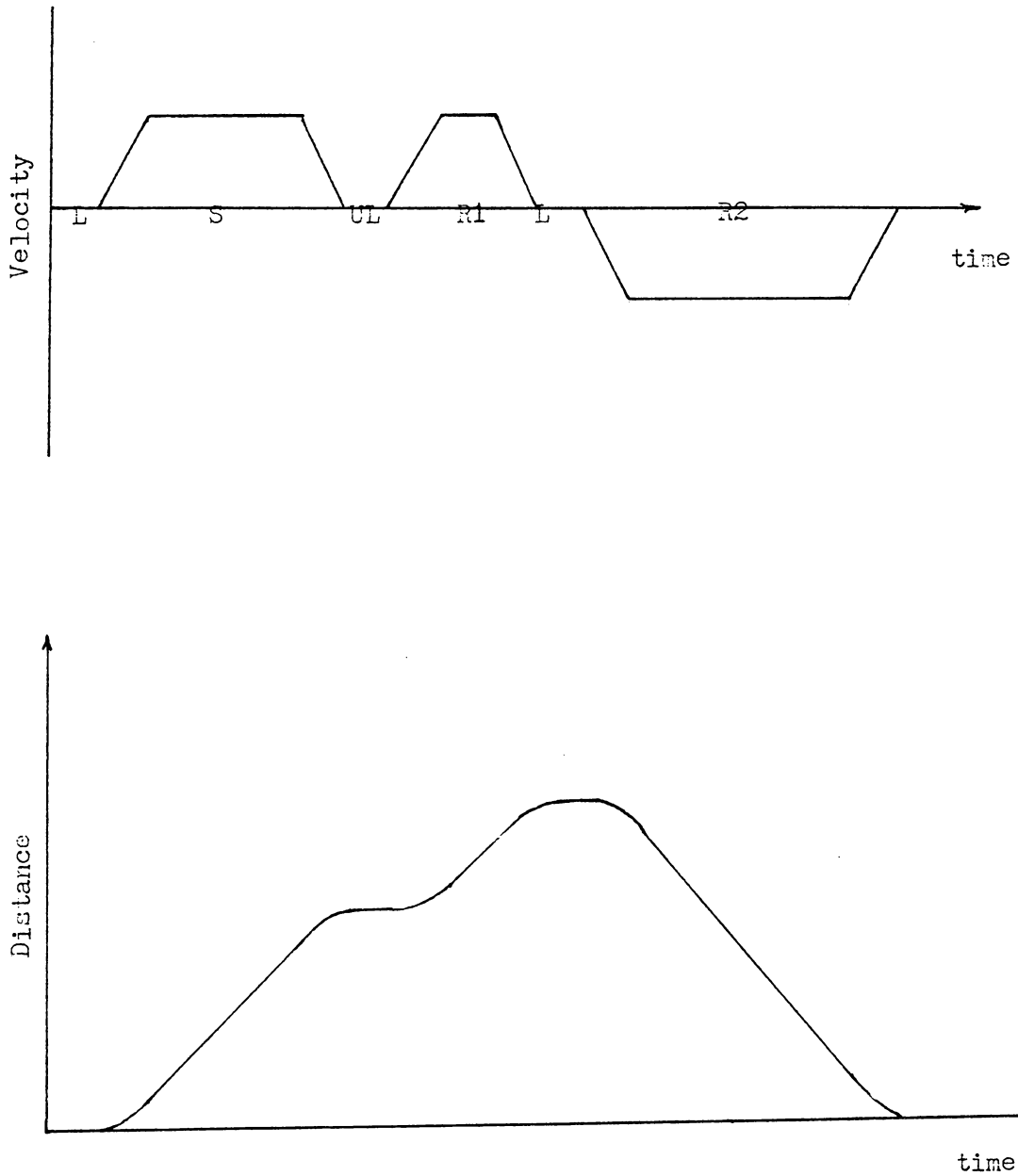

Figure 7: NORMAL OPERATION CYCLE

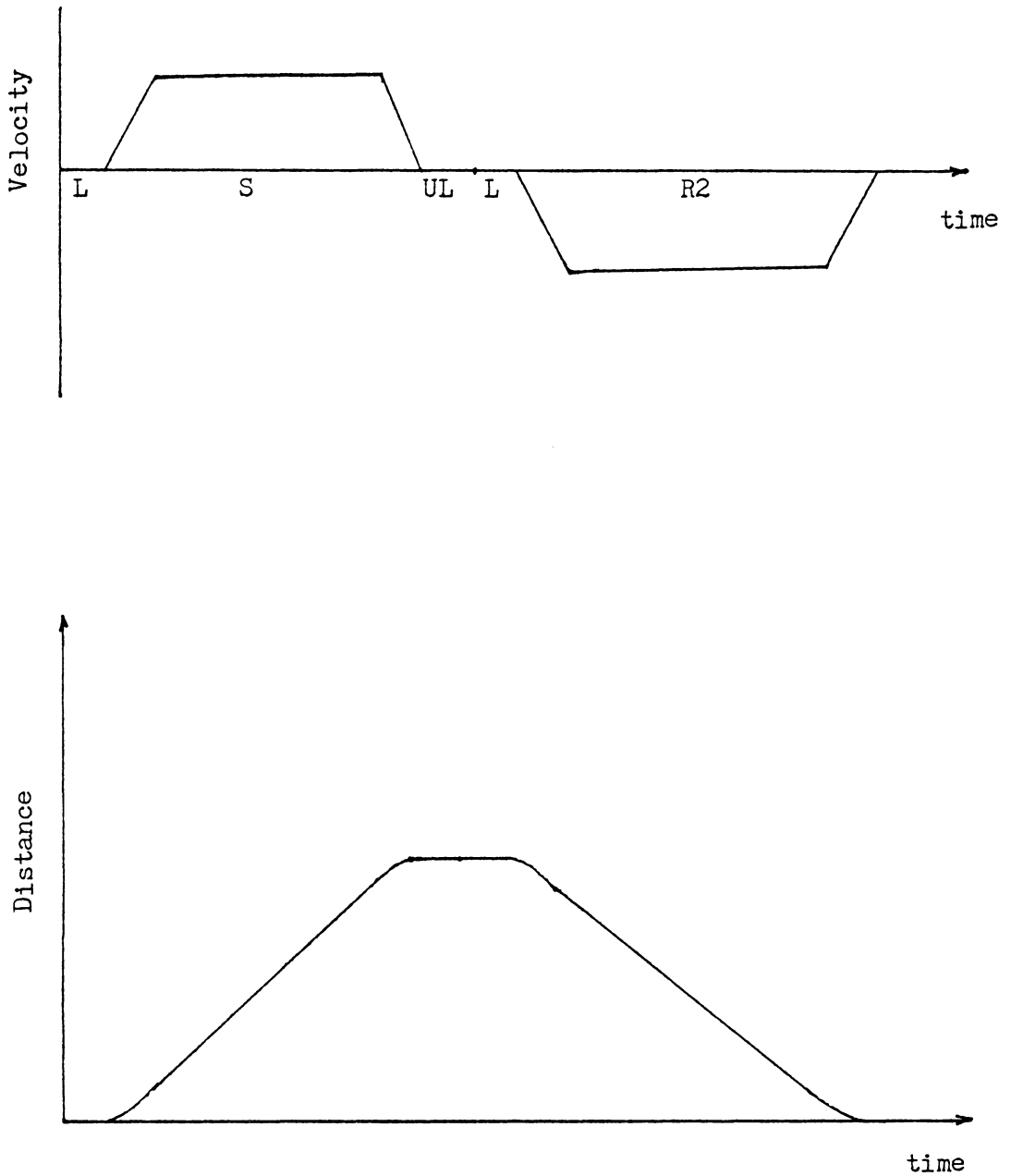

Figure 8: NORMAL OPERATION CYCLE WITH BINS OPPOSITE TO EACH OTHER

rupt can take place. If the part happens to arrive within this range, the crane is forced to turn back to the load/unload station to pick up the part and place it into the system. Figure 9 shows the sequence of operations that would occur in this cycle.

In the second case (type 2), a part demand (retrieval) may take place any time on the trip back to the load/unload station for the interrupt to be acknowledged, so long as the bin location of the interrupt command is closer to the load/unload station than the current location of the crane when the interrupt occurs. This implies that both the horizontal distance and the vertical distance must be less than that of the crane's present position (includes having enough distance to stop the crane). Should the bin location be further away from the load/unload station than the crane's current position, the interrupt will not be acknowledged, unless the crane has travelled less than 25 percent of its scheduled distance on both the horizontal and vertical component from where it started. For this instance, it is similar to case one (Figure 9) where the crane returns to the load/unload station except this time it searches for the bin location of the interrupt command. Figure 10 shows the two sequences of operation that would occur in this cycle.

Interrupts that are not acknowledged will be placed in their respective files and attended to during the normal cycle operation.

4.6 THE MODEL

The store and retrieve routines of the physical movement of the crane are modelled using a SLAM continuous model. The continuous model can include interrupts, which otherwise would be difficult to model in the system. In the program, three files were used to store the commands. File 1 is used to store part retrieval requests from the system. File 2 is used to store part store requests into the system, while file 3 is used to store the request for the crane to return to the load/unload stations for a type 1 interrupt condition. By processing requests commands in file 1, file 2, file 1, file 2, etc, interleaving rule with a FIFO discipline can be modelled. Figure 11 shows the logic behind the control of the system.

In the flowchart, the box "proceed with store/retrieve request" signifies that the crane took a DTFUL step size incrementing the simulated time for the model, which in turn changes the crane's current position. Before taking another step size, the program checks if there are any arrivals to

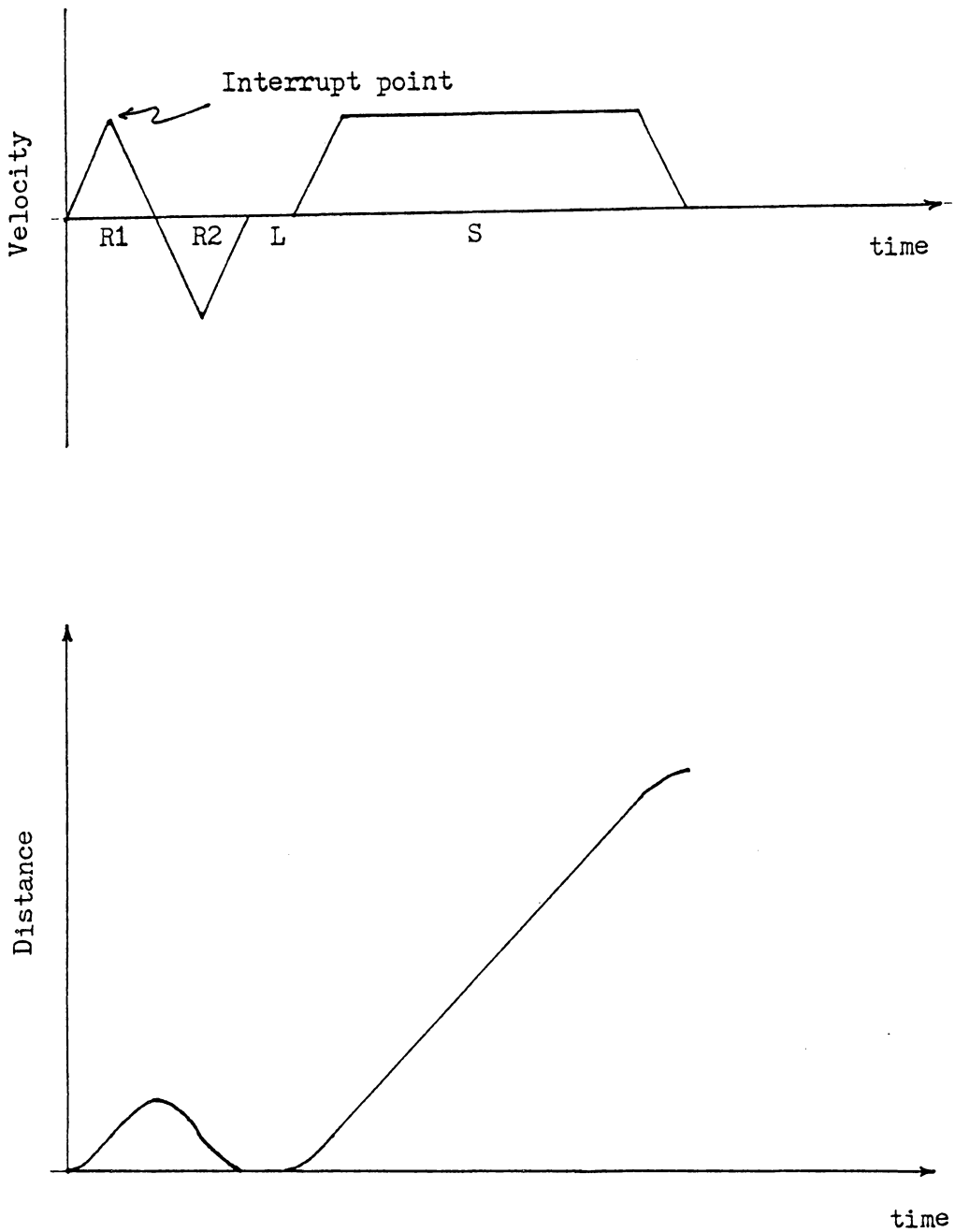

Figure 9: OPERATIONAL CHARACTERISTICS OF TYPE 1 INTERRUPT

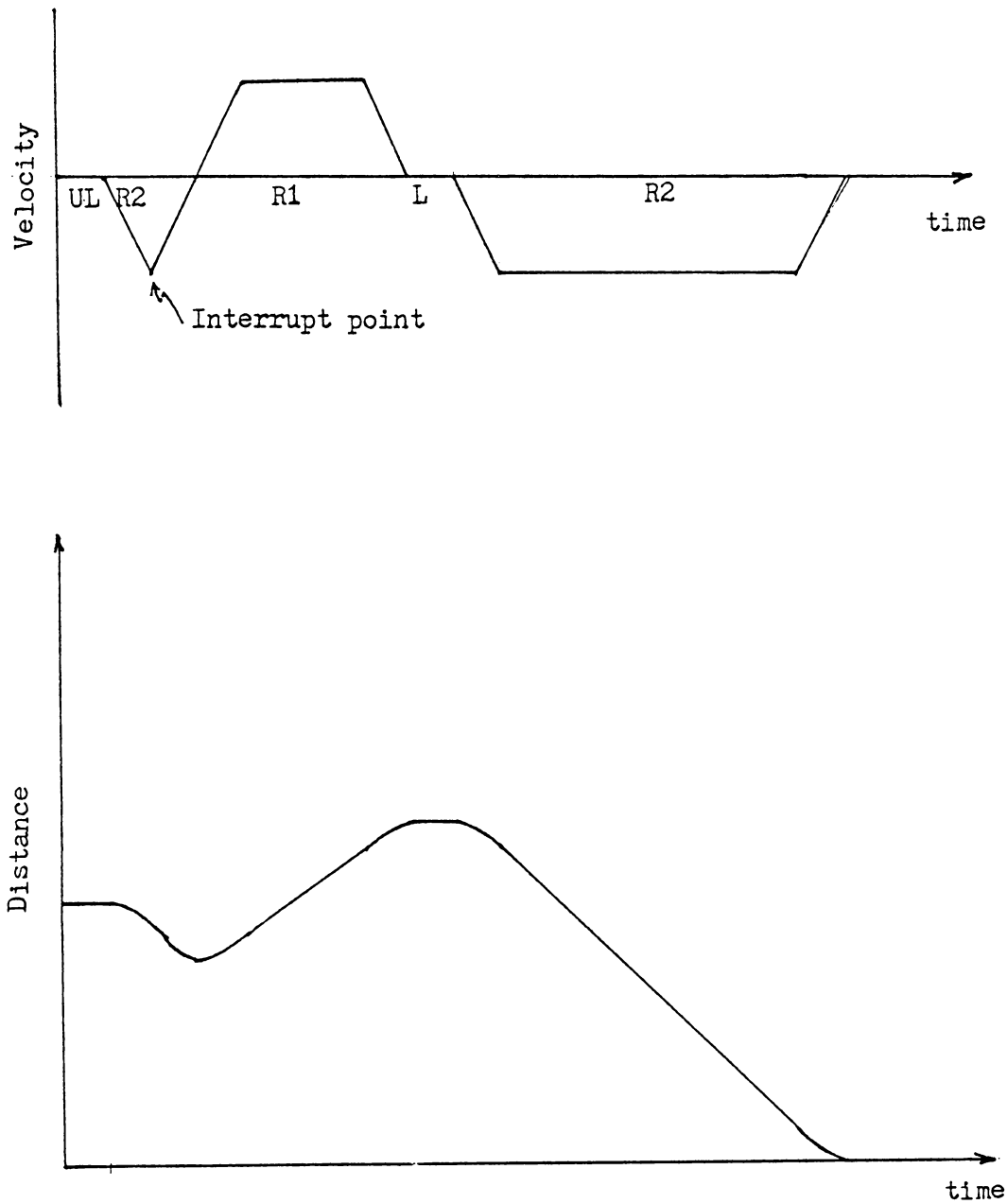

Figure 10: OPERATIONAL CHARACTERISTICS OF TYPE 2 INTERRUPT

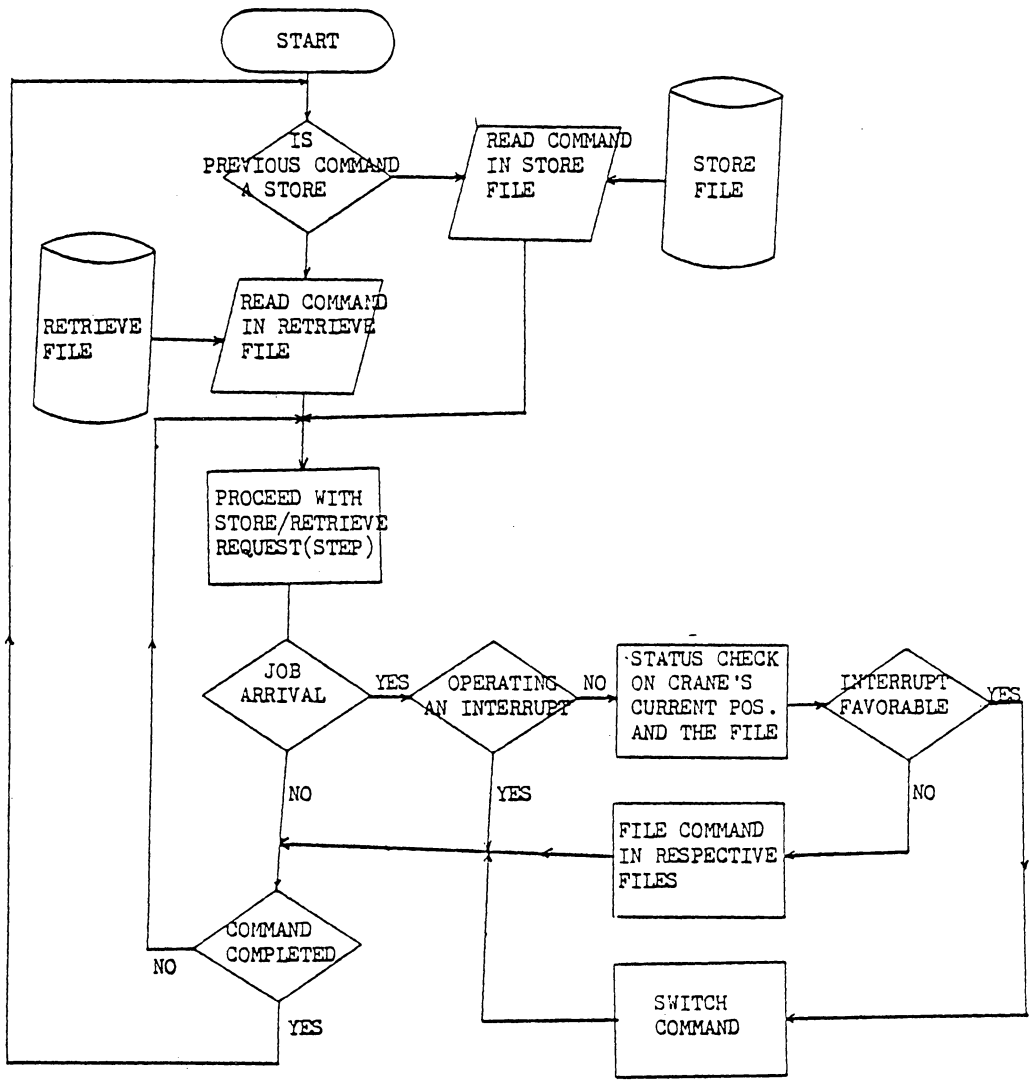

Figure 11: CONTROL LOGIC FLOWCHART

the system. If no part arrives to the system, it proceeds to increment the simulation time. On the other hand, if an arrival occurs, it checks if an interrupt is favorable. The criteria is based on the crane's current position and whether that particular file is empty. The command is switched if the conditions favor an interrupt, or the present command be filed on respective files if it did not favor an interrupt. The program allows only a single interrupt to be processed at one time.

For the system described above, numerous control variables can be included in the system. Table 1 shows a number of control variables which may be implemented. By varying the levels in some of these control variables, a desirable performance level may be found.

Acceleration/deceleration rates are constant in the system, except when processing an interrupt command. In the model, both these rates are assumed to be equivalent under operations of a normal cycle. Intuition suggests that the higher the rate, the shorter is the time required to service the job. The significance of its affecting the overall performance, however, is not known.

A higher maximum velocity will undoubtly decrease the service time of a perspective job. The faster the crane can travel, the less time is consumed by the crane in travelling from bin to bin.

