DIGITAL SIMULATION OF AN AUTOMATED WAREHOUSE

by

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Approved by:

L. E. Grosh

Major Professor

To my parents Mr. and Mrs. U. Ananda Rau,

who mean the world to me.

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CHAPTER I

INTRODUCTION

1.1. INTRODUCTION

"Auto" in Greek means "not requiring human supervision". Automation is the replacement of human supervision of machines and mechanical process by automatic supervision.

An automated warehouse is just that. It requires partial or no supervision at all. Automated warehousing is a relatively new field compared to the other aspects of an industry, but it is growing very rapidly due to the increased use of the computer in industrial applications. There are about 50 automated warehouses in commission in the U.S.A. and 50 more are being planned. It is estimated that there are about 20 automatic warehouses in existence, being planned or built, in the U.K. and about 40 in the rest of Europe. These statistics give a perfect picture of the growing interest in automation in warehousing.

One of the objectives of this thesis is to make a concise report on the automated warehouse. There is not much literature available in this field apart from few reports brought out by people who have some experience operating an automated warehouse. The author has made a sincere effort to make an outline of the types, functions and economics of all the aspects of automated warehousing. The discussions are not detailed but brief and concise, and whatever information given here has been taken from the available literature.

A model of an automated warehouse has been developed, to be simulated on a computer. The automated warehouse has been simulated on an IBM 360/50 computer, using GASP IIA. The capabilities of the various aspects of the warehouse have been determined. The effects of different storage times, various throughputs, and production cycles have been studied. The right amount of preload necessary for the warehouse to operate in accordance with the management policies have been determined. GASP IIA a newer version of the GASP series has been used for the first time in the University.

The first chapter brings out the relative importance of warehousing to the other branches of the industry - like production, sales, etc. One wonders, after a look at the statistics, why warehousing in the past was considered an unnecessary expense, let alone a significant contribution to profits.

The second chapter deals with automated warehousing and its important aspects have been briefly discussed. The third chapter makes a brief survey of the existing literature.

The fourth chapter covers the main objective of the thesis - the simulation. The particular problem has been outlined and a model for an automated warehouse has been developed using GASP IIA. The fifth chapter is mainly devoted to the discussion of the results.

1.2. IMPORTANCE OF WAREHOUSING:

It is, or rather it was frequently asked whether warehousing is a wasted expense. If the cost of supplying customers directly from the manufacturing source is compared to the cost of using warehouses, the latter is generally seen as an added expense. However a closer look at the objective and function of a warehouse will satisfy the most pessimistic and reluctant user of a warehouse.

Warehousing is a function of storing goods between the time they are produced and the time they are needed [44]. In practice goods are produced in long and economical production runs to gain lower unit cost and shipped in large lots to warehouses close to the market. Large shipments reduce the transit charges. From the warehouse the goods are reshipped to customers in smaller quantities as and when needed. The storage of goods near the market enables the deliveries to be made quickly giving better customer service and good will. This marketing technique is one of the main reasons why the field of warehousing is expanding so rapidly. The modern warehouse is more than a storage place. In the warehouse the stocks are split and sorted into various batches and customer orders. The different orders are checked, repacked, labelled and shipped to the various shipping points. Warehousing is a dynamic aspect of an industry and it is one of the key points in the physical distribution channel of any organization.

Warehousing also seems to hold buffer stocks for long production runs and in-process inventories as a reservoir for emergencies or increased demand. Warehousing increases the time and place utility of goods by making them available at the right time and right place to the man who wants them, thus increasing the value of the goods. Without warehouses the nations present distribution system could not exist. Hence as a highly sophisticated field, warehousing is expanding rapidly.

In a typical manufacturing company, approximately one third to one half of the firm's total assets are invested in inventories. About 13 cents of every sales dollar is spent in the physical movement and storage of the product. There are over 200,000 warehouses in the U.S.A. today, employing over 2 million people at an annual operating cost of $20 billion. It is not therefore surprising that warehousing and material handling are given top priority by management [20], and more companies tend to consider automation or mechanization as a means of cost reduction.

The main application of automation in the recent years has been in manufacturing and production process thus reducing the manufacturing costs appreciably. Consequently the cost of warehousing became significant compared to the production costs when the total cost of the product is considered. The ability to reach the customer quickly and efficiently is also a significant factor for automation in warehouses.

Again automated warehousing is rapidly growing due to the increased use of computers for stock record purposes and for calculation and controlling of optimum stock levels. Control of stock by computers involves a substantial capital expenditure. Having installed the computer for control of records and information retrieval, the next step of controlling the physical movement of stock by the same computer is obvious. This involves the expenditure for the material handling equipment only, since the computer is the same.

In the future there is another reason for the development in automated warehousing. This year and in the decade to come, the total system approach is going to be the most intensively used tool in the industry. By total system in handling, we mean that right from the incoming raw materials, through production, and right through the entire physical distribution, ultimately to the customer, the whole series of operation and stock points is considered as one system and not as individual process, or operations, The system consists then of a series of operations linked by a physical flow and the whole system is controlled by a central computer. A high level of perception and instant response is required of each individual system to be a part of a highly complex computerized system. Hence the sophisticated techniques like automation has to be utilized in warehousing, which obviously is a stock point between the operation of the system. A tremendous increase in efficiency and potential savings is foreseen by this total systems approach.

CHAPTER 2

THE AUTOMATED WAREHOUSE

2.1. WHAT IS AN AUTOMATED WAREHOUSE?

2.1.1. Definition: There is no generally accepted definition of the automated warehouse. For many it means a computer-controlled operation with no people, while more often it means providing specialized material handling equipment for the handling and storage of a product. Automated warehouses is just not specialized material handling equipment. It is a system by itself with a central controller, usually a computer, which handles both the information and data processing and the physical handling of the materials according to the operating business decisions. An automatic warehouse then, tries to integrate the necessary information flow required for operating business decisions in a closed loop with the physical handling and storage of a product [20].

At this juncture one point should be made clear. By computer controlled warehousing, it is meant Real-time Systems and not on-line systems. In the real time systems the computer decides and directly interacts with the system environment. In on-line systems computers are directly connected to the input/output terminals which interact with the environment. A real time system must be on-line but an on-line system need not be real-time. Not many warehouses are completely computer controlled. The Kitchens of Sarah Lee Warehouse in Chicago and the Union Carbide's South Charleston warehouse are examples of computer control [55], [90], [83].

Most of the automated warehouses are on-line systems. Since a large percentage of the duties is performance by the computer, in the following report even such systems are called as computer controlled systems, and whenever they are real time or on-line, mention has been made.

2.1.2 Main Duties: The automated warehouse has two main parts, a data processing system and a material handling system. The general relationship is shown in Figure (1). The prime function of the data-processing system is a "memory" for all the current information on the identity, quantity, and location of the stock. In a conventional warehouse this can be compared with the usual stock record index and other paperwork that make up the retinue of a conventional warehouse. The data processing operation of a warehouse requires the precise control of the following information:

1. The warehouse input - the origin, type and number of goods entering the system.
2. The warehouse stocks - the number, type, variety and the physical location of the stock in the warehouse.
3. The warehouse output - the number and variety of goods being extracted, the location from which they are taken, and the destination or customer intended for them [31].

Such information is now completed controlled by the computers. In an ideal automated warehouse the main computer memory will carry information about the number, types, and location of the goods and whenever a new material enters the warehouse the current stock information is updated by the computer which gets the message from the various input-output devices. The computer automatically stores the material in the warehouse and updates the information in its memory. Correspondingly whenever an order for the material comes in, the computer is notified through the