TABLE 1

DESCRIPTION OF THE CONTROL CHARACTERISTICS

Control Variables	Description
1)Acceleration/deceleration effect (3 levels)	The rate of change of speed
2) Velocity effect (3 levels)	Maximum travelling speed
3)FIFO servicing routine for all request (store & retrieve)	Jobs are serviced according in a first come first serve rule
4)Interleaving with FIFO discipline	Jobs are sequentially serviced between the storage request and the retrieve request in a FIFO basis
5)Interleaving with modified FIFO discipline	Jobs are paired between the storage request and the retrieve request so distance between them are small and then serviced on interleaving FIFO discipline
6)Interleaving with FIFO discipline using interrupt	Crane maybe interrupted when it is not intermittingly servicing jobs between store and retrieve request and a job arrive for service
7) Interrupt with: a)Discrete, b)Continuous feedback	Types of feedback siganl that is employed for locating crane's current location
8)Interrupt with rush order	Jobs that require the immediate attention of the crane no matter what the system condition is.

In the case of FIFO service for all requests, the underlying concept is that the waiting time for all jobs will be shortened. However, the control strategy will be at a disadvantage should two jobs of the same type of routine (eg. store) arrive one after another.

According to Hausman [20] interleaving with FIFO discipline has an overall better performance over FIFO service for all requests. However, he did not consider the pairing of store & retrieval requests such that minimum distance is kept between them. Interleaving with a modified FIFO discipline is a control that looks at such a problem. The benefit derived from it is that time to travel from the store location to the retrieve location is shorten, thus less time is consumed. However, the question is how far back into the queue should the search terminate in locating an optimum pair.

Interrupts of the FIFO discipline may have an effect on system performance if the crane is not operating at 100 percent capacity. The conditions for an interrupt to sucessfully occur is that the crane has to have travelled less than 25 percent of its scheduled distance. The concept behind a critical limit of 25 percent is that if the crane should turn back, it has only travelled only 50 percent or less of its original scheduled distance before servicing a job.

The effect of discrete and continuous sensing may also play a role in improving system performance. As mentioned in the previous chapters, discrete sensing requires the crane be at a signal point before an interrupt can take place. This may very well mean that if the discrete signal happens to be slightly over 25 percent the crane scheduled distance, the interrupt will not occur.

A rush order routine may not be of any importance to the system if all jobs have an equal importance. However, should a rush order be requested, and the cost of that particular job waiting in queue is much higher than the rest of the others, it may be an advantage to stop all activities and service that job immediately.

Of the control characteristics described in Table 1, controls 3, 5 and 8 will not be included in this discussion. They relate to system control more so than the control of the crane itself. The rest are applied to two scenario to test their significance on system performance. The two conditions are:

1) Jobs arrive constantly over simulated period, and

2) Jobs arrive randomly over simulated period.

Each of the above conditions will be tested for a crane utilization rate at approximately 65, 80 and 90 percent to det-

ermine the effects of the control variables when confronted with high and low crane utilization rate.

4.7 CHAPTER SUMMARY

This chapter uses a physical model to present a general system, and the restrictions and limitations associated with it. The effect of these restrictions may not be so crucial for some crane types as to others, however, the effect is still present. Once the system has been defined, a control scheme is set up to simulated the actions of the physical system through the use of SLAM. The flowchart describes the logic behind the control of the system, and how interrupts are handled. Finally, a table is presented with a list of the control variables that may affect system performance. By varying these control variables, changes may be observed in the system.

Chapter V

EXPERIMENTAL DESIGN AND RESULTS

The experiment is performed by running combinations of different levels of control within the variables in the program. These include:

1) Acceleration rate,

2) Velocity,

3) Arrival Rate,

4) Constant or random arrival time, and

5) Discrete or continuous interrupt.

Both acceleration and velocity are seperated into three different levels -- a high, median and a low level. The high and low values are both 20 percent apart from that of the median level. The high is 120 percent of that of the median, while the low is only 80 percent of it. Table 2 shows the different levels of velocity and acceleration used for the experiment. In Table 2, the variables marked under X represents the values used on the horizontal component of the crane, and the ones under Y represents those used on the vertical component of the crane. Changes made to any level

must be accompanied by both the horizontal and vertical component values in that level.

The arrival rate is also categorized into three different levels. Jobs can arrive with an exponential interarrival time of mean 20, 23 and 28 seconds apart, or at constant rate. These rates should correspond to a crane utilization of approximately 90, 80 and 65 percent on both constant and random arrival, while running on median velocity rate and acceleration. The purpose is to investigate the effects of the control variables under high and low crane utilization.

5.1 THE EXPERIMENT

After the values of the variables have been defined, results concerning the queue length and crane utilization can be generated from the program. The structure of the approach to the experiment is shown in Figure 12 as a decision tree, with each control variable branching to another. A total of 5 levels can be employed in the tree. However only the first 4 levels needs to be defined for the program to generate any results. The fifth level is used when the system requires interrupts of either discrete or continuous sensing. Up to level IV, a total of 54 combinations can be examined. A complete enumeration would required 128 more combinations to

TABLE 2

VALUES ON THE VARIABLES USED

Description	High		Medium		Low	
	X	Y	X	Y	X	Y
Acceleration	4.2	3.2	3.5	2.5	2.8	1.8
Velocity	9.6	7.8	8.0	6.5	6.4	5.2

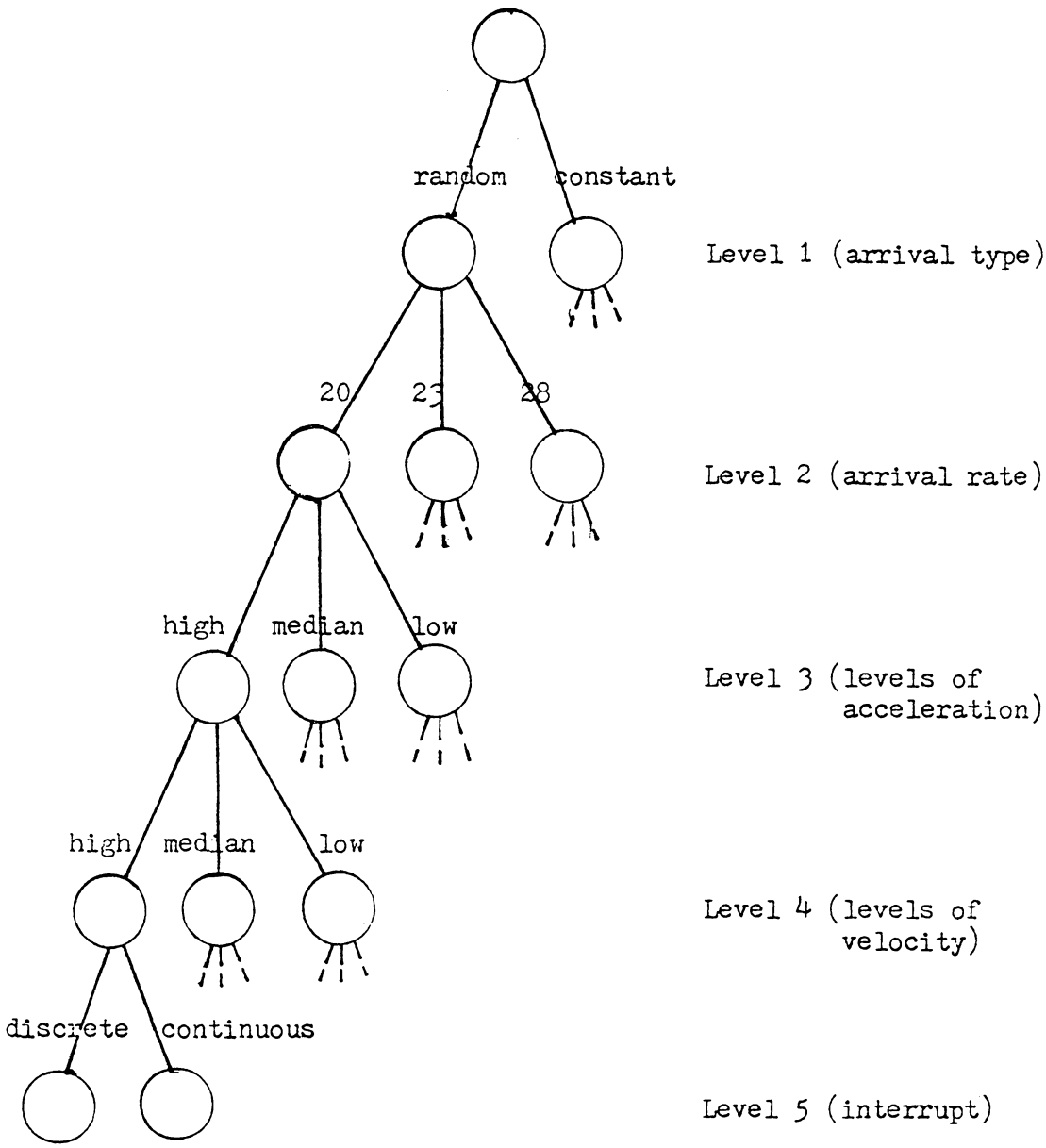

Figure 12: DECISION TREE ON CONTROL VARIABLES

complete the tree -- an expensive approach. Since values can be obtained at the fouth level, only the best results of two treatment combinations from each arrival rate of each type of arrival time (constant/random) undergo level V to determine if interrupt benefits such systems.

In order for the experiment to generate any meaningful results, 5 replications were run for each set of treatment combinations. Each replicate was ran for a 4 hour simulation time to ensure a steady state has been reached. This means for the 54 combinations, 270 runs needed to be made. Appendix C plots the queue length of each queue for each 100 seconds in the simulated time. The figure shows that variation in queue length decreases after the intial 2 hour of simulation and steady state is attained within the 4 hour simulation time.

For the experiment with no interrupts, the storage queue length and crane utilization are used to test treatment combinations. The retrieve queue length will not be tested, since stored jobs and retrieved jobs will be evenly distributed from the arrival distribution (reference chapter 2). However, in conditions where interrupt occurs, both queues need to be measured since a type I interrupt favors shorter store queues, while a type II interrupt favors shorter retrieve queues (reference chapter 4)

5.1.1 Results from Experiment 1

A Duncan multiple range test is performed to test the significance between each treatment combination of each arrival rate from the results derived from the 54 combinations of level IV of the tree. A tabular form of the description of each treatment combination is presented in Table 3. The test results of either the queue length or crane utilization of the three arrival rates at an alpha value of .05 are presented in Tables 4 throught 9. Tables 10-15 shows the same test with an alpha value of .1.

From the tables presented, it is evident that for a shorter queue length, constant arrival time at each of the arrival rates has an overall better queue performance than that of random arrival time for almost all treatment combinations. For low crane utilization, constant arrival time showed an overwhelming superority over random arrival time in terms of queue length performance, with its worst treatment combination (trt 18) having a shorter queue length over the best (highest velocity and acceleration) treatment combination (trt 5) in random time. However, during high crane utilization, high level of velocity and acceleration under random arrival time becomes does not significantly differ from the same level of velocity and acceleration under cons-

TABLE 3

DESCRIPTION OF TREATMENT COMBINATION

Treatment	Acceleration	Velocity	Arrival type
1	median	median	random
2	---- *	high	----
3	----	low	----
4	high	median	----
5	----	high	----
6	----	low	----
7	low	median	----
8	----	high	----
9	----	low	----
10	median	median	constant
11	----	high	----
12	----	low	----
13	high	median	----
14	----	high	----
15	----	low	----
16	low	median	----
17	----	high	----
18	----	low	----

* same variable as the previous

TABLE 4

TEST OF STORE QUEUE LENGTH AT 20 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.05 DF=72 MSE=.386276
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	3.3446	5	9	L	L	R
A						
B A	2.7016	5	3	M	L	R
B						
B	2.2769	5	6	H	L	R
B						
B C	1.8787	5	7	L	M	R
C						
D C	1.4226	5	8	L	H	R
D C						
D C E	1.3085	5	1	M	M	R
D C E						
D F C E	1.1573	5	18	L	L	C
D F C E						
G D F C E	1.0703	5	4	H	M	R
G D F E						
G D F E	0.8929	5	2	M	H	R
G D F E						
G D F E	0.6451	5	5	H	H	R
G D F E						
G D F E	0.5610	5	12	M	L	C
G D F E						
G D F E	0.5259	5	15	H	L	C
G F E						
G F E	0.4391	5	16	L	M	C
G F						
G F	0.2847	5	17	L	H	C
G F						
G F	0.2448	5	10	M	H	C
G						
G	0.2010	5	13	H	M	C
G						
G	0.1573	5	11	M	H	C
G						
G	0.1412	5	14	H	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 5

TEST OF STORE QUEUE LENGTH AT 23 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.05 DF=72 MSE=.0125332
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	1.4678	5	9	L	L	R
B	1.2201	5	3	M	L	R
C	0.9684	5	7	L	M	R
C C						
C	0.8927	5	6	H	L	R
D	0.6741	5	8	L	H	R
D						
D	0.6600	5	1	M	M	R
D						
E D	0.5633	5	4	H	M	R
E						
E F	0.4833	5	2	M	H	R
F						
F	0.3989	5	5	H	H	R
F						
G F	0.3487	5	18	L	L	C
G						
G H	0.2299	5	15	H	L	C
G H						
G H	0.2200	5	12	M	L	C
H						
H	0.1818	5	16	L	M	C
H						
H	0.1358	5	17	L	H	C
H						
H	0.1247	5	10	M	M	C
H						
H	0.1135	5	13	H	M	C
H						
H	0.1007	5	11	M	H	C
H						
H	0.0975	5	14	H	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 6

TEST OF STORE QUEUE LENGTH AT 28 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.05 DF=72 MSE=.00371
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	0.56746	5	9	L	L	R
B	0.48566	5	3	M	L	R
B						
B	0.47578	5	7	L	M	R
B						
C B	0.45046	5	6	H	L	R
C						
C D	0.37908	5	8	L	H	R
D						
E D	0.35928	5	1	M	M	R
E D						
E D F	0.30248	5	4	H	M	R
E F						
E F	0.28548	5	2	M	H	R
F						
F	0.26204	5	5	H	H	R
G	0.13148	5	18	L	L	C
G						
G	0.11086	5	15	H	L	C
G						
G	0.10792	5	12	M	L	C
G						
G	0.10260	5	16	L	M	C
G						
G	0.09350	5	17	L	H	C
G						
G	0.08584	5	10	M	M	C
G						
G	0.08354	5	13	H	M	C
G						
G	0.08000	5	14	H	H	C
G						
G	0.07820	5	11	M	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 7

TEST OF CRANE UTILIZATION AT 20 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.05 DF=72 MSE=1.60007
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	99.828	5	18	L	L	C
B	97.760	5	12	M	L	C
B						
B	97.418	5	15	H	L	C
B						
B	96.910	5	16	L	M	C
B						
B	96.534	5	9	L	L	R
C	94.694	5	3	M	L	R
C						
C	93.800	5	17	L	H	C
D	92.040	5	6	H	L	R
D						
D	92.012	5	7	L	M	R
D						
D	90.728	5	10	M	M	C
E	88.504	5	8	L	H	R
E						
E	88.262	5	1	M	M	R
E						
E	88.086	5	13	H	M	C
F	85.514	5	4	H	M	R
F						
G F	84.888	5	11	M	H	C
G						
G H	83.434	5	2	M	H	R
H						
H	82.216	5	14	H	H	C
I	80.576	5	5	H	H	R

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 8

TEST OF CRANE UTILIZATION AT 23 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.05 DF=72 MSE=1.57207
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING		MEAN	N	TRT	ACC.	VEL.	ARR.
	A	94.252	5	18	L	L	C
	B	89.054	5	9	L	L	R
	B						
C	B	88.418	5	12	M	L	C
C	B						
C	B D	87.916	5	15	H	L	C
C	D						
C	D	86.810	5	3	M	L	R
	D						
	D	86.520	5	16	L	M	C
	E	83.958	5	6	H	L	R
	E						
F	E	82.516	5	7	L	M	R
F							
F		82.082	5	17	L	H	C
	G	79.440	5	8	L	H	R
	G						
	G	79.246	5	1	M	M	R
	G						
	G	79.114	5	10	M	M	C
	H	76.436	5	4	H	M	R
	H						
I	H	75.844	5	13	H	M	C
I							
I	J	74.294	5	2	M	H	R
	J						
	J	74.010	5	11	M	H	C
	K	71.614	5	14	H	H	C
	K						
	K	70.292	5	5	H	H	R

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 9

TEST OF CRANE UTILIZATION AT 28 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.05 DF=72 MSE=5.36977
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	78.486	5	18	L	L	C
A						
B A	76.474	5	9	L	L	R
B						
B C	73.952	5	3	M	L	R
C						
D C	72.670	5	12	M	L	C
D C						
D C	72.648	5	15	H	L	C
D C						
D C	72.036	5	6	H	L	R
D C						
D C	71.326	5	16	L	M	C
D						
D	70.580	5	7	L	M	R
E	67.630	5	17	L	H	C
E						
E	67.318	5	8	L	H	R
E						
E	66.838	5	1	M	M	R
E						
F E	64.790	5	10	M	M	C
F						
F	63.752	5	4	H	M	R
F						
F G	62.442	5	13	H	M	C
F G						
F G H	62.094	5	2	M	H	R
G H						
I G H	60.362	5	11	M	H	C
I H						
I H	59.158	5	5	H	H	R
I						
I	58.874	5	14	H	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 10

TEST OF STORE QUEUE LENGTH AT 20 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.1 DF=72 MSE=.386276
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING			MEAN	N	TRT	ACC.	VEL.	ARR.
A			3.3446	5	9	L	L	R
A								
B A			2.7016	5	3	M	L	R
B								
B C			2.2769	5	6	H	L	R
C								
D C			1.8787	5	7	L	M	R
D								
D E			1.4226	5	8	L	H	R
D E								
D E	F		1.3085	5	1	M	M	R
E	F							
G E	F		1.1573	5	18	L	L	C
G E	F							
G E	F		1.0703	5	4	H	M	R
G E	F							
G H E	F		0.8929	5	2	M	H	R
G H	F							
G H	F		0.6451	5	5	H	H	R
G H								
G H			0.5610	5	12	M	L	C
G H								
G H			0.5259	5	15	H	L	C
G H								
G H			0.4391	5	16	L	M	C
H								
H			0.2847	5	17	L	H	C
H								
H			0.2448	5	10	M	M	C
H								
H			0.2010	5	13	H	M	C
H								
H			0.1573	5	11	M	H	C
H								
H			0.1412	5	14	H	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 11

TEST OF STORE QUEUE LENGTH AT 23 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.1 DF=72 MSE=.0125332
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	1.4678	5	9	L	L	R
B	1.2201	5	3	M	L	R
C	0.9684	5	7	L	M	R
C C						
C	0.8927	5	6	H	L	R
D	0.6741	5	8	L	H	R
D						
D	0.6600	5	1	M	M	R
D						
E D	0.5633	5	4	H	M	R
E						
E F	0.4833	5	2	M	H	R
F						
G F	0.3989	5	5	H	H	R
G						
G	0.3487	5	18	L	L	C
H	0.2299	5	15	H	L	C
H						
H	0.2200	5	12	M	L	C
H						
H	0.1818	5	16	L	M	C
H						
H	0.1358	5	17	L	H	C
H						
H	0.1247	5	10	M	M	C
H						
H	0.1135	5	13	H	M	C
H						
H	0.1007	5	11	M	H	C
H						
H	0.0975	5	14	H	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 12

TEST OF STORE QUEUE LENGTH AT 28 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.1 DF=72 MSE=.00371
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	0.56746	5	9	L	L	R
B	0.48566	5	3	M	L	R
B						
B	0.47578	5	7	L	M	R
B						
B	0.45046	5	6	H	L	R
C	0.37908	5	8	L	H	R
C						
D C	0.35928	5	1	M	M	R
D						
D E	0.30248	5	4	H	M	R
E						
E	0.28548	5	2	M	H	R
E						
E	0.26204	5	5	H	H	R
F	0.13148	5	18	L	L	C
F						
F	0.11086	5	15	H	L	C
F						
F	0.10792	5	12	M	L	C
F						
F	0.10260	5	16	L	M	C
F						
F	0.09350	5	17	L	H	C
F						
F	0.08584	5	10	M	M	C
F						
F	0.08354	5	13	H	M	C
F						
F	0.08000	5	14	H	H	C
F						
F	0.07820	5	11	M	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 13

TEST OF CRANE UTILIZATION AT 20 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.1 DF=72 MSE=1.60007
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	99.828	5	18	L	L	C
B	97.760	5	12	M	L	C
B						
B	97.418	5	15	H	L	C
B						
B	96.910	5	16	L	M	C
B						
B	96.534	5	9	L	L	R
C	94.694	5	3	M	L	R
C						
C	93.800	5	17	L	H	C
D	92.040	5	6	H	L	R
D						
D	92.012	5	7	L	M	R
D						
D	90.728	5	10	M	M	C
E	88.504	5	8	L	H	R
E						
E	88.262	5	1	M	M	R
E						
E	88.086	5	13	H	M	C
F	85.514	5	4	H	M	R
F						
F	84.888	5	11	M	H	C
G	83.434	5	2	M	H	R
G						
G	82.216	5	14	H	H	C
H	80.576	5	5	H	H	R

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 14

TEST OF CRANE UTILIZATION AT 23 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.1 DF=72 MSE=1.57207
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TRT	ACC.	VEL.	ARR.
A	94.252	5	18	L	L	C
B	89.054	5	9	L	L	R
B						
B	88.418	5	12	M	L	C
B						
C B	87.916	5	15	M	L	C
C						
C	86.810	5	3	M	L	R
C						
C	86.520	5	16	L	M	C
D	83.958	5	6	H	L	R
E	82.516	5	7	L	M	R
E						
E	82.082	5	17	L	H	C
F	79.440	5	8	L	H	R
F						
F	79.246	5	1	M	M	R
F						
F	79.114	5	10	M	M	C
G	76.436	5	4	H	M	R
G						
G	75.844	5	13	H	M	C
H	74.294	5	2	M	H	R
H						
H	74.010	5	11	M	H	C
I	71.614	5	14	H	H	C
J	70.292	5	5	H	H	R

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

TABLE 15

TEST OF CRANE UTILIZATION AT 28 SEC. BETWEEN ARRIVALS

DUNCAN'S TEST WITH ALPHA=.1 DF=72 MSE=5.36977
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING			MEAN	N	TRT	ACC.	VEL.	ARR.
	A		78.486	5	18	L	L	C
	A							
	A		76.474	5	9	L	L	R
	B		73.952	5	3	M	L	R
	B							
C	B		72.670	5	12	M	L	C
C	B							
C	B		72.648	5	15	H	L	C
C	B							
C	B		72.036	5	6	H	L	R
C	B							
C	B		71.326	5	16	L	M	C
C								
C			70.580	5	7	L	M	R
	D		67.630	5	17	L	H	C
	D							
E	D		67.318	5	8	L	H	R
E	D							
E	D		66.838	5	1	M	M	R
E								
E	F		64.790	5	10	M	M	C
	F							
G	F		63.752	5	4	H	M	R
G	F							
G	F	H	62.442	5	13	H	M	C
G		H						
G		H	62.094	5	2	M	H	R
		H						
	I	H	60.362	5	11	M	H	C
	I							
	I		59.158	5	5	H	H	R
	I							
	I		58.874	5	14	H	H	C

* H = high level M = median level L = low level
R = random arrival time C = constant arrival time

tant arrival time. The high density in work load has made some treatment combinations (especially low acceleration and velocity) more suceptable to a greater change in queue length than others. A comparison of the tables show that the percentage difference between treatments 5 and 9, and treatments 14 and 18 widening its margin between each other as more jobs arrive to the system. The widening of the test margin in the Duncan test has led some treatment combinations under random arrival time (trt 5 & 2) insignificantly different from that of the constant arrival time. It is obvious that the higher the crane utilization, a 20 percent increase in crane speed or accleration would promote much greater gain in shortening queue length. Figure 13 shows how the rate of increase in queue length between treatment combinations 5 and 9 diverges from each other as the arrival rate increases.

As for the crane utilization, the results between random arrival time and constant arrival time of the same treatment (same velocity and acceleration) becomes significantly different when both values of crane utilization goes beyond 80 percent. The drop in the value (crane utilization) under random time has made it more siginficantly different from

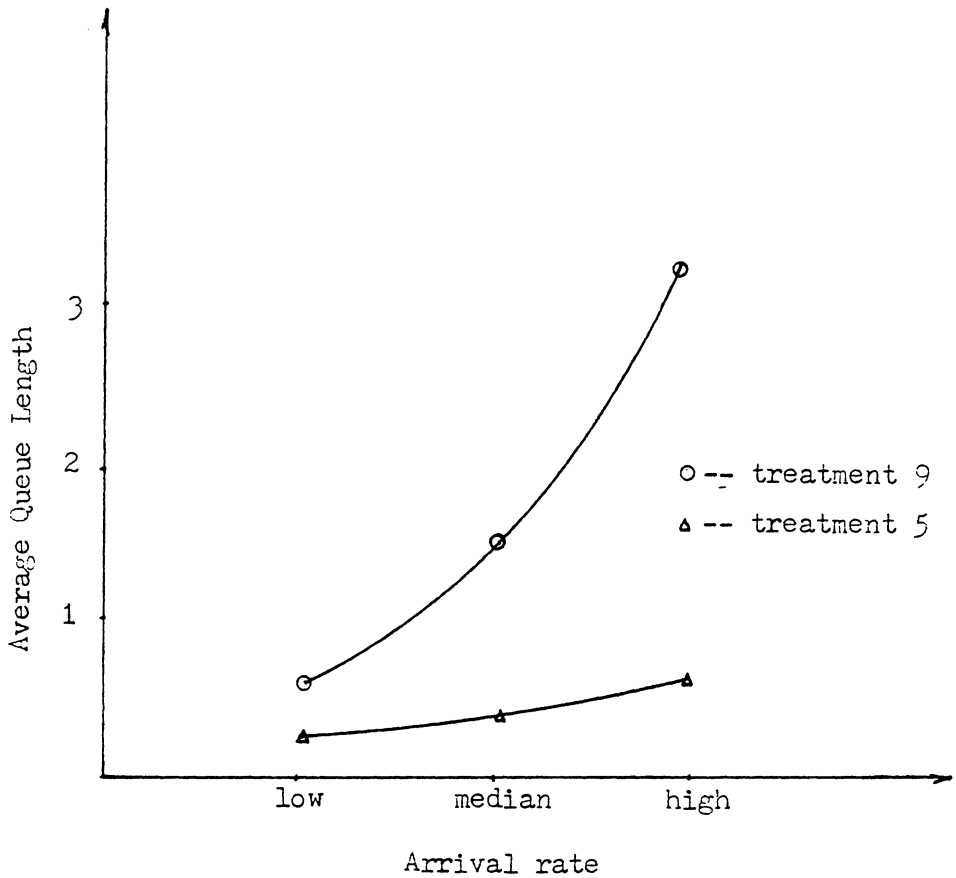

Figure 13: COMPARSION OF DIFFERENT TREATMENT UNDER HIGH AND LOW CRANE OPERATION

that of constant time if an alpha value of .05. The same is true when larger values of alpha is used. The inconsistency of the job arrival within random arrival time have caused this effect.

The tables indicate that the effect of an increase in either acceleration or velocity will significantly reduce the queue length at higher crane utilization (approxiamtely 80-99%). In addition, the crane utilization becomes significantly lower for random arrival time than that of constant arrival time during high crane utilization. All this point to the fact that the effects of changes to the control variables and the nature of job arrivals only becomes significant at high crane utilization.

To pursue the problem even further, the effects between different levels of acceleration versus velocity arises. In the simulation model, the number of bins passed before maximum velocity is attained (median level of acceleration and velocity -- treatment 1) approaches 2 1/4 bins on the horizontal component of the storage system. It is conceived that if most travel required less than a 4-5 bin distance, acceleration alone becomes an important factor in shortening travel time since most travel would not travel under maximum velocity rate. However, if the average travel distance becomes farther than 5 bin distance, the effects of both maximum velocity limit and acceleration becomes important.

The number of bins travelled for each treatment combinations in the experiment before the crane reaches maximum speed is listed in Table 16. The values ranges from a little above 1 bin distance travelled to over a 4 bin distance. On the average, for a 25 x 15 ASR System; the crane average travel distance (estimated from the load/unload station to the middle of the ASR System) approaches 13 bins (25/2) on the horizontal component and 8 bins (15/2) on the vertical component. Table 17 shows the ratio of queue length, by comparing either a 20% decrease in velocity or a 20% decrease in acceleration for treatments 2, 4 and 5 grouping (a 20% reduction in either velocity or acceleration from treatment 5) and a 1, 2 and 8 grouping (a 20% reduction in either velocity or acceleration form treatment 2). The results suggested that the percentage reduction in acceleration between treatment 5 and 2 (with same velocity but 20% reduction in acceleration) has a lesser effect in reducing the queue length of the system than treatment 5 and 4 (with same acceleration but 20% reduction in velocity) Contrary, the percentage reduction between treatment 2 and 8 (same velocity but different acceleration) has a greater effect on the system than treatment 1 and 2 (same acceleration but different velocity). By referring to Table 16, and the average travelling distance of the crane, maximum velocity is almost

never attained on the vertical component before it starts to decelerate again, while on the average approximately 1/3 of the distance travels on maximum speed on the horizontal component for treatment 8. The great length in time and distance before the crane reaches maximum velocity, causes acceleration to have more effect on queue performance than velocity. The reverse is true for treatment grouping 2, 4, 5. Here velocity contributes more in reducing queue length. In this situation, the number of bin distance is slightly above 3 (unlike the other grouping where the value is above 4). For such a system (25 x 15 bin), it appears that the critical value between which an equal percentage decrease in either velocity or acceleration having an equal effect on the percentage reduction in queue length lies between the region of an acceleration range of approximately 3 to 4 bin distance.

The same is true for constant arrival times. The critical region rests between 3 to 4 bin distance, since only the manner in which job arrives are different.

From this analysis, it appears that an equal percent change in acceleration has greater effect in reducing queue length more so than that of velocity, when the value of the velocity is very much larger than that of acceleration

(grouping 1, 2 and 8). However, the effect to queue length also relys on the size of the ASR System as well as how the ASR System is layout (square or rectangular). For the experiment (2, 4 and 5 grouping), when the distance travelled under maximum velocity (9 bins) for treatment 5 is above that travelled under acceleration/deceleration (6 bins) on the horizontal component, an reduction in velocity affects the queue length more than a reduction in the acceleration rate. The results does not matter even if the distance travelled on the vertical component for the same treatment under maximum velocity (2 bins) is lower than that travelled (6 bins) under acceleration rate. However, if the storage system were to be smaller (eg. 20 x 15 bins), average distance travelled under maximum velocity will be reduce to 4 bins while the number of bins travelled under acceleration rate remains the same. The effects of a change in velocity would be opposite than if the storage area is 25 x 15 bins. On the other hand, if the storage area is larger (eg. 35 x 22 bins), an increase in velocity becomes much more important to shortening queue length. In addition, for a rectangular ASR System, an equal percentage increase in both component in velocity may not help shorten the queue length because on one component, the increase may be advantage to the combination between velocity and acceleration while it may be a disad-

vantage -- more distance travelled under acceleration rate than under maximum velocity. Therefore, the rule of thumb is to make acceleration as high as possible when compared with velocity.

5.1.2 Results from Experiment 2

In an effort to improve queue length performance, as well as crane utilization for both types of arrivals, an interrupt of crane service was perceived as an alternative to improve performance. The conditions of an interrupt occurance was discussed in Chapter 4. The critical value for which an interrupt to occur is set before the crane has travelled 25 percent of its scheduled distance. An additional experiment which has a critical value of .35 is also performed to determine if distance is the factor which enhances better performance. The interrupt data of treatment 2,5,11 and 14 are listed in Appendix B, which shows the number of sucessful interrupts and attempts made on both type I and type II interrupt. The results show no more than 2 percent of the jobs actually got service through interrupts under random arrival times, while those under constant arrival times hardly got service. Intuitively, from this outcome, interrupts should not and would not affect the system signi-

TABLE 16

NUMBER OF BINS PASSED BEFORE MAXIMUM VELOCITY IS ATTAINED

Treatment	Horizontal Component	Vertical Component
1	2.25	2.10
2	3.29	3.04
3	1.46	1.35
4	1.90	1.65
5	2.74	2.37
6	1.20	1.12
7	2.15	2.93
8	4.11	4.23
9	1.82	1.87

TABLE 17

RATIO CHANGE IN QUEUE LENGTH WITH A 20 % DROP IN EITHER VELOCITY OR ACCELERAION

Arrival rate	Trt 5/Trt 2	Trt 5/Trt 4
28	91.78%	86.63%
23	82.53%	70.80%
20	72.24%	60.27%

Arrival rate	Trt 2/Trt 8	Trt 2/Trt 1
28	75.30%	79.40%
23	71.69%	73.22%
20	61.89%	68.23%

Treatment 1 -- median acceleration, median velocity
Treatment 2 -- median acceleration, high velocity
Treatment 4 -- high acceelration, median velocity
Treatment 5 -- high acceleration, high velocity
Treatment 8 -- low acceleration, high velocity

* all treatments are of random arrival time

ficantly. Following this intuition, if interrupts are only a small portion of the total number of jòbs that are serviced, the use of discrete or continuous sensing should not affect the outcome of system performance drastically. To support the claim, a SAS model was constructed to determine if discrete and continuous interrupts and operations without interrupts under each arrival rate are significantly different. Test were not performed with constant arrival times since there is hardly an interrupt occurance, and for a steady state system, the results should not be significantly different. Table 18 shows the results of the F value and the PR < F (alpha value) value for the test under critical value of .25 of distance scheduled to travel. All of the results show that an alpha value of at least .5 is required to fully justify that the results are significantly different. However, this implies that the test have a 50 percent chance of making a mistake. A few exceptions existed where the PR >F value went below .5, however, variation within the data may have caused this.

In order to justify whether distance is the factor governing improvment in performance, a SAS model test the difference between the results of treatment 2 with no interrupt and one with a 35 percent critical value on interrupt. The alpha value from this test is generally is generally lower

than that with a critical value of .25. Although there is a slight increase in the number of interrupts (Appendix B) it hovers around only 3 percent of the jobs that arrives to the system. Therefore, it is possible that variation among data may have caused the increase in confidence rather than by the effects of the interrupt. Longer critical distance are not tested, since for a 50 percent critical value, the crane will use the same amount of travel time servicing the interrupt than if it had iqnored it.

5.2 CHAPTER SUMMARY

This chapter is intended to identify the variables used for the program and some of the values used in the experiment. It also outlines the procedure of why and how the testing are performed and presents its results in table form. Although, no conclusion were drawn, speculations about the results are discussed.

TABLE 18

SAS RESULTS BETWEEN INTERRUPT AND NON-INTERUPT

TYPE	ARRIVAL RATE						TEST ON TREATMENT COMBINATION
	20		23		28		
	F	PR>F	F	PR>F	F	PR>F	
STORAGE	.01	.9856	1.19	.3389	.60	.5637	TREATMENT 2 WITH A .25 CRITICAL VALUE
RETRIEVE	.20	.8187	.62	.5556	.93	.4200	
UTILIZ.	1.07	.3731	1.51	.2597	.47	.6363	
STORAGE	.12	.8909	.02	.9767	.12	.8903	TREATMENT 5 WITH A .25 CRITICAL VALUE
RETRIEVE	.27	.7685	.53	.6010	.54	.5941	
UTILIZ	.15	.8647	.10	.9068	.22	.8082	
STORAGE	.38	.5543	.00	.9905	.65	.4433	TREATMENT 2 WITH A .35 CRITICAL VALUE
RETRIEVE	1.74	.2237	1.88	.2078	.85	.3841	
UTILIZ	1.26	.2940	1.92	.2031	.93	.3641	

Chapter VI

CONCLUSION

The findings uncovered from this research provide qualitative results which largely depend on the assumptions and the levels of velocity and acceleration used. The size and the shape of the ASR System affects the outcome as well. The following is a list of findings from this research.

1) The effect of an increase in speed or acceleration decreases queue length. The rate at which the queue decreases improve as the crane utilization gets higher.

2) An increase in velocity alone may not always be as effective in reducing queue length, as an equal percentage increase in its acceleration. The marginal difference between the acceleration and speed, the shape and size of the system all affect the outcome.

3) Crane's operation under random arrival times is significantly lower than that of constant times at high job arrival rate.

4) Effects of discrete signal and continuous signal sensing do not significantly affect the performance of this system.

5) Interrupts has no significant effect on system performance.

6) Interrupt decision policy (distance travelled) does not produces a significantly greater number of interrupts. In fact, performance measures are not significantly different from that of a non-interrupt criteria.

The above findings are based on the assumptions described in Chapter 2. Any variations of the assumptions may change the outcome of the research.

6.1 RECOMMENDATIONS FOR FUTURE RESEARCH

In experiment 1, an accelerating range for which an equal percentage change in acceleration surpasses that of the same changes made to velocity, in regards to shorter queue length, was discussed. Investigation should continue to pursue in determining whether the ratio between the distance travelled under maximum velocity and that under acceleration, is the only criteria with which to measure if equal percentage change to either velocity or acceleration have equal effect on queue length. The idea is to find a criteria in determining when the ceiling of the velocity is reached, such that a further increase in velocity would pro-

duce a lesser percentage effect in reducing queue length than a change in the acceleration rate.

For this experiment, FIFO discipline is applied to the retrieve queue. Should this discipline be released, such that the crane has a collection of 3 or 4 retrieve jobs from which to pick, the crane utilization and retrieve as well as storage queue should diminish. The idea behind it is to choose the job that is closest to where it has store the part or is along the crane's returning route back to the load/unload station. It is unknown whether the waiting time on the retrieve queue will increase significantly. The concept is to find a range for the collection of retrieve jobs to choose from, such that queue length and crane's utilization decreases significantly while the retrieve waiting time does not differ significantly.

In experiment 2, the effects of interrupt is insignificant even by widening the interrupt critical distance. Interrupt may make a difference in shortening queue length and lowering crane utilization if the distribution between retrieve and store job varies from hour to hour, but for a 8-hour work day, the total number of retrieve jobs and store jobs is approximately the same.

6.2 CHAPTER SUMMARY

The chapter sequentially lists the answers to the question raised in chapter 2. It also points out a couple of research that needs to be pursued in this area in order to arrive at a optimal control strategy.

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Appendix A

USER'S GUIDE AND PROGRAM LISTING

A.1 INTRODUCTION

Much of the studies concerning AS/RS deals specifically with locating the ideal bin to store a part. Control algorithium on such topics include, class-based turn over rule [Husman,32]. Little concern is focused on the crane's local activities of how and in what way the crane stores or retrieves a part into or out of the system. Control variables dedicated to such a criteria are shown on a decision tree in Figure 3 (chapter5). They are variables govering the way the crane moves through the aisle. The outcome from the simulation varies by changes made to these variables. By examining the combination of all the variables, a better crane operational performance can be found.

The program is designed to be able to simulate all single aisle ASR System with minor modification. The acceleration rate and maximum velocity can take on any form (eg. expression or constant) and be input into the system with minor changes. Interrupts may or may not be included in the system. They are generated in either one of the two condi-

tions described in chapter 4. The response time of an interrupt depends largerly on the type of feedback siganl that are employed. For continuous feedback signal, the response is instantaneous. On the other hand, discrete feedback signal may required a second or two before it respond.

The system is conditioned so that all jobs are generated from a single source. The rate between store and retrieve jobs are evenly distributed through a random generator.

A.2 THE MODEL

The program is divided into a number of subroutines wich performs specific task for the overall system. Tables 19, 20 and 21 show a list of the SLAM variables used while Tables 22, 23 and 24 show a list of the non-SLAM variables employed in the common block.

The input variable for the system are in the following format:

```
---AA.A--B
---C.C--D.D--E.E--F.F--G.G--H.H
-I-J
---2.000--K.KKK--4.000
---2.000--L.LLL--4.000
--M
```

TABLE 19

DESCRIPTION OF SLAM VARIABLES

Variables	Description
XX(1)	state of the crane on horizontal component (eg. accelerating, etc.)
XX(2)	state of the crane on vertical component (eg. accelerating, etc.)
XX(3)	flag for interrupt occurance (1=interrupt occuring)
XX(4)	flag for store or retrieve (1=retrieve, 2=store)
XX(5)	flag for crane busy (1=crane busy, 0=idle)
XX(6)	flag for loading and unloading of parts (1=unloading, 2=loading)
XX(7)	flag for crane carrying parts on its fork.
XX(8)	flag for whether the crane needs to turn in the opposite to service an interrupt (1=X-axis, 2=Y-axis and 3=both axis)
XX(9)	flag used in subroutine state for detecting loading or unloading of parts

TABLE 20

DESCRIPTION OF SLAM VARIABLES

Variables	Description
XX(10)	flag used to bypass reading in another command after it has completed a load operation
XX(25)	flag to check if crane has retreive anything on its fork (1=nothing)
XX(26)	deceleration point for the horizontal component
XX(27)	deceleration point for the vertical component
XX(28)	horizontal component velocity
XX(29)	vertical component velocity

TABLE 21

DESCRIPTION OF SLAM VARIABLES

Variables	Description
SS(1)	distance travelled for the command on X-axis
SS(2)	velocity for the horizontal component
SS(3)	distance travelled for the command on Y-aixs
SS(4)	velocity for the vertical component
SS(5)	absolute distance travelled on the horizontal component
SS(6)	absolute distance travelled in the vertical component
SS(7)	distance travelled before it arrives at a discrete signal on X-aixs
SS(8)	distance travelled before it arrives at a discrete signal on Y-axis
SS(9)	distance travelled before it starts to decelerate on X-axis
SS(10)	distance travelled before it starts to decelerate on Y-axis

TABLE 22

DESCRIPTION OF NON-SLAM VARIABLES

Variables	Description
XACC	acceleration on the horizontal component
YACC	acceleration on the vertical component
XDIST	horizontal distance travelled for each command
YDIST	vertical distance travelled for each command
INO	counter to determine if both both component reaches the bin
NXSIG	number of discrete signal in horizontal component
NYSIG	number of discrete signal on the vertical component
SXPOS	matrix to store values of discrete points on the horizontal component
SYPOS	matrix to store values of discrete points on the vertical component
NOCR	counter used for discrete interrupt

TABLE 23

DESCRIPTION OF NON-SLAM VARIABLES

Variables	Description
IXSART	starting bin location of crane on horizontal component
IYSART	starting bin location of crane on vertical component
IZSART	starting bin location of crane on Z-axis
IXEND	ending bin location of crane on horizontal component
IYEND	ending bin location of crane on vertical component
IZEND	ending bin location of crane on Z-axis
ULTIM	unloading time
TIML	loading time
TBA	time between arrival
INTR	flag for no (0), discrete (1), and continuous (2) interrupt
TACC	temporary acceleration used for interrupt

TABLE 24

DESCRIPTION OF NON-SLAM VARIABLES

Variables	Description
NOTURN	identifier on the next command eg. store, retrieve or return to load/unload station
NBIN	matrix to store bin status of the stacker system
XVEL	maximum velocity on the horizontal component
YVEL	maximum velocity on the vertical component
ANOTF	number of entities to file 1
ANOTS	number of entities to file 2
ANOTT	number of entities to file 3
ANOOF	number of entities out file 1
ANOOS	number of entities out file 2
ANOOT	number of entities out file 3
OIS	request for type 1 interrupt
OIR	request for type 2 interrupt
NATS	generation of jobs through random generator or fixed by user
TSTATU	temporary status of crane, eg. accelerating, at maximum constant speed or decelerating

Input value A represents the time between job arrivals. The base case is an exponential interrarrival rate with mean A. Since individual user may have their own distribution, any changes will required changes made to subroutine ARRIV. The variable representing the time interval is TBA.

Input value B is to signified whether the system has an interrupt feature. A zero implies that interrupt does not exit in the system. A one implies that discrete interrupt sensing is required while a two implies continouous sensing are to be employed.

Input value C and D are the maximum velocities of the crane on the horizontal and vertical component respectively.

Input value E and F are the constant acceleration/deceleration rate for the horizontal and vertical component of the crane respectively. The variables representing it are XACC and YACC. For every change in the acceleration rate, the value of XACC and YACC have to be updated in subroutine RSTART, XINTER and YINTER. In addition, the value of XACC have to be inputed on a condition statement in subroutne CHERET. All of these are necessary because the acceleration rate changes as soon as an interrupt occurs. If an interrupt is to occured on any point along the track, the crane has to find a deceleration rate for which it will stop directly next to a bin. The value is calculated in subroutine INTERR.

Input G and H are the loading and unloading time required at both the load/unload station and for every bin.

Input I and J are the number of discrete signal the user requires at each bin on the horizontal and vertical component. Presently the number is set at three, however, if more signals are required, changes have to be made to the program. Both K and L can be left at zero. The program will calculate these values depending on the speed and acceleration chosen for the crane.

Input M is the flag for whether the system is to generate the jobs through a random generator or fixed by an input file. A zero implies that the random generator is to come up with the bin location, while a one implies that it looks in subroutine LOCBIN for a scheduled routine.

The description of each subroutine will not be included since the program listing already describe the nature of each subroutine. A flowchart of each subroutine is also provided for reference to the program.

PROGRAM LISTING

```
//B0699 JOB 41DA1,CHIENG,TIME=3
/*JOBPARM LINES=9
/*ROUTE PRINT VM1.INDC99
//STEP1 EXEC FTG1CG,PARM.FORT=NOSOURCE,LIB='VPI.SLAM2'
//FORT.SYSIN DD *
      DIMENSION NSET(30000)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      COMMON QSET(30000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=25000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      READ(NCRDR,103) TBA,INTR
  103 FORMAT(2X,F5.2,1X,I2)
      READ (NCRDR,104) XVEL,YVEL,XACC,YACC,TIML,ULTIM
  104 FORMAT(2X,6F5.2)
      READ(NCRDR,101) NXSIG,NYSIG
  101 FORMAT(2I2)
      READ(NCRDR,102)(SXPOS(I),I=1,NXSIG)
      READ(NCRDR,102)(SYPOS(J),J=1,NYSIG)
  102 FORMAT(2X,3F7.4)
      READ(NCRDR,115) NATS
  115 FORMAT(1X,I2)
C*** FIND THE DECELERATION POINT
      XX(26)=(XVEL**2)/(2*XACC)
      XX(27)=(YVEL**2)/(2*YACC)
C*** FIND THE SECOND DISCRETE SIGANL
      DO 33 J=1,5
      SXPOS(2)=XX(26)-J*4.
      IF (SXPOS(2).LT.4.) GOTO 34
   33 CONTINUE
   34 SXPOS(2)=4.-SXPOS(2)
      IF (SXPOS(2).LT.2.) GOTO 88
   87 DO 44 J=1,5
      SYPOS(2)=XX(27)-J*4.
      IF (SYPOS(2).LT.4.) GOTO 45
   44 CONTINUE
   45 SYPOS(2)=4.-SYPOS(2)
      IF (SYPOS(2).LT.2.) GOTO 99
   98 WRITE(NPRNT,101) NXSIG,NYSIG
      WRITE(NPRNT,102) (SXPOS(I),I=1,3)
```

```
      WRITE(NPRNT,102) (SYPOS(J),J=1,3)
      WRITE(NPRNT,103) TBA,INTR
      WRITE(NPRNT,104) XVEL,YVEL,XACC,YACC,TIML,ULTIM
      WRITE(NPRNT,115) NATS
      GOTO 222
   88 SXPOS(1)=SXPOS(2)
      SXPOS(2)=2.
      GOTO 87
   99 SYPOS(1)=SYPOS(2)
      SYPOS(2)=2.
      GOTO 98
C*** CHECK IF THE DISCRETE SIGNAL 2 =1 OR 3 WILL IT GO THRU
  222 CALL SLAM
      STOP
      END
C*****************************************************************
C                                                                *
C    THIS SUBROUTINE INITIALIZE THE CONDITIONS OF THE SYSTEM.    *
C    IT CALLS THE FIRST ARRIVAL TO THE SYSTEM.                   *
C                                                                *
C*****************************************************************
      SUBROUTINE INTLC
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** INTIALIZE THE COUNTERS
      ANOTF=0.
      ANOTS=0.
      ANOTT=0.
      ANOOF=0.
      ANOOS=0.
      ANOOT=0.
      ANOOI=0.
      OIR=0.
      OIS=0.
C*** INTIALIZE THE STATUS OF THE SYSTEM
      DO 50 I=1,25
      XX(I)=0.0
   50 CONTINUE
C*** INITIALIZE THE STARTING CONDITION OF THE SYSTEM
      NOCR=0
      INO=0
      XX(28)=XVEL
      XX(29)=YVEL
      II=0
      DO 100 I=1,10
      SS(I)=0.0
```

```
      IF (I.GE.7.AND.I.LE.10) SS(I)=1.0E10
  100 CONTINUE
C*** INITIALIZE THE STARTING POSITION OF X,Y(I/O POINT)
      IXSART=0
      IYSART=0
      IXEND=0
      IYEND=0
      IZSART=1
      IZEND=1
C*** INITIALIZE THE STATUS OF EACH BIN (4X4X4) FOR A 100FTX60FT
C*** DOUBLE SIDED STROAGE SYSTEM (50% FULL)
      DO 200 I=1,25
      DO 200 J=1,15
      DO 200 K=1,2
      CONDI=DRAND(1)
      NBIN(I,J,K)=0
      IF (CONDI.LE..5) NBIN(I,J,K)=1
 200  CONTINUE
C*** GENERATE THE FIRST ARRIVAL
      CALL SCHDL(8,0.0,ATRIB)
      RETURN
      END
C*********************************************************************
C                                                                    *
C    THIS SUBROUTINE FILES ALMOST ALL THE ARRIVAL ROUTINES, EXCEPT *
C    THOSE OF AN INTERRUPT. IT CHECKS EVERY ARRIVAL TO DETERMINE   *
C    IF AN INTERRUPT CAN OCCUR AND ALSO SCHEDULE ANOTHER ARRIVAL   *
C                                                                    *
C*********************************************************************
      SUBROUTINE ARRIV
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      II=II+1
C*** INTIALIZE THE PRIORITY LEVEL
      ATRIB(5)=0.
C*** DETERMINE WHETHER IT IS TIME DEPEND
      IF (TBA.LE.0..AND.II.GE.801) GOTO 115
      IF (TBA.GT.0..AND.II.GE.800) GOTO 13
C*** DETERMINE THE NEXT ARRIVAL
      DT=EXPON(TBA,3)
      CALL SCHDL(8,DT,ATRIB)
C*** DETERMINE IF THE MOVEMENT REQUIRES STORING OR RETRIEVING
C*** A PART AND WHERE TO
  13  CALL LOCBIN
C*** CHECK IF IT HAS AN INTERRUPT
      IF (INTR.LE.0) GOTO 20
C*** FIND OUT THE DISTANCE TRAVELLED BEFORE AN INTERRUPT IS FLAVOUABLE
```

```
      XYZ=IABS(IXEND-IXSART)*4.
      YXZ=IABS(IYEND-IYSART)*4.
C*** CONDITION FOR AT THE START SO THAT THE VALUES WILL NOT BE ZERO
      IF (XYZ.EQ.0..OR.YXZ.EQ.0.) GOTO 20
      XPER=SS(1)/XYZ
      YPER=SS(3)/YXZ
C*** CHECK IF THE CRANE IS RETURNING TO L/UL STATION WITHOUT A PART
C*** ON ITS FORK
      IF (IXEND.EQ.0.AND.IYEND.EQ.0.AND.XX(7).EQ.0..AND.NNQ(1).EQ.0
     *.AND.ATRIB(4).EQ.1.AND.XX(5).EQ.1.AND.XX(4).EQ.1.) GOTO 77
 81   IF (IXEND.EQ.0.AND.IYEND.EQ.0.AND.XX(7).EQ.0..AND.NNQ(1).EQ.0.AND
     *.ATRIB(4).EQ.1..AND.XPER.LE..35.AND.YPER.LE..35.AND.
     *XX(5).EQ.1..AND.XX(4).EQ.1.) GOTO 100
C*** ANOTHER CRITERIA
      XDIR=ATRIB(1)*4.+XX(26)
      YDIR=ATRIB(2)*4.+XX(27)
      IF (SS(5).GE.XDIR.AND.SS(6).GE.YDIR.AND.XX(7).EQ.0.AND.
     *IXEND.EQ.0.AND.IYEND.EQ.0.AND.ATRIB(4).EQ.1.AND.NNQ(1).EQ.0.
     *AND.XX(5).EQ.1..AND.XX(4).EQ.1.)  GOTO 78
 82   IF (SS(5).GE.XDIR.AND.SS(6).GE.YDIR.AND.XX(7).EQ.0.AND.
     *IXEND.EQ.0.AND.IYEND.EQ.0.AND.ATRIB(4).EQ.1.AND.NNQ(1).EQ.0.
     *AND.XX(5).EQ.1..AND.XX(4).EQ.1.)  GOTO 100
C*** IF THE CRANE JUST LEFT EMPTY AND A STORE ROUTINE ARRIVES
      IF (IXSART.EQ.0.AND.IYSART.EQ.0.AND.XX(4).EQ.1.AND.ATRIB(4).EQ.
     *2..AND.NNQ(2).EQ.0.AND.XX(5).EQ.1.) GOTO 79
 83   IF (IXSART.EQ.0.AND.IYSART.EQ.0.AND.XX(4).EQ.1.AND.ATRIB(4).EQ.
     *2..AND.XPER.LE..35.AND.YPER.LE..35.AND.NNQ(2).EQ.0
     *.AND.XX(5).EQ.1.) GOTO 100
C*** DETERMINE WHICH QUEUE THE ORDER GOES TO
 20   IF (ATRIB(4).EQ.1.) CALL FILEM(1,ATRIB)
      IF (ATRIB(4).EQ.2.) CALL FILEM(2,ATRIB)
      IF (ATRIB(4).EQ.1.) ANOTF=ANOTF+1.
      IF (ATRIB(4).EQ.1.) CALL COLCT(ANOTF,1)
      IF (ATRIB(4).EQ.2.) ANOTS=ANOTS+1.
      IF (ATRIB(4).EQ.2.) CALL COLCT(ANOTS,2)
C*** IF ARRIVALS ARE NOT TIME DEPENDANT
      IF (TBA.LE.0.) RETURN
C*** CHECK IF THE CRANE IS BUSY
      IF (XX(5).GT.0.) GOTO 10
C*** SET THE CRANE IN MOTION
      NOTURN=1
      IF (ATRIB(4).EQ.2.) NOTURN=2
      IF (IXEND.NE.0.AND.IYEND.NE.0.AND.ATRIB(4).EQ.2.) NOTURN=3
      CALL RSTART
  10  RETURN
 100  IF (XX(3).GT.0.) GOTO 20
C*** XX(24) CANNOT BE HERE SINCE TI IS NOT SURE WHETHER THE INT WILL
C*** GO THRU
      IF (INTR.EQ.1) CALL DISPOS
      IF (INTR.EQ.2) CALL INTERR
```

```
      RETURN
C*** CONDITION FOR NO TIME DEPENDANT
 115  NOTURN=2
      CALL RSTART
      RETURN
 77   OIR=OIR+1.
      CALL COLCT(OIR,8)
      GOTO 81
 78   OIR=OIR+1.
      CALL COLCT(OIR,8)
      GOTO 82
 79   OIS=OIS+1.
      CALL COLCT(OIS,9)
      GOTO 83
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE UPDATES THE CONDITION OF THE VARIABLES BY        *
C   TAKING MINUTE STEPS SIZES.  IT ALSO SCHEDULES LOADING AND        *
C   UNLOADING EVENT TO OCCUR.                                        *
C                                                                    *
C*********************************************************************
      SUBROUTINE STATE
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      IF (XX(9).GT.0.) RETURN
C*** CHECK IF THE CRANE IS IDLE
      IF (XX(5).EQ.0.) RETURN
C*** CHECK IF THERE IS A LOAD OR UNLOAD OPERATION
      IF (XX(6).GT.0.) GOTO 100
C*** CHECK IF ANY MOVEMENT ON THE X-AXIS
      IF (XDIST.EQ.0.) GOTO 200
      IF (XX(1).EQ.0.) DD(2)=XACC
      IF (XX(1).EQ.1.) DD(2)=0.0
      IF (XX(1).EQ.2.) DD(2)=-XACC
      IF (SS(2).LT.0.) GOTO 10
      DD(1)=SS(2)
C*** UPDATE THE ABSOLUTE POSTION ON THE X-AXIS
C*** CHECK THE DIRECTION
      XX(12)=1.
      IF ((IXEND-IXSART).LT.0) XX(12)=2.
      IF (XX(12).EQ.2.) DD(5)=-SS(2)
      IF (XX(12).EQ.1.) DD(5)=SS(2)
      GOTO 40
  10  DD(1)=0.
      DD(5)=0.
```

```
      DD(2)=0.
C*** CHECK IF ANY MOVEMENT ON THE Y-AXIS
  40  IF (YDIST.EQ.0.) GOTO 300
      IF (XX(2).EQ.0.) DD(4)=YACC
      IF (XX(2).EQ.1.) DD(4)=0.
      IF (XX(2).EQ.2.) DD(4)=-YACC
      IF (SS(4).LT.0.) GOTO 50
      DD(3)=SS(4)
C*** UPDATE THE ABSOLUTE POSITION ON THE Y-AIXS
C*** CHECK THE DIRECTION
      XX(13)=1.
      IF ((IYEND-IYSART).LT.0) XX(13)=2.
      IF (XX(13).EQ.1.) DD(6)=SS(4)
      IF (XX(13).EQ.2.) DD(6)=-SS(4)
      RETURN
  50  DD(3)=0.
      DD(6)=0.
      DD(4)=0.
      RETURN
C*** NO MOVEMENT ON THE X-AXIS
  200 INO=1
      GOTO 40
C*** NO MOVEMENT ON THE Y-AXIS
  300 INO=1
      RETURN
C*** LOADING OR THE UNLOADING OF PARTS
  100 IF (XX(6).EQ.1.) CALL SCHDL(9,ULTIM,ATRIB)
      IF (XX(6).EQ.2.) CALL SCHDL(9,TIML,ATRIB)
      XX(9)=1.
      RETURN
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE SCHEDULES THE THE OCCURANCE OF EACH EVENT        *
C                                                                    *
C*********************************************************************
      SUBROUTINE EVENT(IX)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      GOTO (1,2,3,4,5,6,7,8,9,10,11),IX
  1   XX(1)=1.
      IF (XX(8).GT.0.) RETURN
      XX(26)=SS(1)
      SS(9)=XDIST-SS(1)
      RETURN
  2   XX(1)=2.
```

```
      RETURN
   3  XX(2)=1.
      IF (XX(8).GT.0.) RETURN
      XX(27)=SS(3)
      SS(10)=YDIST-SS(3)
      RETURN
   4  XX(2)=2.
      RETURN
   5  INO=INO+1
      IF (INO.LT.2) RETURN
C*** CONDITION FOR TYPE 1 INTERRUPT
      XX(10)=0.
      IF (XX(8).EQ.3.) GOTO 9
C*** CONDITION TO RESET ABSOLUTE VALUES
      SS(5)=IXEND*4.
      SS(6)=IYEND*4.
      IF (XX(25).GT.0.) GOTO 200
      XX(6)=1.
      IF (XX(7).EQ.0..AND.XX(4).EQ.1.) XX(6)=2.
      RETURN
C*** SET IT TO GO TO RSTART
 200  XX(10)=0.
      XX(25)=0.
      GOTO 9
   6  CALL DISPOS
      RETURN
   7  NOCR=NOCR+1
      IF (NOCR.GT.1) GOTO 100
      CALL INTERR
      RETURN
 100  NOCR=0
      RETURN
   8  CALL ARRIV
      RETURN
   9  IF (XX(4).EQ.2..AND.XX(6).EQ.2.) XX(10)=1.
      XX(6)=0.
      XX(9)=0.
      IF (XX(10).GT.0.) RETURN
      IF (XX(8).EQ.0.) XX(3)=0.
      CALL RSTART
      RETURN
  10  IF (XX(8).NE.1.) GOTO 5
      CALL XINTER
      RETURN
  11  IF (XX(8).NE.2.) GOTO 5
      CALL YINTER
      RETURN
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE FINDS THE DISCRETE SIGNAL POINT THE CRANE        *
```

```
C   IS DESTINED TO ARRIVE NEXT. AT THE DISCRETE POINT THE MAKE      *
C   DECISIONS ON WHETHER TO INTERRUPT THE PROCESS, ETC.             *
C                                                                   *
C*******************************************************************
      SUBROUTINE DISPOS
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      XCSPOS=0.
      YCSPOS=0.
      DO 100 I=1,25
      DO 100 J=1,3
      XSIPOS=((I-1)*4)+SXPOS(J)
      UNKNO1=ABS(SS(5)-XSIPOS)
      IF(UNKNO1.LE..01) GOTO 99
      IF((IXEND-IXSART).GT.0) GOTO 150
C** GOING IN THE NEGATIVE DIR
C** STORE THE LAST NO.
      XII=XCSPOS
      XCSPOS=XSIPOS-SS(5)
      IF (XCSPOS.GT.0.) GOTO 200
      GOTO 100
C** GOING IN THE POSITIVE DIR
  150 XCSPOS=XSIPOS-SS(5)
      IF (XCSPOS.GT.0.) GOTO 200
  100 CONTINUE
  200 IF ((IXEND-IXSART).LT.0) XCSPOS=XII
      DO 300 I=1,15
      DO 300 J=1,NYSIG
      YSIPOS=((I-1)*4)+SYPOS(J)
      UNKNO2=ABS(SS(6)-YSIPOS)
      IF (UNKNO2.LE..01) GOTO 99
      IF ((IYEND-IYSART).GT.0) GOTO 350
C** GOING IN THE -IVE DIR
      YII=YCSPOS
      YCSPOS=YSIPOS-SS(6)
      IF (YCSPOS.GT.0.) GOTO 400
      GOTO 300
C** GOING IN THE +IVE DIR
  350 YCSPOS=YSIPOS-SS(6)
      IF (YCSPOS.GT.0.) GOTO 400
  300 CONTINUE
  400 IF ((IYEND-IYSART).LT.0) YCSPOS=YII
      SS(7)=XCSPOS+SS(1)
      SS(8)=YCSPOS+SS(3)
      RETURN
   99 CALL INTERR
```

```
      RETURN
      END
C*********************************************************************
C                                                                     *
C   THIS SUBROUTINE CHECKS WHETHER THE CRANE HAS TO GO IN ANOTHER     *
C   DIRECTION TO PROCEED ON WITH THE INTERRUPT OR GO IN THE SAME      *
C   DIRECTION FOR EITHER THE HORIZONTAL OR VERTICAL COMPONENT.        *
C                                                                     *
C*********************************************************************
      SUBROUTINE INTERR
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** COUNT THE NUMBER OF INTERRUPT
      ANOOI=ANOOI+1.
      CALL COLCT(ANOOI,7)
C*** SET THE INTERRUPT FLAG, SINCE THERE IS NO INTERRUPT
      XX(3)=1.
C*** IF NOT CARRYING ANYTHING, CHECK IF IT IS STORING OR RETRIEVING
      IF (ATRIB(4).EQ.2.) GOTO 800
C*** RETRIEVE,CHECK IF IT HAS PASSED THE X-INTERRUPT PT.
      XX(14)=1.
      ANOTF=ANOTF+1.
      CALL COLCT(ANOTF,1)
      NOTURN=3
 2000 CALL CHERET(XX(1),IXEND,IXSART,SS(5),XACC,ATRIB(1),XDIST,SS(1)
     *,SS(9),SS(2))
      XACC=TACC
      XX(1)=TSTATU
      IF (XX(8).GT.0.) GOTO 300
C*** CONDITION SATISFIED, DO NOT HAVE TO TURN BACK
C*** OPERATE THE CRANE UNDER NORMAL CONDITION
      XBEGI=IXSART*1.
      TEST=ABS(ATRIB(1)-XBEGI)*4.
      XCRIT=2*XX(26)
      SS(9)=TEST-XX(26)
      IF (TEST.LT.XCRIT) SS(9)=TEST/2.
C*** CHECK IF IT HAS PASSED THE Y-INTERRUPT POINT
  300 CALL CHERET(XX(2),IYEND,IYSART,SS(6),YACC,ATRIB(2),YDIST,SS(3)
     *,SS(10),SS(4))
      YACC=TACC
      XX(2)=TSTATU
      IF (XX(8).GT.1.) GOTO 1100
C*** NO REQUIREMENT FOR TURING BACK
C*** IF NO TURNING BACK IS REQUIRED
      YBEGI=IYSART*1.
      TEST=ABS(ATRIB(2)-YBEGI)*4.
```

```
      YCRIT=2*XX(27)
      SS(10)=TEST-XX(27)
      IF (TEST.LT.YCRIT) SS(10)=TEST/2.
 1100 CALL SWFILE
      XX(14)=0.
      IF (XX(8).GT.0.) RETURN
C*** UPDATE THE BIN STATUS
      NOTURN=3
      RETURN
C*** FOR THE ROUTINE THAT REQUIRES A STORING
  800 CALL FILEM(2,ATRIB)
      ANOTS=ANOTS+1.
      CALL COLCT(ANOTS,2)
      NOTURN=2
C*** PUT THE RETURN I/O COMMAND IN
      ATRIB(1)=0.
      ATRIB(2)=0.
      ATRIB(3)=1.
      ATRIB(4)=2.
      GOTO 2000
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE LOCATES THE BIN OF EACH OF THE ARRIVALS MAKING   *
C   SURE THAT IS DOES NOT EXIST IN THE FILES AND THAT NO CONFLICT    *
C   EXIST BETWEEN THE MOVE AND THE STATUS OF THE BIN.                *
C                                                                    *
C*********************************************************************
      SUBROUTINE LOCBIN
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** CHECK IF THE SYSTEM IS DYNAMIC OR STATIC
      IF (NATS.GT.0) GOTO 100
C*** DETERIMINE IF THE ORDER REQUIRES STORING OR RETRIEVING
  10  PP=DRAND(1)
      ATRIB(4)=1.
      IF (PP.GE..5) ATRIB(4)=2.
C*** FIND THE BIN LOCATION
  5   ATRIB(1)=INT(UNFRM(1.,26.,1))
      ATRIB(2)=INT(UNFRM(1.,16.,1))
      ATRIB(3)=INT(UNFRM(1.,3.,1))
C*** CHECK IF ANY ORDER IN THE QUEUE CONTAINS THE SAME FILE
C*** CHECK FILES, FILE 1=RETRIEVE  FILE 2=STORE
C*** SUBSTITUTE THE VALUE OF ATRIB(4) TO INTEGER
      ITYPE=ATRIB(4)
      NRAN1=NFIND(1,ITYPE,1,0,ATRIB(1),0.0)
```

```
      NRAN2=NFIND(1,ITYPE,2,0,ATRIB(2),0.0)
      NRAN3=NFIND(1,ITYPE,3,0,ATRIB(3),0.0)
      IF (NRAN1.GT.0.AND.NRAN2.GT.0.AND.NRAN3.GT.0) GOTO 5
C*** CHECK IF ANY CONFLICT EXIST BETWEEN THE STATUS AND MOVEMENT
      IF (NBIN(ATRIB(1),ATRIB(2),ATRIB(3)).EQ.1.AND.ATRIB(4).EQ.2.)
     *GOTO 10
      IF (NBIN(ATRIB(1),ATRIB(2),ATRIB(3)).EQ.0.AND.ATRIB(4).EQ.1.)
     *GOTO 10
      RETURN
C*** STATIC SYSTEM
  100 IF (II.EQ.2) GOTO 110
      IF (II.EQ.3) GOTO 120
      ATRIB(1)=10.
      ATRIB(2)=8.
      ATRIB(3)=1.
      ATRIB(4)=2.
      RETURN
  110 ATRIB(1)=4.
      ATRIB(2)=14.
      ATRIB(3)=2.
      ATRIB(4)=2.
      RETURN
  120 ATRIB(1)=14.
      ATRIB(2)=4.
      ATRIB(3)=1.
      ATRIB(4)=1.
      RETURN
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE CHECKS IF THE CRANE CAN STOP IN TIME TO PROCEED  *
C   ON WITH THE INTERRUPT WITHOUT TURNING AROUND IN THE OPPOSITE     *
C   DIRECTION. HOWEVER, IF IT HAS TO TURN AROUND, IT                 *
C   CHANGES THE DECELERATION RATE SO THAT IT CAN STOP AT ONE         *
C   OF THE BIN LOCTIONS.                                             *
C                                                                    *
C*********************************************************************
      SUBROUTINE CHERET(STATUS,IEND,ISTART,PREVAL,ACC,BEWPOS,TODIST,
     *DISTTR,DECPT,PREVEL)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** CONVERT THE TRANSFER VARIABLE
      TACC=ACC
      TSTATU=STATUS
C*** CONVERT THE NEW POSITION INTO DISTANCE
      EWPOS=BEWPOS*4.
C*** CHECK IF THE CRANE HAS PASSED THE INTERRUPT POINT
```

```
      IF ((IEND-ISTART).GT.0.AND.(PREVAL-EWPOS).GT.0.) GOTO 100
      IF ((IEND-ISTART).LT.0.AND.(PREVAL-EWPOS).LT.0.) GOTO 100
C*** CAN IT STOP IN TIME
      DIST=ABS(PREVAL-EWPOS)
      IF (STATUS.EQ.0..AND.DISTTR.LE.DIST) RETURN
      IF (STATUS.EQ.1..AND.DIST.GE.(TODIST-DECPT)) RETURN
C*** THE TASK CANNOT BE ACCOMPLISHED
  100 IF (ACC.EQ.XACC) XX(8)=1.
      IF (XX(8).EQ.1..AND.ACC.EQ.YACC) XX(8)=3.
      IF (XX(8).EQ.0..AND.ACC.EQ.YACC) XX(8)=2.
C*** CONDITION OF HOW TO SLOW THE CRANE DOWN
      IF (STATUS.GT.0.) GOTO 20
C*** STATUS EQUALS ZERO
      TSTATU=2.
      XOBIN=(DISTTR*2)/4.
      VAL=XOBIN-INT(XOBIN)
      IF (VAL.LE..01) RETURN
C*** DISTANCE NEEDED TO ADD TO MAKE IT REACH A BIN
      DISNED=(1.-VAL)*4.
C*** DECELERATION RATE
      TACC=(PREVEL**2)/(2*(DISNED+DISTTR))
      RETURN
C*** STATUS EQUALS ONE
   20 TSTATU=2.
      ESTDIS=XX(27)
      IF (ACC.EQ.3.5) ESTDIS=XX(26)
      ESTBIN=(DISTTR+ESTDIS)/4.
      COMP=ESTBIN-INT(ESTBIN)
      IF (COMP.LE..01) RETURN
      DIFF=(1.-COMP)*4.
      TACC=(PREVEL**2)/(2*(DIFF+ESTDIS))
      RETURN
      END
C*********************************************************************
C                                                                    *
C    THIS SUBROUTINE PLACES THE ORIGINAL COMMAND TO ITS APPROPRIATE *
C    FILE AND PLACES THE INTERRUPT COMMAND TO THE PROCESSOR'S       *
C    IMMEDIATE ATTENTION.                                           *
C                                                                    *
C*********************************************************************
      SUBROUTINE SWFILE
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** CONDITION FOR NON STORING FILE
C     IF (XX(14).GT.0.) GOTO 100
C*** STORE THE PRESENT CONDITON IN TEMPORARY VARIABLE
```

```
      JXEND=IXEND
      JYEND=IYEND
      JZEND=IZEND
      KMOV=XX(4)
C*** UPDATE THE NEW FILE
  100 IXEND=ATRIB(1)
      IYEND=ATRIB(2)
      IZEND=ATRIB(3)
      XX(4)=ATRIB(4)
C*** CONDTION FOR NO STORING FILE
      IF (XX(14).GT.0.) GOTO 122
C*** PUT THE DATA INTO THE ATRIB
      ATRIB(1)=JXEND
      ATRIB(2)=JYEND
      ATRIB(3)=JZEND
      ATRIB(4)=KMOV
      ATRIB(5)=1.
C*** UPDATE THE BIN STATUS
C     NBIN(JXEND,JYEND,JZEND)=1
C*** FILE THE ORIGINAL MOVEMENT
      CALL FILEM(1,ATRIB)
      ANOOF=ANOOF-1.
      CALL COLCT(ANOOF,4)
  122 IF (XX(8).EQ.0.) GOTO 400
C*** COMMAND CANNOT BE DONE
      ATRIB(1)=IXEND
      ATRIB(2)=IYEND
      ATRIB(3)=IZEND
      ATRIB(4)=XX(4)
      ATRIB(5)=1.
C*** CHANGE TO THE RETRIEVE ROUTINE THAT DOES NOT HAVE TO TURN BACK
C*** ON THE ABSOLUTE DISTANCE IN SUB STATE
      IF (XX(8).EQ.1..OR.XX(8).EQ.3.) IXEND=JXEND
      IF (XX(8).EQ.2..OR.XX(8).EQ.3.) IYEND=JYEND
C*** FILE THE INTERRUPT COMMAND
      IF (ATRIB(4).EQ.2.) CALL FILEM(3,ATRIB)
      IF (ATRIB(4).EQ.2.) ANOTT=ANOTT+1.
      IF (ATRIB(4).EQ.2.) CALL COLCT(ANOTT,3)
      IF (XX(14).EQ.1..AND.XX(8).GT.0.) CALL FILEM(1,ATRIB)
      RETURN
C*** CONDTION FOR THE RETRIEVE FILE BEING NOT TURNING BACK
  400 XX(25)=0.
      CALL CALCU
      XX(7)=0.
      XX(5)=1.
      ANOOF=ANOOF+1.
      CALL COLCT(ANOOF,4)
      NBIN(IXEND,IYEND,IZEND)=0.
      RETURN
      END
C*********************************************************************
```

```
C                                                                       *
C   THIS SUBROUTINE IS CALLED WHEN THE CRANE FINISHES ONE COMAND        *
C   AND REQUEST SERVICING ANOTHER.                                      *
C                                                                       *
C***********************************************************************
      SUBROUTINE RSTART
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      INO=0
      XX(1)=0.
      XX(2)=0.
C*** UPDATING THE ORIGINAL ACCELERATION OF THE CRANE
      XACC=3.5
      YACC=2.5
      DO 100 I=1,10
      IF (I.EQ.5.OR.I.EQ.6) GOTO 100
      SS(I)=0.0
      IF (I.GE.7.AND.I.LE.10) SS(I)=1.0E10
 100  CONTINUE
C*** CHECK IF ANY EARLIER OPERATION CANNOT BE ACCOMPLISHED
      IF (XX(8).EQ.3.) GOTO 700
C*** RESUME NORMAL OPERATION
      IF (NOTURN.EQ.2) GOTO 400
      IF (NOTURN.EQ.3) GOTO 150
C*** RETRIEVE FILE FOR NON-INTERRUPT
C*** CHECK IF THERE IS ANY THING IN IT
      IF (NNQ(1).LE.0) GOTO 400
  50  IF (NNQ(1).LE.0.AND.NNQ(2).LE.0.) GOTO 1
      NOTURN=3
      CALL RMOVE(1,1,ATRIB)
      ANOOF=ANOOF+1.
      CALL COLCT(ANOOF,4)
      CALL UPDATE
      XX(7)=0.
      XX(5)=1.
      NBIN(IXEND,IYEND,IZEND)=0
C*** CHECK IF ANY MOVEMENT IS REQUIRED TO RETRIEVE THE PART
      IF (XDIST.EQ.0..AND.YDIST.EQ.0.) GOTO 77
      RETURN
  77  INO=1
      CALL SCHDL(5,0.0,ATRIB)
      RETURN
C*** STORE FILE,CHECK IF NAY THINF IS THERE
 400  IF (NNQ(2).LE.0) GOTO 50
      IF (IXEND.GT.0.OR.IYEND.GT.0) GOTO 150
      CALL RMOVE(1,2,ATRIB)
```

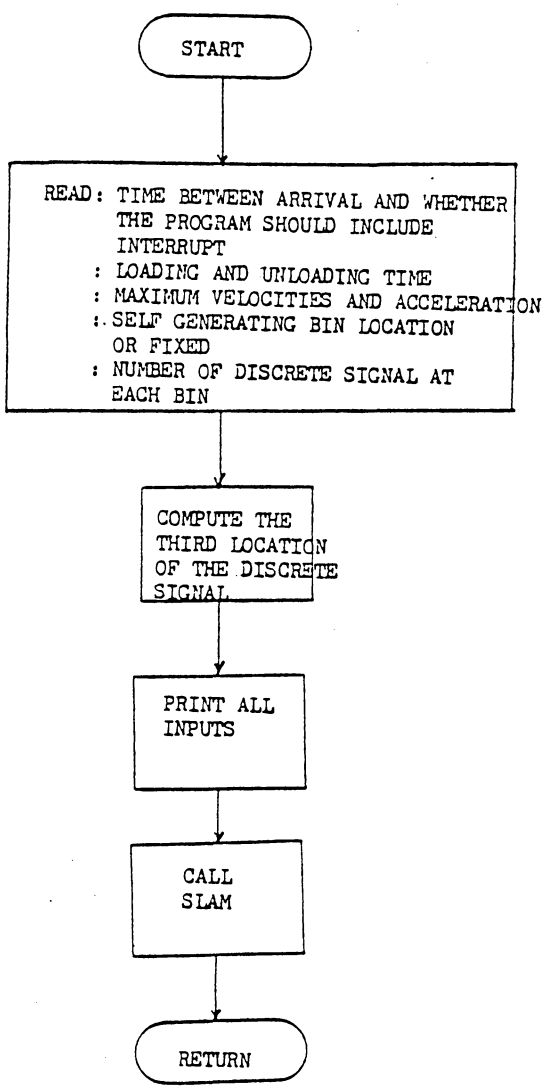
```
      ANOOS=ANOOS+1.
      CALL COLCT(ANOOS,5)
      NOTURN=1
      CALL UPDATE
      XX(6)=2.
      XX(7)=1.
      XX(5)=1.
      NBIN(IXEND,IYEND,IZEND)=1
      XX(9)=0.
      RETURN
C*** RETURN TO I/O
C*** CHECK IF THE CRANE HAS RETRIEVE ANYTHING
  150 IF (XX(4).EQ.2.) XX(25)=1.
      NOTURN=2
      IXSART=IXEND
      IYSART=IYEND
      IZSART=IZEND
      IXEND=0
      IYEND=0
      IZEND=1
      XX(7)=1.
C*** CONDITION FOR A CRANE NOT CARRYTING ANYTHING
      IF (XX(25).GT.0.) XX(7)=0.
      XX(5)=1.
      XX(4)=1.
      CALL CALCU
      RETURN
C*** XX(8) EQUAL THREE
 700  IF (XX(4).EQ.2.) CALL RMOVE(1,3,ATRIB)
      IF (XX(4).EQ.1.) CALL RMOVE(1,1,ATRIB)
      IF (XX(4).EQ.2.) ANOOT=ANOOT+1.
      IF (XX(4).EQ.2.) CALL COLCT(ANOOT,6)
      IF (XX(4).EQ.1.) ANOOF=ANOOF+1.
      IF (XX(4).EQ.1.) CALL COLCT(ANOOF,4)
      IXEND=INT((SS(5)+.1)/4.)
      IYEND=INT((SS(6)+.1)/4.)
      IZEND=1
      XX(8)=0.
      XX(25)=0.
      CALL UPDATE
      RETURN
   1  XX(5)=0.
      IF ((ANOTF+ANOTS).GE.800) MSTOP=-1
      RETURN
      END
C*********************************************************************
C                                                                    *
C    THIS SUBROUTINE IS CALLED WHEN AN INTERRUPT OCCURS AND THAT     *
C    ONLY THE HORIZONTAL COMPONENT REQUIRES TURNING IN THE OPPOSITE  *
C    DIRECTION TO RETRIEVE A PART                                    *
C                                                                    *
C*********************************************************************
```

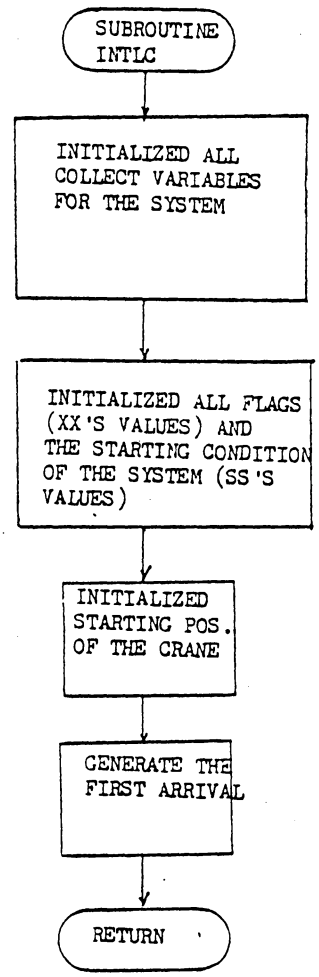
```
      SUBROUTINE XINTER
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** UPDATE THE ACCELERATION AND CRANE STATUS
      XX(1)=0.
      XACC=3.5
      SS(1)=0.
      SS(2)=0.
      SS(7)=1.0E10
      SS(9)=1.0E10
C*** REMOVE THE ENTITY FROM FILE 1
      CALL RMOVE(1,1,ATRIB)
      ANOOF=ANOOF+1.
      CALL COLCT(ANOOF,4)
C*** UPDATE CURRENT CRANE POSITION AND FINAL POSITION
      IXSART=INT((SS(5)+.1)/4.)
      IXEND=ATRIB(1)
      SXDIST=IXEND-IXSART
      XVAL=2*XX(26)
      XDIST=(ABS(SXDIST))*4.
      IF (XDIST.LT.XVAL.AND.XDIST.GT.0.) SS(9)=XDIST/2.
C*** SET FLAGS TERMINATING INTERRUPT AND RESUME UNLOADING TIME
      XX(8)=0.
      XX(25)=0.
C*** UPDATE BIN STATUS
      NBIN(IXEND,IYEND,IZEND)=0.
      NOTURN=3
      RETURN
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE IS CALLED WHEN AN INTERRUPT OCCURS AND THAT      *
C   ONLY THE VERTICAL COMPONENT REQUIRES TURNING IN THE OPPOSITE     *
C   DIRECTION TO RETRIEVE A PART.                                    *
C                                                                    *
C*********************************************************************
      SUBROUTINE YINTER
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
C*** UPDATE THE CRANE STATUS AND ACCELERATION RATE
      XX(2)=0.
      YACC=2.5
```

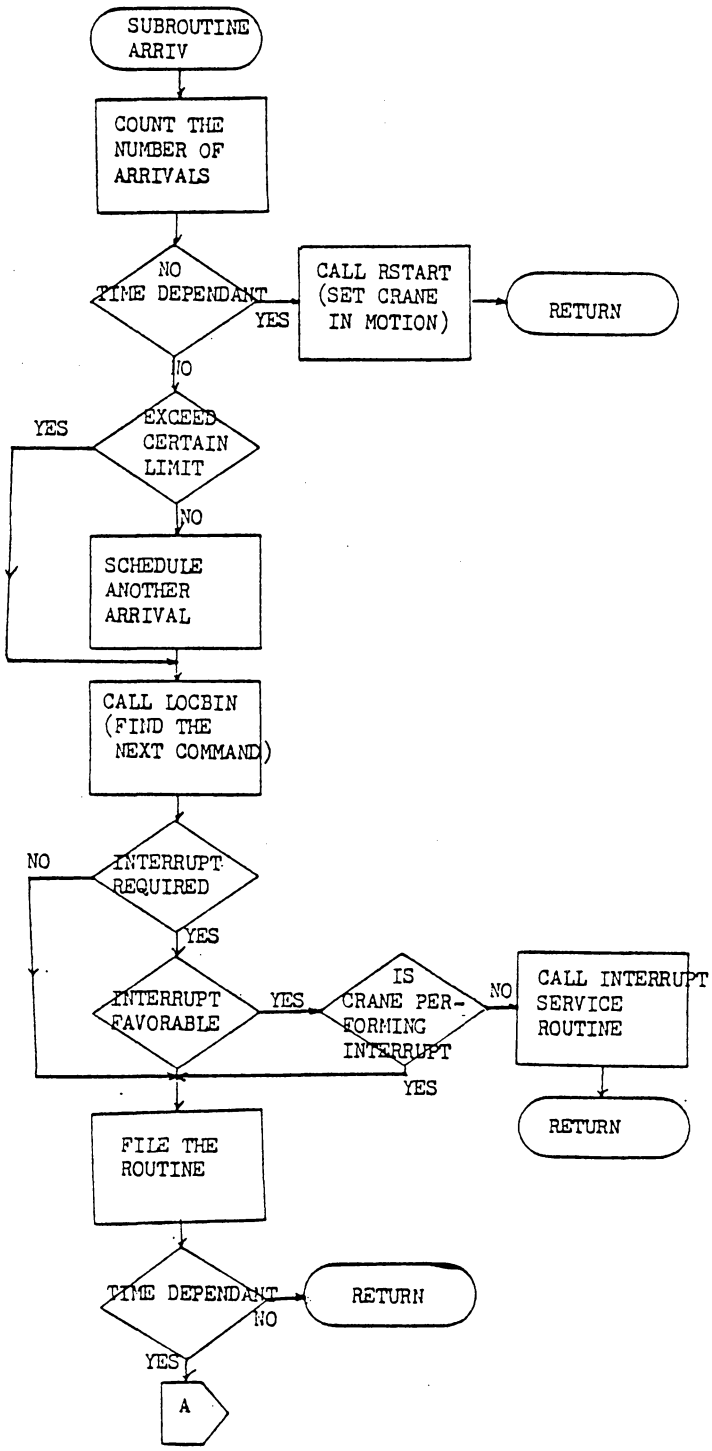
```
      SS(3)=0.
      SS(4)=0.
      SS(8)=1.0E10
      SS(10)=1.0E10
C*** REMOVE THE ENTITY FROM THE FILE
      CALL RMOVE(1,1,ATRIB)
      ANOOF=ANOOF+1.
      CALL COLCT(ANOOF,4)
C*** UPDATE THE CRANE CURRENT POSITION AND FINAL POSTION
      IYSART=INT((SS(6)+.1)/4.)
      IYEND=ATRIB(2)
      SYDIST=IYEND-IYSART
      YVAL=2*XX(27)
      YDIST=(ABS(SYDIST))*4.
      IF (YDIST.LT.YVAL.AND.YDIST.GT.0.) SS(10)=YDIST/2.
C*** SET FLAGS TERMINATING INTERRUPTS AND RESUME UNLOADING TIME
      XX(8)=0.
      XX(25)=0.
C*** UPDATE THE BIN STATUS
      NBIN(IXEND,IYEND,IZEND)=0
      NOTURN=3
      RETURN
      END
C*********************************************************************
C                                                                    *
C   THIS SUBROUTINE IS CALLED WHEN ONE COMAND IS FINISHED AND SOME   *
C   UPDATING HAS TO BE DONE.                                         *
C                                                                    *
C*********************************************************************
      SUBROUTINE UPDATE
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      IXSART=IXEND
      IYSART=IYEND
      IZSART=IZEND
      IXEND=ATRIB(1)
      IYEND=ATRIB(2)
      IZEND=ATRIB(3)
      XX(4)=ATRIB(4)
      CALL CALCU
      RETURN
      END
C
C
      SUBROUTINE UERR(KODE)
      CALL PRNTF(2)
```

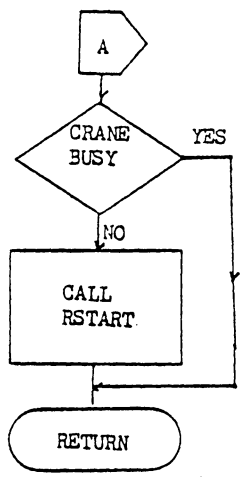
```
      CALL PRNTT(-1)
      CALL PRNTS
      RETURN
      END
C*********************************************************************
C                                                                    *
C    THIS SUBROUTINE CALCULATES THE DISTANCE REQUIRED TO TRAVEL      *
C    TO THE BIN.                                                     *
C                                                                    *
C*********************************************************************
      SUBROUTINE CALCU
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     *,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ XACC,YACC,XDIST,YDIST,INO,NXSIG,NYSIG,SXPOS(3),NATS
     *,SYPOS(3),NOCR,IXSART,IYSART,IXEND,IYEND,IZSART,IZEND,ULTIM,TIML
      COMMON/UCOM2/ TBA,INTR,TACC,TSTATU,NOTURN,NBIN(30,20,5),XVEL,YVEL
      COMMON/UCOM3/ ANOTF,ANOTS,ANOTT,ANOOF,ANOOS,ANOOT,ANOOI,OIR,OIS
      SXDIST=IXEND-IXSART
      SYDIST=IYEND-IYSART
      XDIST=(ABS(SXDIST))*4.
      YDIST=(ABS(SYDIST))*4.
      XVAL=2*XX(26)
      YVAL=2*XX(27)
      IF (XDIST.LT.XVAL.AND.XDIST.GT.0.) SS(9)=XDIST/2.
      IF (YDIST.LT.YVAL.AND.YDIST.GT.0.) SS(10)=YDIST/2.
      RETURN
      END
//GO.FT07F001 DD DSN=&&SEQ,UNIT=SYSDA,DISP=(NEW,DELETE),
// SPACE=(TRK,(20,5)),DCB=(LRECL=133,BLKSIZE=1330,BUFNO=1,
// RECFM=FB)
//GO.SYSIN DD *
   20.0  0
    8.0  6.5  3.5  2.5  1.0  1.0
 3 3
    2.000  2.857  4.000
    2.000  2.398  4.000
  0
GEN,CHIENG,ASRS,3/1/83,1;
LIMITS,3,5,100;
PRIORITY/1,HVF(5)/NCLNR,FIFO;
PRIORITY/2,HVF(5)/NCLNR,FIFO;
INITIALIZE,0,14400;
TIMST,XX(3),INTER SIG;
TIMST,XX(5),CRANE BUSY;
TIMST,XX(8),TYPES OF INT;
STAT,1,NO. TO FILE 1;
STAT,2,NO. TO FILE 2;
STAT,3,NO. TO FILE 3;
STAT,4,NO. OUT FILE 1;
STAT,5,NO. OUT FILE 2;
STAT,6,NO. OUT FILE 3;
```

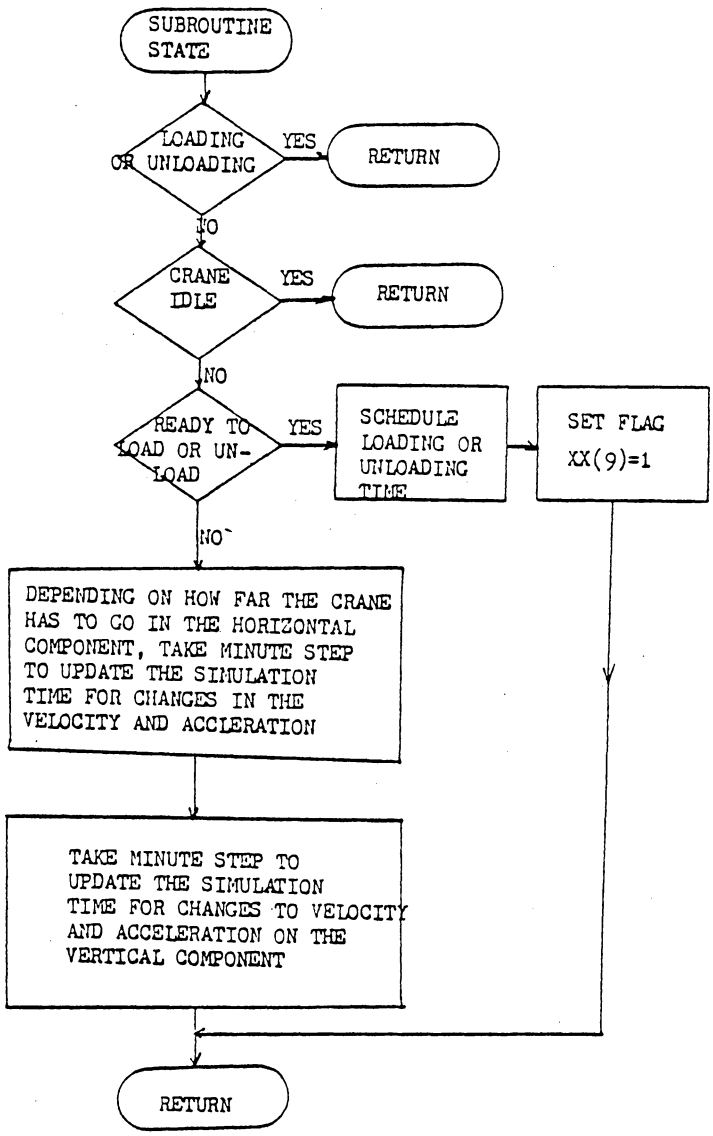
```
STAT,7,NO. OF INTERRUPT;
STAT,8,NO. OF INT1 REQ;
STAT,9,NO. OF INT2 REQ;
CONTINUOUS,6,4,.000001,.05,.05,W,0.00001,0.0001;
SEVNT,1,SS(2),XP,XX(28),.5;
SEVNT,2,SS(1),XP,SS(9),.5;
SEVNT,3,SS(4),XP,XX(29),.5;
SEVNT,4,SS(3),XP,SS(10),.5;
SEVNT,10,SS(2),XN,0.0,.5;
SEVNT,11,SS(4),XN,0.0,.5;
SEVNT,7,SS(1),XP,SS(7),.5;
SEVNT,7,SS(3),XP,SS(8),.5;
FINI;
/*
//
```

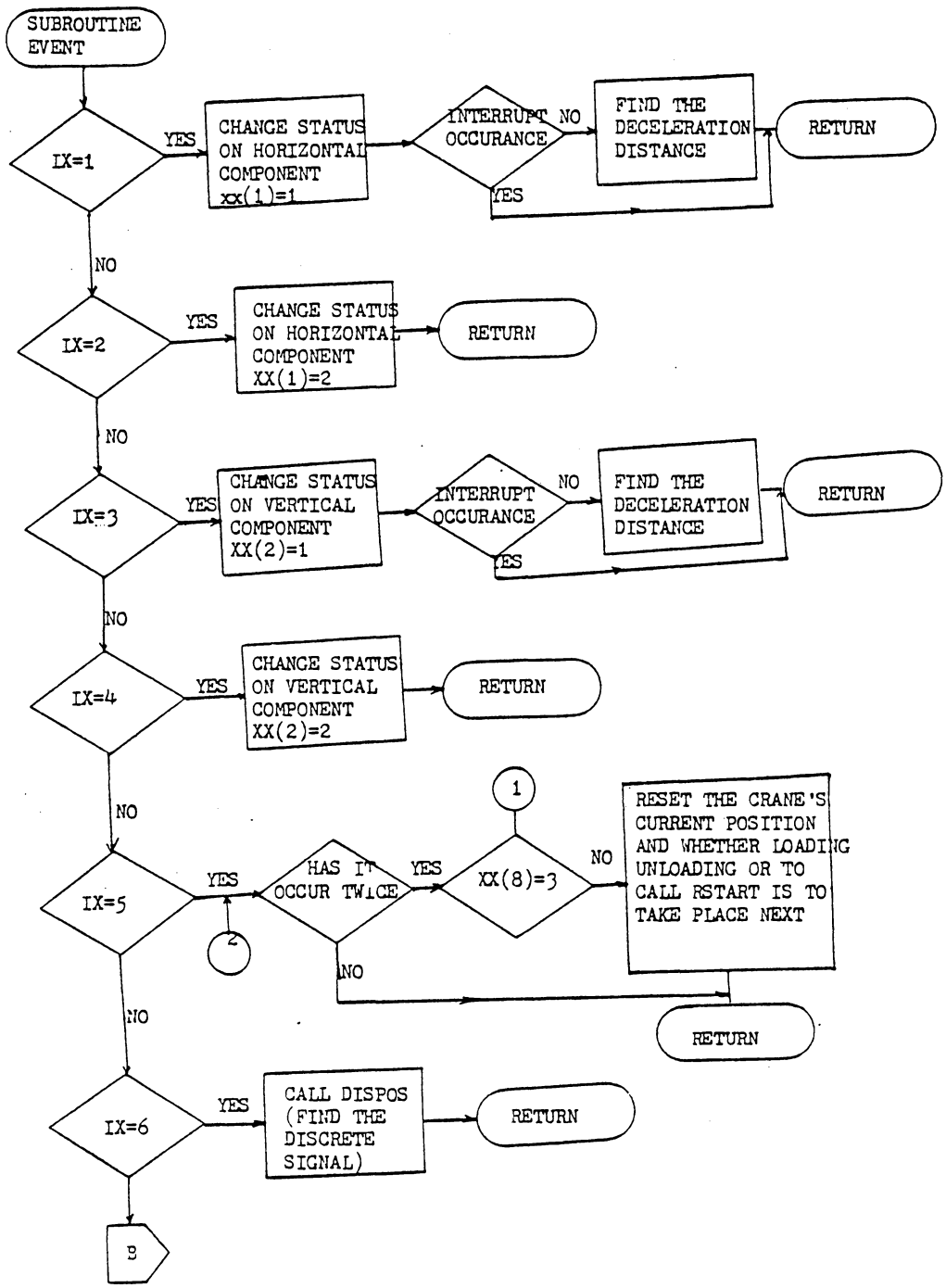

START
READ: TIME BETWEEN ARRIVAL AND WHETHER THE PROGRAM SHOULD INCLUDE INTERRUPT
: LOADING AND UNLOADING TIME
: MAXIMUM VELOCITIES AND ACCELERATION
: SELF GENERATING BIN LOCATION OR FIXED
: NUMBER OF DISCRETE SIGNAL AT EACH BIN
COMPUTE THE THIRD LOCATION OF THE DISCRETE SIGNAL
PRINT ALL INPUTS
CALL SLAM
RETURN

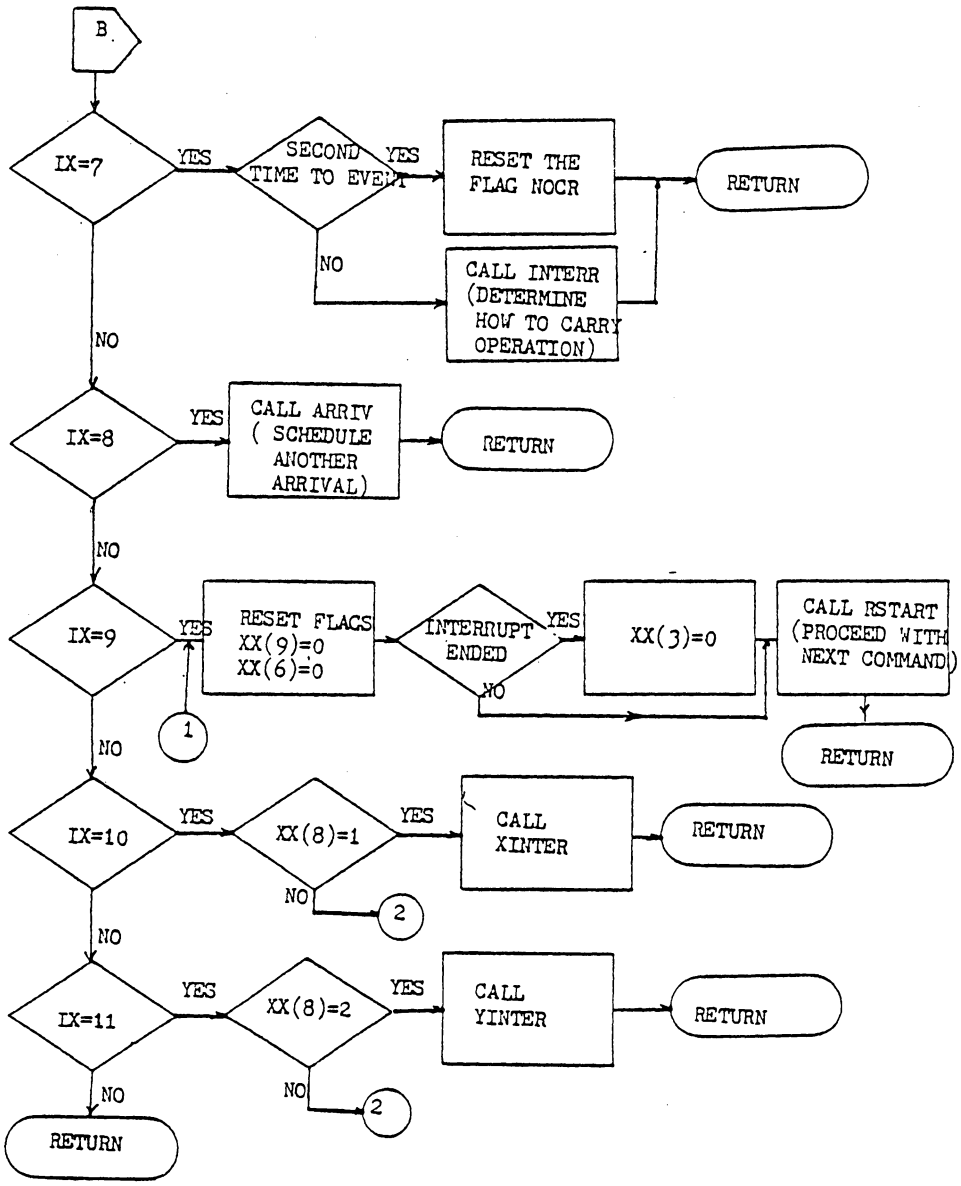

SUBROUTINE INTLC
INITIALIZED ALL COLLECT VARIABLES FOR THE SYSTEM
INITIALIZED ALL FLAGS (XX'S VALUES) AND THE STARTING CONDITION OF THE SYSTEM (SS'S VALUES)
INITIALIZED STARTING POS. OF THE CRANE
GENERATE THE FIRST ARRIVAL
RETURN

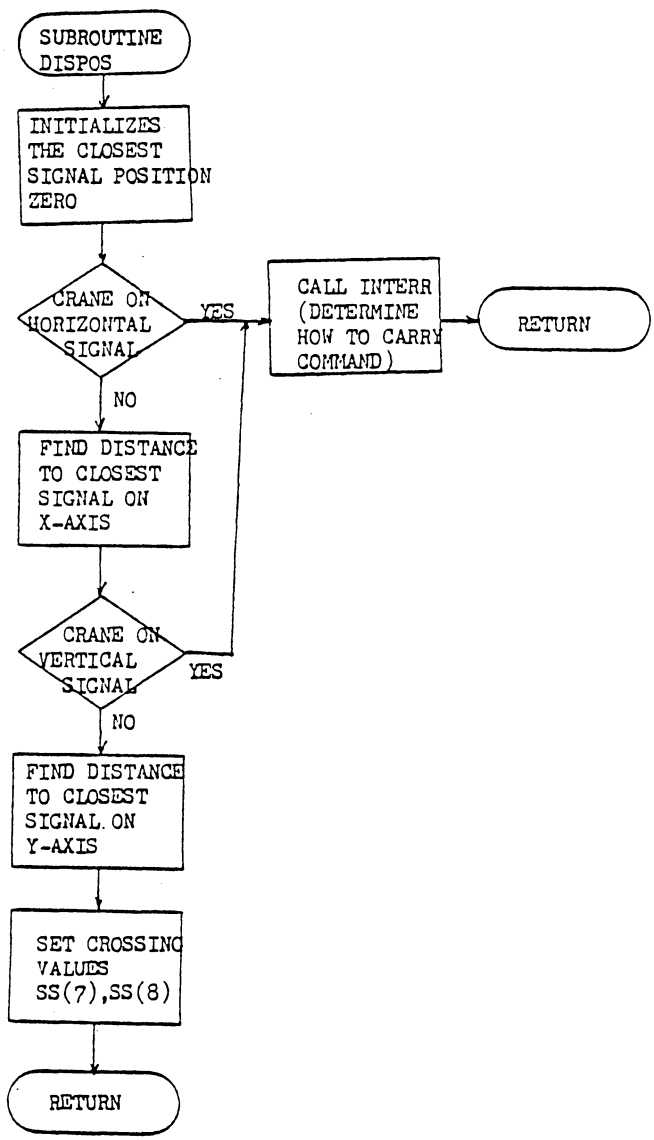

SUBROUTINE ARRIV
COUNT THE NUMBER OF ARRIVALS
NO TIME DEPENDANT
YES
CALL RSTART (SET CRANE IN MOTION)
RETURN
NO
YES
EXCEED CERTAIN LIMIT
NO
SCHEDULE ANOTHER ARRIVAL
CALL LOCBIN (FIND THE NEXT COMMAND)
NO
INTERRUPT REQUIRED
YES
INTERRUPT FAVORABLE
YES
IS CRANE PERFORMING INTERRUPT
NO
CALL INTERRUPT SERVICE ROUTINE
RETURN
YES
FILE THE ROUTINE
TIME DEPENDANT
NO
RETURN
YES
A

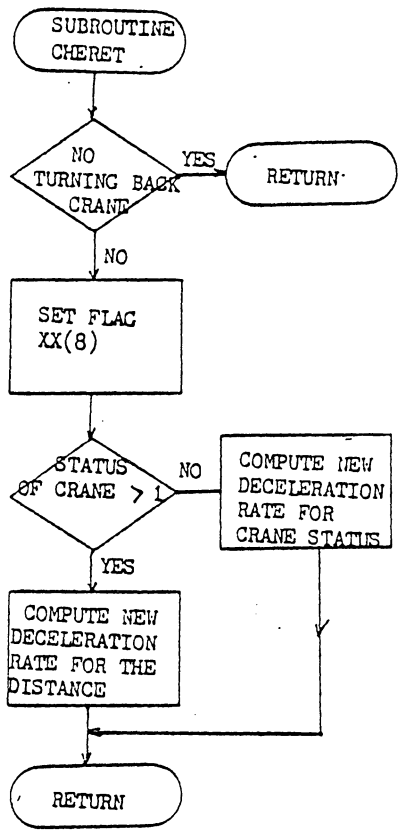

A
CRANE BUSY
YES
NO
CALL RSTART
RETURN

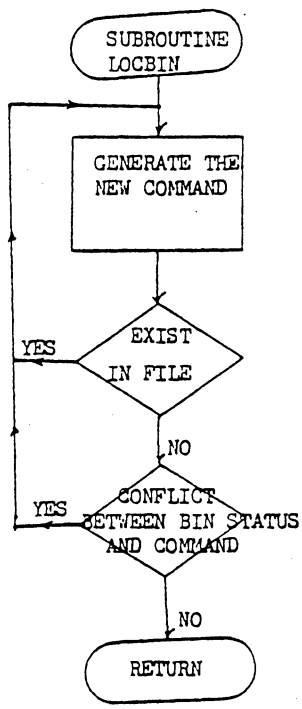

SUBROUTINE STATE
LOADING OR UNLOADING
YES
RETURN
NO
CRANE IDLE
YES
RETURN
NO
READY TO LOAD OR UN-LOAD
YES
SCHEDULE LOADING OR UNLOADING TIME
SET FLAG XX(9)=1
NO
DEPENDING ON HOW FAR THE CRANE HAS TO GO IN THE HORIZONTAL COMPONENT, TAKE MINUTE STEP TO UPDATE THE SIMULATION TIME FOR CHANGES IN THE VELOCITY AND ACCLERATION
TAKE MINUTE STEP TO UPDATE THE SIMULATION TIME FOR CHANGES TO VELOCITY AND ACCELERATION ON THE VERTICAL COMPONENT
RETURN

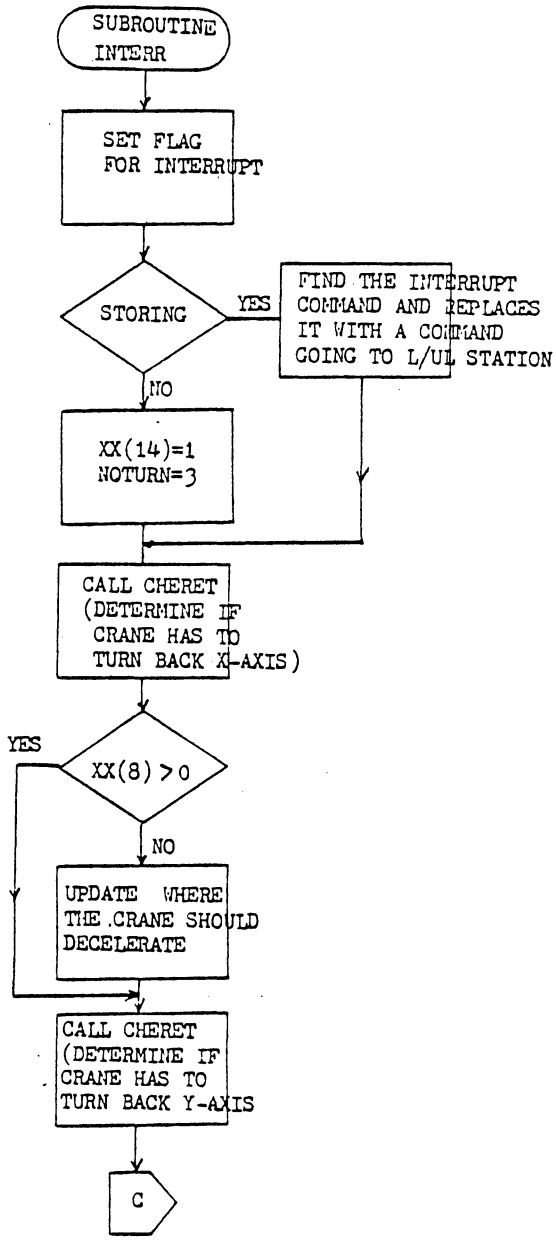

SUBROUTINE EVENT
IX=1
YES
CHANGE STATUS ON HORIZONTAL COMPONENT xx(1)=1
INTERRUPT OCCURANCE
NO
FIND THE DECELERATION DISTANCE
RETURN
YES
NO
IX=2
YES
CHANGE STATUS ON HORIZONTAL COMPONENT XX(1)=2
RETURN
NO
IX=3
YES
CHANGE STATUS ON VERTICAL COMPONENT XX(2)=1
INTERRUPT OCCURANCE
NO
FIND THE DECELERATION DISTANCE
RETURN
YES
NO
IX=4
YES
CHANGE STATUS ON VERTICAL COMPONENT XX(2)=2
RETURN
NO
IX=5
YES
HAS IT OCCUR TWICE
YES
XX(8)=3
NO
RESET THE CRANE'S CURRENT POSITION AND WHETHER LOADING UNLOADING OR TO CALL RSTART IS TO TAKE PLACE NEXT
1
2
NO
RETURN
NO
IX=6
YES
CALL DISPOS (FIND THE DISCRETE SIGNAL)
RETURN
B

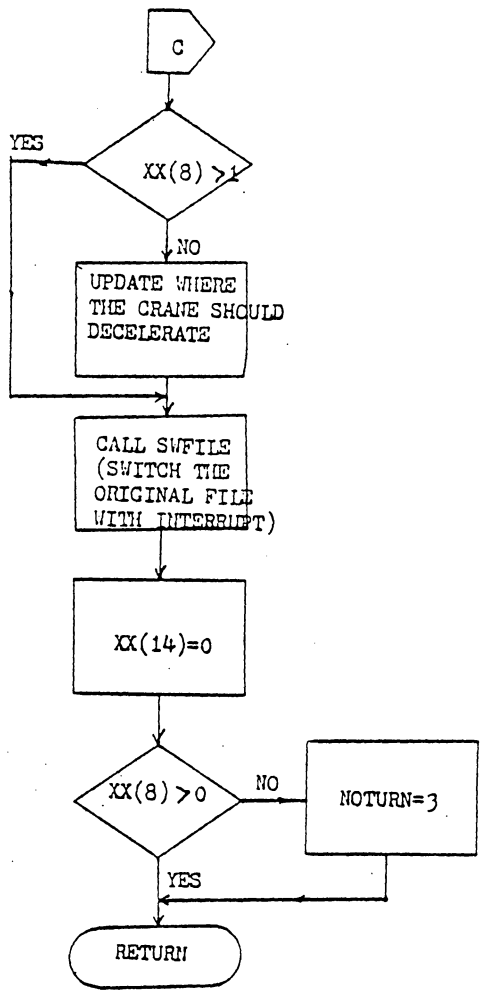

B
IX=7
YES
SECOND TIME TO EVENT
YES
RESET THE FLAG NOCR
RETURN
NO
CALL INTERR (DETERMINE HOW TO CARRY OPERATION)
NO
IX=8
YES
CALL ARRIV (SCHEDULE ANOTHER ARRIVAL)
RETURN
NO
IX=9
YES
RESET FLAGS XX(9)=0 XX(6)=0
INTERRUPT ENDED
YES
XX(3)=0
CALL RSTART (PROCEED WITH NEXT COMMAND)
NO
RETURN
1
NO
IX=10
YES
XX(8)=1
YES
CALL XINTER
RETURN
NO
2
NO
IX=11
YES
XX(8)=2
YES
CALL YINTER
RETURN
NO
2
NO
RETURN

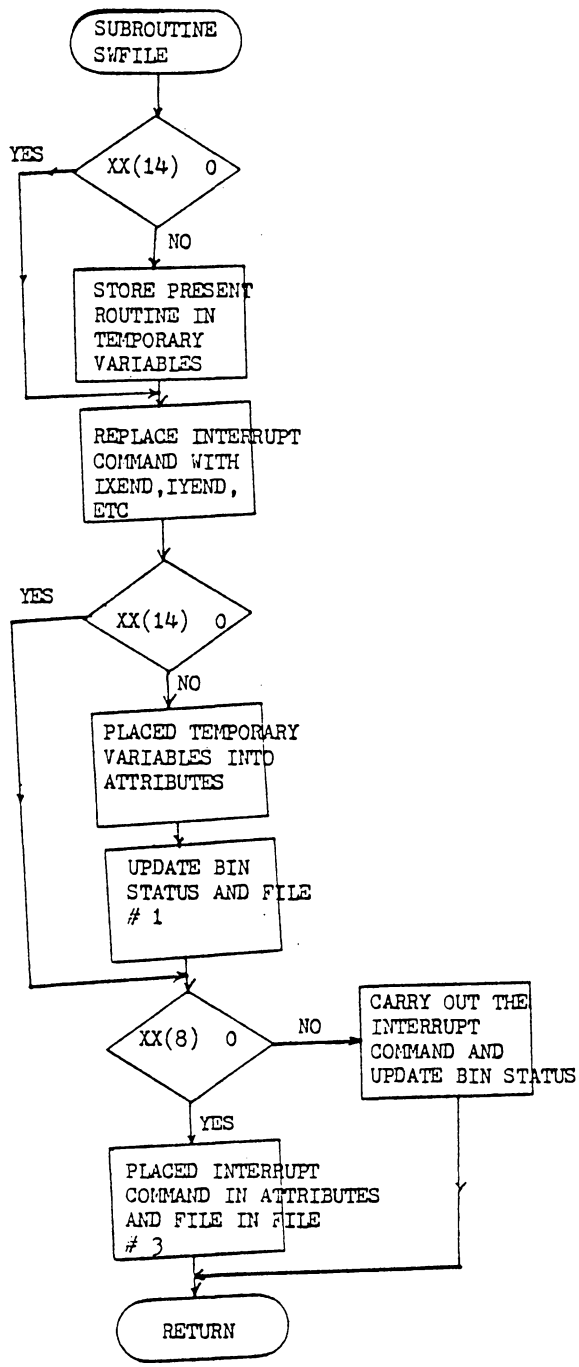

SUBROUTINE DISPOS
INITIALIZES THE CLOSEST SIGNAL POSITION ZERO
CRANE ON HORIZONTAL SIGNAL
YES
CALL INTERR (DETERMINE HOW TO CARRY COMMAND)
RETURN
NO
FIND DISTANCE TO CLOSEST SIGNAL ON X-AXIS
CRANE ON VERTICAL SIGNAL
YES
NO
FIND DISTANCE TO CLOSEST SIGNAL ON Y-AXIS
SET CROSSING VALUES SS(7),SS(8)
RETURN

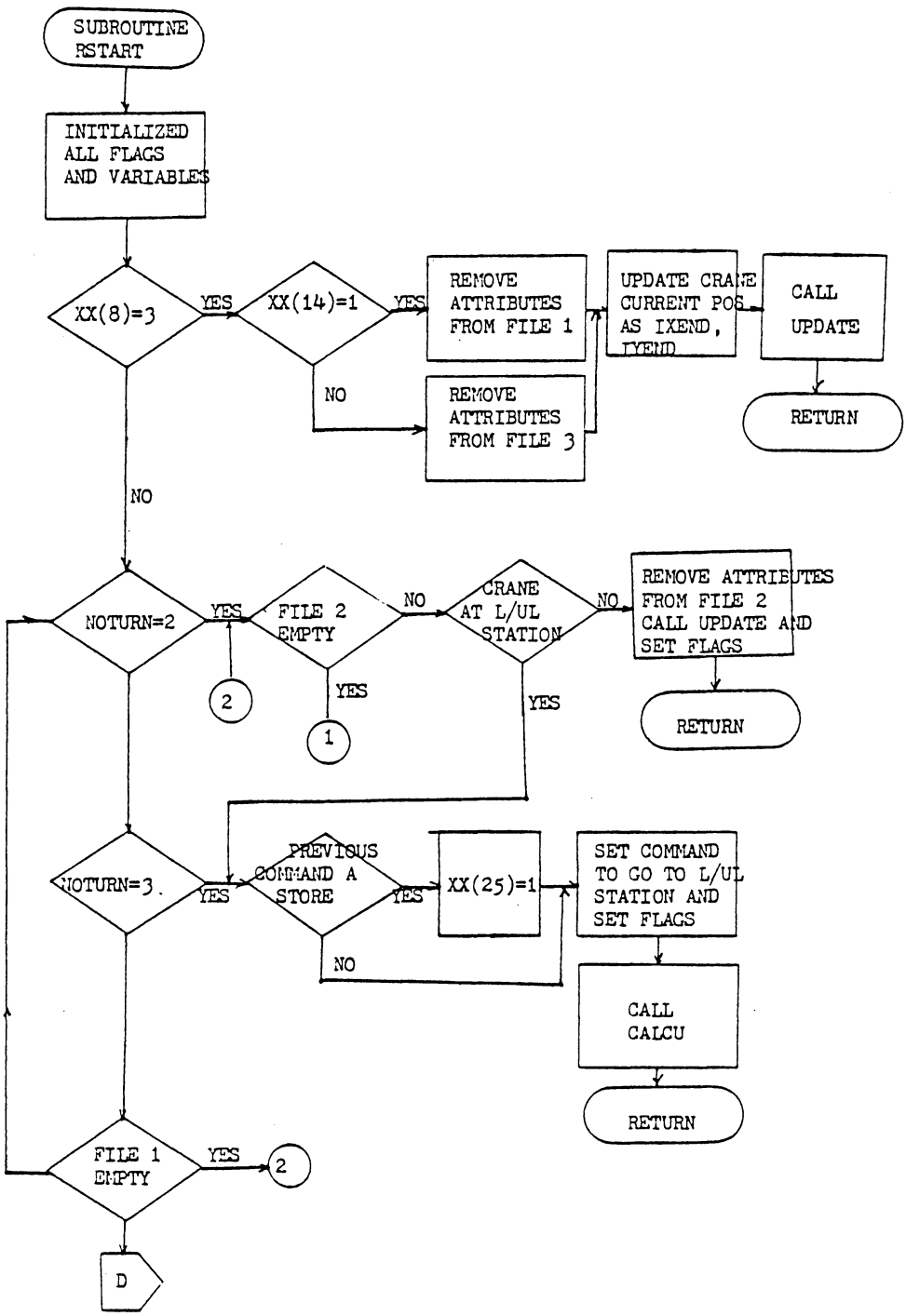

SUBROUTINE CHERET
NO TURNING BACK CRANE
YES
RETURN
NO
SET FLAG XX(8)
STATUS OF CRANE > 1
NO
COMPUTE NEW DECELERATION RATE FOR CRANE STATUS
YES
COMPUTE NEW DECELERATION RATE FOR THE DISTANCE
RETURN

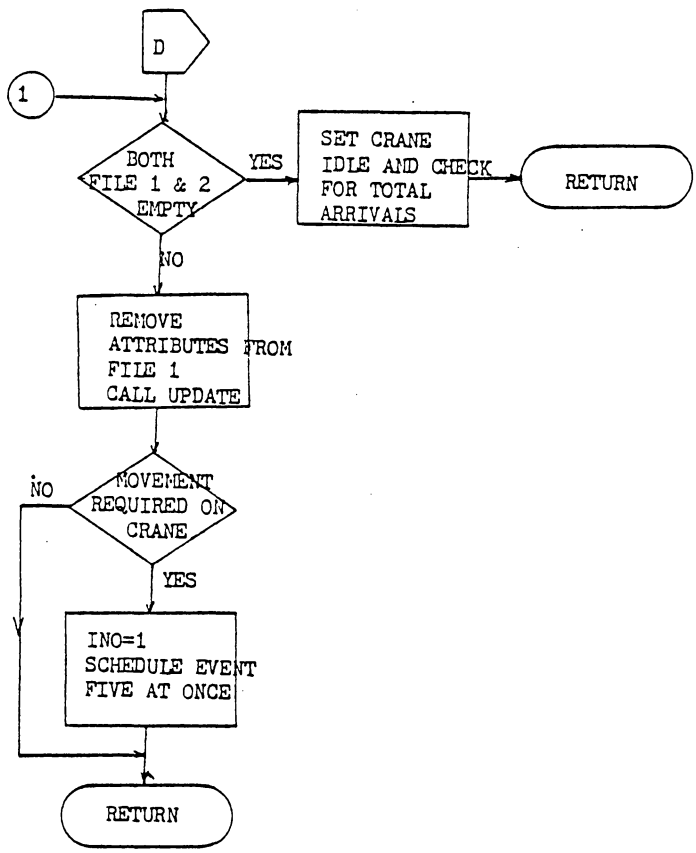

SUBROUTINE LOCBIN
GENERATE THE NEW COMMAND
EXIST IN FILE
YES
NO
CONFLICT BETWEEN BIN STATUS AND COMMAND
YES
NO
RETURN

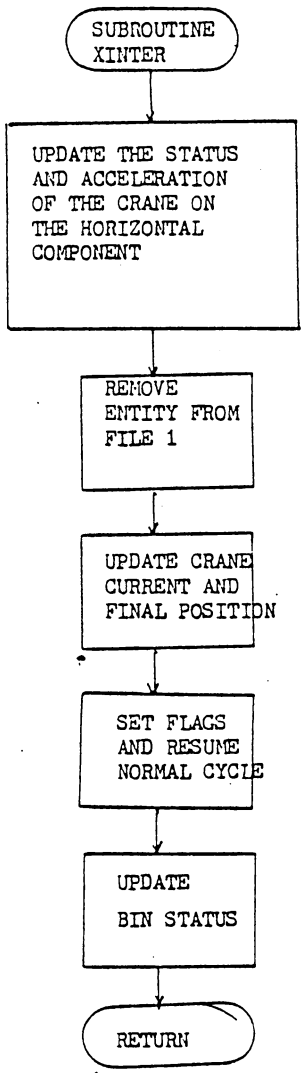

SUBROUTINE INTERR
SET FLAG FOR INTERRUPT
STORING
YES
FIND THE INTERRUPT COMMAND AND REPLACES IT WITH A COMMAND GOING TO L/UL STATION
NO
XX(14)=1 NOTURN=3
CALL CHERET (DETERMINE IF CRANE HAS TO TURN BACK X-AXIS)
YES
XX(8) > 0
NO
UPDATE WHERE THE CRANE SHOULD DECELERATE
CALL CHERET (DETERMINE IF CRANE HAS TO TURN BACK Y-AXIS
C

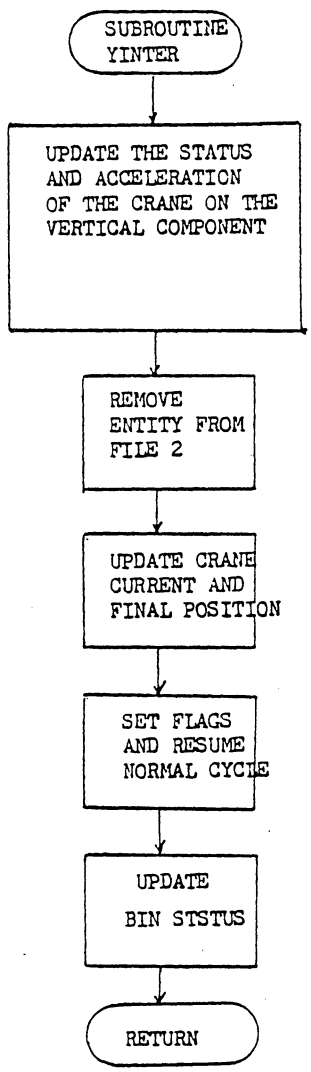

C
YES
XX(8) >1
NO
UPDATE WHERE THE CRANE SHOULD DECELERATE
CALL SWFILE (SWITCH THE ORIGINAL FILE WITH INTERRUPT)
XX(14)=0
XX(8) >0
NO
NOTURN=3
YES
RETURN


SUBROUTINE SWFILE
XX(14) 0
YES
NO
STORE PRESENT ROUTINE IN TEMPORARY VARIABLES
REPLACE INTERRUPT COMMAND WITH IXEND,IYEND, ETC
XX(14) 0
YES
NO
PLACED TEMPORARY VARIABLES INTO ATTRIBUTES
UPDATE BIN STATUS AND FILE # 1
XX(8) 0
NO
CARRY OUT THE INTERRUPT COMMAND AND UPDATE BIN STATUS
YES
PLACED INTERRUPT COMMAND IN ATTRIBUTES AND FILE IN FILE # 3
RETURN


SUBROUTINE RSTART
INITIALIZED ALL FLAGS AND VARIABLES
XX(8)=3
YES
XX(14)=1
YES
REMOVE ATTRIBUTES FROM FILE 1
UPDATE CRANE CURRENT POS AS IXEND, IYEND
CALL UPDATE
RETURN
NO
REMOVE ATTRIBUTES FROM FILE 3
NO
NOTURN=2
YES
FILE 2 EMPTY
NO
CRANE AT L/UL STATION
NO
REMOVE ATTRIBUTES FROM FILE 2 CALL UPDATE AND SET FLAGS
RETURN
2
YES
1
YES
NOTURN=3
YES
PREVIOUS COMMAND A STORE
YES
XX(25)=1
SET COMMAND TO GO TO L/UL STATION AND SET FLAGS
NO
CALL CALCU
RETURN
FILE 1 EMPTY
YES
2
D

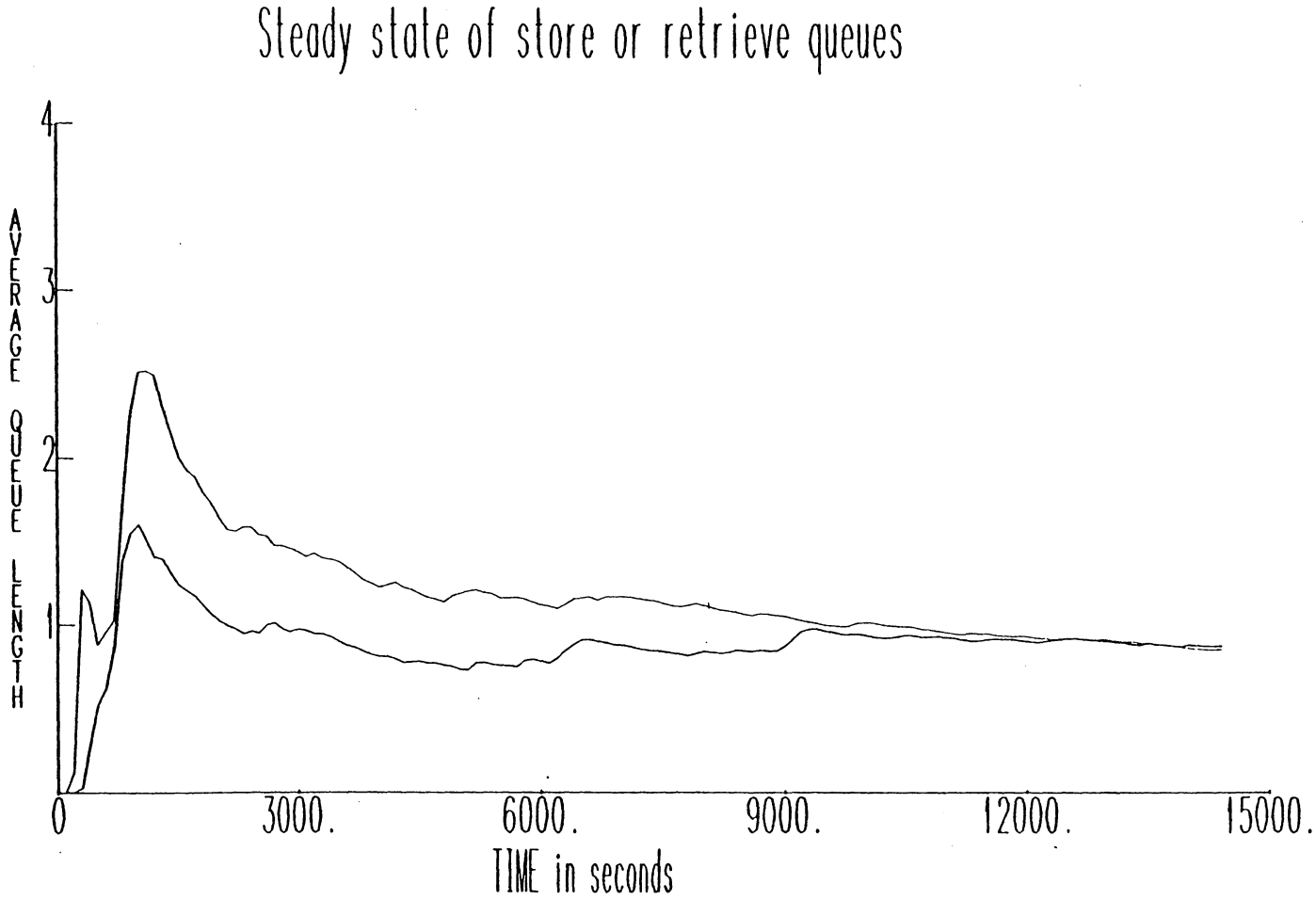

D
1
BOTH FILE 1 & 2 EMPTY
YES
SET CRANE IDLE AND CHECK FOR TOTAL ARRIVALS
RETURN
NO
REMOVE ATTRIBUTES FROM FILE 1 CALL UPDATE
NO
MOVEMENT REQUIRED ON CRANE
YES
INO=1 SCHEDULE EVENT FIVE AT ONCE
RETURN


SUBROUTINE XINTER
UPDATE THE STATUS AND ACCELERATION OF THE CRANE ON THE HORIZONTAL COMPONENT
REMOVE ENTITY FROM FILE 1
UPDATE CRANE CURRENT AND FINAL POSITION
SET FLAGS AND RESUME NORMAL CYCLE
UPDATE BIN STATUS
RETURN


SUBROUTINE YINTER
UPDATE THE STATUS AND ACCELERATION OF THE CRANE ON THE VERTICAL COMPONENT
REMOVE ENTITY FROM FILE 2
UPDATE CRANE CURRENT AND FINAL POSITION
SET FLAGS AND RESUME NORMAL CYCLE
UPDATE BIN STSTUS
RETURN

APPENDIX B

Steady State of Storage and Retrieves Queues


Steady state of store or retrieve queues
AVERAGE QUEUE LENGTH
4
3
2
1
0
3000.
6000.
9000.
12000.
15000.
TIME in seconds

APPENDIX C

Data from Simulation Program

RAW DATA OF ALL TREATMENTS WITHOUT INTERRUPT

ARRIVAL RATE	TRT	REP.	AVG STORE QUEUE	AVG. RETRIEVE QUEUE	CRANE UTILIZATION
20.0	1	1	1.7040	1.2319	89.78
		2	1.1291	1.1619	89.12
		3	1.0954	.7415	85.84
		4	.9944	1.2313	87.97
		5	1.6197	1.2229	88.60
	2	1	.6863	.7076	78.50
		2	.7238	.5958	81.97
		3	.6685	.6203	78.59
		4	.6109	.5456	79.58
		5	.6107	.6345	77.59
	3	1	.3854	.4159	65.70
		2	.3783	.2787	68.82
		3	.3536	.3832	70.82
		4	.3327	.1608	60.79
		5	.3464	.2917	68.06
	4	1	1.1326	.8924	83.37
		2	.9612	.7826	85.14
		3	.7415	.5699	80.51
		4	.6411	.9572	84.68
		5	.9883	.8534	83.47
	5	1	.5270	.5310	73.49
		2	.5560	.4527	77.00
		3	.5061	.4421	74.23
		4	.4192	.4466	74.17
		5	.4081	.5332	72.58
	6	1	.2881	.3085	60.86
		2	.2994	.2171	63.09
		3	.3292	.2418	65.20
		4	.2551	.1693	57.71
		5	.2556	.2929	63.61
	7	1	4.5982	2.5544	93.56
		2	2.3413	1.5645	96.36
		3	1.0229	2.3009	93.01
		4	1.9314	3.2942	96.30
		5	3.6141	2.5934	94.24
	8	1	1.5122	.8640	86.79
		2	1.3243	.8676	89.27
		3	1.1218	1.1305	85.55

	4	.9059	.8312	87.24
	5	1.2362	1.0445	85.20
9	1	.5220	.5693	72.13
	2	.5178	.4237	76.48
	3	.6046	.5247	77.81
	4	.3809	.2562	68.73
	5	.4030	.5089	74.61
10	1	.2107	.0988	91.26
	2	.2573	.1123	90.32
	3	.2172	.1484	89.97
	4	.2628	.1045	90.41
	5	.2760	.1344	91.68
11	1	.1201	.0225	79.61
	2	.1187	.0257	78.28
	3	.1177	.0202	78.57
	4	.1299	.0192	80.05
	5	.1370	.0246	79.06
12	1	.0899	.0007	65.37
	2	.0832	.0013	64.39
	3	.0815	.0007	63.84
	4	.0818	.0013	64.98
	5	.0928	.0013	65.37
13	1	.1425	.0395	85.15
	2	.1656	.0435	84.67
	3	.1401	.0565	84.11
	4	.1694	.0387	84.73
	5	.1688	.0400	85.78
14	1	.1137	.0073	75.25
	2	.0958	.0067	74.06
	3	.0953	.0077	73.04
	4	.0950	.0047	73.18
	5	.1037	.0050	74.52
15	1	.0816	.0000	60.81
	2	.0756	.0000	60.05
	3	.0741	.0000	59.51
	4	.0748	.0001	60.51
	5	.0849	.0000	60.93
16	1	.5613	.5909	98.44
	2	.4993	.3445	97.06
	3	.4702	.3375	97.51
	4	.5738	.4029	97.59
	5	.7005	.4899	98.20

	17	1	.2034	.0884	89.15
		2	.2081	.1088	87.34
		3	.2046	.1011	87.77
		4	.2208	.0894	89.72
		5	.2631	.1179	88.11
	18	1	.1135	.0108	73.43
		2	.1067	.0096	72.17
		3	.1041	.0085	71.55
		4	.1027	.0105	72.90
		5	.1126	.0102	73.30
23.0	1	1	1.4676	.8550	86.92
		2	1.0978	.8681	86.95
		3	.7895	.6763	82.31
		4	.7915	.7728	85.76
		5	1.2049	.9658	85.63
	2	1	.6499	.5046	79.24
		2	.5790	.5090	76.00
		3	.5347	.4682	76.91
		4	.5770	.6021	75.40
		5	.4760	.5800	74.63
	3	1	.3307	.3506	62.30
		2	.3239	.2528	64.81
		3	.2763	.3242	66.53
		4	.2655	.1712	59.57
		5	.3160	.2502	65.55
	4	1	.7068	.5991	80.56
		2	.5232	.5759	79.42
		3	.4994	.4696	78.25
		4	.9433	.8751	84.30
		5	.5529	.8293	80.35
	5	1	.3779	.4708	70.25
		2	.3438	.4246	60.94
		3	.4114	.3382	71.12
		4	.4683	.3737	69.82
		5	.3929	.3641	71.33
	6	1	.3038	.2122	59.39
		2	.2149	.2505	56.53
		3	.2853	.2124	60.54
		4	.2825	.1844	58.52
		5	.2237	.2166	60.81
	7	1	3.1819	2.0565	92.72
		2	1.7392	1.5026	91.68

	17	1	.2034	.0884	89.15
		2	.2081	.1088	87.34
		3	.2046	.1011	87.77
		4	.2208	.0894	89.72
		5	.2631	.1179	88.11
	18	1	.1135	.0108	73.43
		2	.1067	.0096	72.17
		3	.1041	.0085	71.55
		4	.1027	.0105	72.90
		5	.1126	.0102	73.30
23.0	1	1	1.4676	.8550	86.92
		2	1.0978	.8681	86.95
		3	.7895	.6763	82.31
		4	.7915	.7728	85.76
		5	1.2049	.9658	85.63
	2	1	.6499	.5046	79.24
		2	.5790	.5090	76.00
		3	.5347	.4682	76.91
		4	.5770	.6021	75.40
		5	.4760	.5800	74.63
	3	1	.3307	.3506	62.30
		2	.3239	.2528	64.81
		3	.2763	.3242	66.53
		4	.2655	.1712	59.57
		5	.3160	.2502	65.55
	4	1	.7068	.5991	80.56
		2	.5232	.5759	79.42
		3	.4994	.4696	78.25
		4	.9433	.8751	84.30
		5	.5529	.8293	80.35
	5	1	.3779	.4708	70.25
		2	.3438	.4246	60.94
		3	.4114	.3382	71.12
		4	.4683	.3737	69.82
		5	.3929	.3641	71.33
	6	1	.3038	.2122	59.39
		2	.2149	.2505	56.53
		3	.2853	.2124	60.54
		4	.2825	.1844	58.52
		5	.2237	.2166	60.81
	7	1	3.1819	2.0565	92.72
		2	1.7392	1.5026	91.68

	3	1.4207	1.7252	90.12
	4	2.0680	1.6491	93.21
	5	2.9745	1.9693	92.47
8	1	1.0929	.8987	83.65
	2	.6811	.6439	82.26
	3	.8116	.8294	83.51
	4	.9857	.8620	86.20
	5	.8922	1.1874	84.17
9	1	.4325	.4130	70.59
	2	.3890	.3861	72.14
	3	.4790	.4305	75.61
	4	.4303	.2889	67.78
	5	.5215	.3179	74.06
10	1	.2162	.0944	88.62
	2	.2219	.0814	88.68
	3	.1726	.0689	87.74
	4	.2078	.0733	86.76
	5	.1865	.1271	88.63
11	1	.1089	.0160	76.36
	2	.1075	.0177	74.96
	3	.1068	.0129	75.33
	4	.1177	.0125	76.79
	5	.1206	.0167	75.78
12	1	.0978	.0006	64.32
	2	.0857	.0003	62.71
	3	.0788	.0007	61.70
	4	.0774	.0003	61.19
	5	.0780	.0007	62.29
13	1	.1324	.0285	81.91
	2	.1398	.0333	81.83
	3	.1642	.0364	83.15
	4	.1370	.0309	82.60
	5	.1324	.0289	81.59
14	1	.1026	.0055	72.15
	2	.1041	.0045	72.17
	3	.0901	.0038	69.97
	4	.0994	.0052	71.70
	5	.0915	.0050	72.08
15	1	.0880	.0000	59.17
	2	.0836	.0000	59.25
	3	.0799	.0000	59.24
	4	.0722	.0000	58.04

	5	.0763	.0000	58.67
16	1	.5221	.3766	97.47
	2	.6759	.4430	97.73
	3	.4978	.3776	96.63
	4	.4835	.5405	97.38
	5	.4500	.5180	97.88
17	1	.2241	.0846	87.82
	2	.2335	.1235	88.71
	3	.2707	.1142	89.07
	4	.1937	.0771	85.48
	5	.2275	.1066	88.50
18	1	.1212	.0130	73.18
	2	.1074	.0108	72.54
	3	.1136	.0096	73.20
	4	.1052	.0109	71.52
	5	.1069	.0136	72.80
1	1	2.0676	1.8550	91.88
	2	1.3499	3.4764	92.88
	3	1.4851	1.3574	92.59
	4	1.3045	1.0887	90.03
	5	3.1862	1.9910	92.68
2	1	.9135	.7274	81.93
	2	.9298	.6281	83.68
	3	1.0746	.6124	82.80
	4	.8075	.7358	83.44
	5	1.1164	.6391	80.72
3	1	.5921	.2960	67.37
	2	.4698	.4099	72.43
	3	.5820	.3803	74.13
	4	.2481	.3390	66.02
	5	.4869	.3589	72.95
4	1	1.5577	1.6066	89.25
	2	1.4359	.8367	89.84
	3	.8320	.8768	84.67
	4	1.3461	1.3580	88.90
	5	1.9415	1.0814	89.86
5	1	.7335	.5321	78.05
	2	.5961	.5848	79.73
	3	.7869	.7922	79.99
	4	.6786	.5764	80.70
	5	.5754	.7101	78.73

6	1	.3141	.3407	65.60
	2	.3358	.3257	67.68
	3	.5227	.2493	70.93
	4	.3327	.2310	63.62
	5	.3901	.2815	68.76
7	1	6.1341	3.9474	95.67
	2	2.4219	2.3782	97.63
	3	2.5829	1.4229	96.20
	4	4.0435	6.4048	95.37
	5	1.5407	2.9108	97.80
8	1	1.9361	1.4502	88.89
	2	1.0874	.9226	88.01
	3	1.3776	1.2253	88.40
	4	1.2914	1.2848	91.61
	5	1.6465	1.3169	88.36
9	1	.4837	.6441	74.86
	2	.5820	.3926	76.96
	3	.7788	.6907	80.42
	4	.3601	.4256	70.93
	5	.6327	.4272	79.20
10	1	.3844	.2588	96.88
	2	.5466	.3498	97.63
	3	.4658	.2949	96.41
	4	.3971	.5914	96.82
	5	.4018	.2654	96.81
11	1	.1761	.0455	86.34
	2	.1974	.0711	87.36
	3	.2001	.0598	87.52
	4	.1635	.0501	84.61
	5	.1721	.0543	86.77
12	1	.1126	.0030	71.70
	2	.1085	.0042	71.77
	3	.0974	.0036	71.09
	4	.1015	.0024	71.79
	5	.0930	.0036	70.28
13	1	.2815	.1357	93.68
	2	.3459	.1777	94.53
	3	.2822	.1470	94.45
	4	.2592	.1528	93.48
	5	.2549	.1583	92.86
14	1	.1380	.0182	81.88
	2	.1428	.0255	82.77

	3	.1453	.0229	82.93
	4	.1200	.0195	80.47
	5	.1328	.0210	82.36
15	1	.1032	.0002	67.95
	2	.0981	.0004	68.01
	3	.0894	.0002	67.41
	4	.0929	.0002	68.06
	5	.0839	.0004	66.72
16	1	1.1660	.7148	99.87
	2	1.5087	.9628	99.85
	3	.9346	1.2086	99.86
	4	1.2093	.9670	99.67
	5	.9680	.9134	99.89
17	1	.3647	.2339	94.98
	2	.4117	.2262	95.00
	3	.3100	.1840	92.48
	4	.3348	.2243	94.51
	5	.3222	.1906	94.29
18	1	.1453	.0251	79.04
	2	.1281	.0196	78.33
	3	.1349	.0212	79.10
	4	.1216	.0189	77.31
	5	.1275	.0247	78.65

DATA FROM DISCRETE INTERRUPT AT 25% OF DISTANCE TRAVELLED

ARRI RATE	TRT	REP.	AVG. STO QUE	AVG RET QUE	CRANE UTIL	NO. OF INT	TYPE1 REQ	TYPE2 REQUEST
20.	2	1	.9169	.7534	82.03	10	14	31
		2	.6923	1.0831	82.12	14	25	28
		3	.7813	.6848	82.63	11	32	29
		4	1.1361	.6743	82.15	10	30	34
		5	.8471	.7944	79.22	8	28	29
23	2	1	.4341	.3613	72.93	8	16	19
		2	.3882	.6445	71.19	13	14	17
		3	.6751	.3424	72.42	14	23	26
		4	.4428	.3488	72.04	11	14	19
		5	.6541	.4614	74.88	7	19	22
28	2	1	.3475	.2361	62.51	10	12	19
		2	.2466	.1961	60.44	11	14	17
		3	.2841	.2084	59.27	13	18	15
		4	.2964	.2144	60.17	7	15	16
		5	.3566	.2253	61.72	12	17	21
20	11	1	.1397	.0413	84.41	1	1	2
		2	.1577	.0402	85.62	0	0	0
		3	.1684	.0566	83.98	0	1	1
		4	.1538	.0448	85.11	0	0	0
		5	.1621	.0478	84.73	0	1	0
23	11	1	.1044	.0083	74.11	0	0	0
		2	.0962	.0076	73.24	0	0	0
		3	.1133	.0038	75.08	0	0	0
		4	.1167	.0046	73.89	0	0	0
		5	.1087	.0043	72.83	0	0	0
28	11	1	.0775	0.0	60.14	0	0	0
		2	.0884	0.0	61.23	0	0	0
		3	.0843	0.0	60.83	0	0	0
		4	.0913	0.0	62.01	0	0	0
		5	.0871	0.0	60.37	0	0	0

0	5	1	.8405	.7422	83.17	9	30	23
		2	.7014	.6034	81.14	11	24	27
		3	.8022	.6837	77.63	6	25	26
		4	.5847	.5724	78.89	10	30	32
		5	.5241	.4791	80.23	11	26	21
23	5	1	.3472	.3544	71.46	7	25	19
		2	.4623	.4306	68.47	9	22	21
		3	.4185	.4022	69.23	8	18	22
		4	.3877	.3471	73.01	11	23	27
		5	.3924	.3305	70.11	10	20	24
28	5	1	.2647	.1688	61.44	5	16	19
		2	.2318	.2302	56.43	7	18	21
		3	.2862	.2054	58.72	6	19	15
		4	.2473	.2114	60.17	4	17	14
		5	.2336	.1978	60.88	6	16	17
20	14	1	.1501	.0313	82.07	0	0	0
		2	.1344	.0302	81.22	0	0	0
		3	.1307	.0276	80.67	0	0	0
		4	.1215	.0285	84.06	0	0	0
		5	.1351	.0294	78.60	0	0	0
23	14	1	.1017	.0056	72.03	0	0	0
		2	.1105	.0042	67.98	0	0	0
		3	.0843	.0048	70.34	0	0	0
		4	.0975	.0052	71.14	0	0	0
		5	.0981	.0049	72.64	0	0	0
28	14	1	.0688	0.0	60.11	0	0	0
		2	.0842	0.0	59.44	0	0	0
		3	.0753	0.0	61.06	0	0	0
		4	.0814	0.0	58.83	0	0	0
		5	.0744	0.0	59.97	0	0	0

DATA FROM CONTINUOUS INTERRUPT AT 25% OF DISTANCE TRAVELLED

ARRI RATE	TRT	REP.	AVG. STO QUE	AVG RET QUE	CRANE UTIL	NO. OF INT	TYPE1 REQ	TYPE2 REQUEST
20.	2	1	.8215	.7859	82.13	6	16	28
		2	.8199	.5401	79.40	10	23	19
		3	1.0892	1.1461	85.15	14	23	38
		4	.9832	.6303	83.77	10	30	22
		5	.7460	.5901	81.26	8	25	26
23	2	1	.7047	.5092	74.56	9	25	20
		2	.4835	.4565	71.75	10	21	20
		3	.6345	.3370	74.22	7	17	27
		4	.5919	.4808	76.47	3	20	20
		5	.4938	.3055	73.48	6	16	21
28	2	1	.3698	.2195	61.54	7	15	14
		2	.2976	.2376	62.06	9	14	20
		3	.3478	.2474	61.07	8	17	21
		4	.2257	.1894	58.65	4	13	20
		5	.3436	.2206	63.37	10	10	19
20	11	1	.1450	.0425	84.25	1	1	2
		2	.1667	.0578	85.99	0	4	3
		3	.1705	.0437	84.12	0	2	2
		4	.1594	.0392	85.74	1	2	1
		5	.1608	.0473	85.83	0	1	0
23	11	1	.1012	.0092	74.89	0	0	0
		2	.0981	.0060	73.01	0	0	0
		3	.1216	.0037	75.34	0	0	0
		4	.1148	.0045	73.83	0	0	0
		5	.1020	.0038	73.61	0	0	0
28	11	1	.0726	0.0	61.86	0	0	0
		2	.0853	0.0	60.25	0	0	0
		3	.0785	0.0	60.40	0	0	0
		4	.0957	0.0	62.04	0	0	0
		5	.0840	0.0	60.22	0	0	0
20	5	1	.8805	.7530	84.03	15	27	34
		2	.6412	.5761	79.05	7	23	32
		3	.8142	.7021	78.13	11	30	27
		4	.5213	.5978	81.02	10	22	30
		5	.5634	.4434	76.44	12	35	30
23	5	1	.3614	.4521	70.82	10	21	24
		2	.4453	.3227	67.28	9	23	18
		3	.4324	.3162	71.22	11	24	27
		4	.3866	.3654	69.97	6	19	21

		5	.3941	.3526	70.89	8	18	19
28	5	1	.2356	.1486	55.64	3	15	22
		2	.2964	.2273	63.21	7	16	24
		3	.2752	.1980	60.52	4	18	17
		4	.2421	.2053	59.28	6	19	16
		5	.2262	.2162	61.82	6	15	18
20	14	1	.1341	.0288	82.54	1	2	3
		2	.1281	.0321	80.27	0	0	0
		3	.1304	.0297	81.67	0	0	0
		4	.1377	.0305	83.05	0	1	1
		5	.1524	.0267	81.92	0	1	0
23	14	1	.1031	.0051	71.24	0	0	0
		2	.1012	.0047	70.08	0	0	0
		3	.0995	.0043	68.41	0	0	0
		4	.0841	.0053	73.24	0	0	0
		5	.0962	.0042	72.11	0	0	0
28	14	1	.0754	0.0	59.14	0	0	0
		2	.0824	0.0	60.77	0	0	0
		3	.0693	0.0	58.71	0	0	0
		4	.0772	0.0	61.14	0	0	0
		5	.0850	0.0	59.60	0	0	0

DATA FROM CONTINUOUS INTERRUPT AT 35% OF DISTANCE TRAVELLED

ARRI RATE	TRT	REP.	AVG. STO QUE	AVG RET QUE	CRANE UTIL	NO. OF INT	TYPE1 REQ	TYPE2 REQUEST
20.	2	1	.8013	.6790	80.30	11	25	28
		2	.7958	.5528	83.82	12	28	16
		3	.7692	.5196	76.92	8	24	26
			.7348	.6168	82.13	17	22	26
		5	1.0421	.7732	84.55	19	19	32
23	2	1	.4224	.3042	72.89	16	23	20
		2	.5167	.4571	67.47	12	24	19
		3	.4865	.4907	75.16	14	21	20
		4	.4131	.3195	69.16	14	20	25
		5	.5751	.5059	74.94	9	25	23
28	2	1	.2785	.2808	60.93	9	17	15
		2	.2669	.2405	58.78	3	12	18
		3	.3282	.1996	65.45	10	17	13
		4	.2146	.1656	56.16	8	11	21
		5	.2431	.1942	59.49	13	12	22

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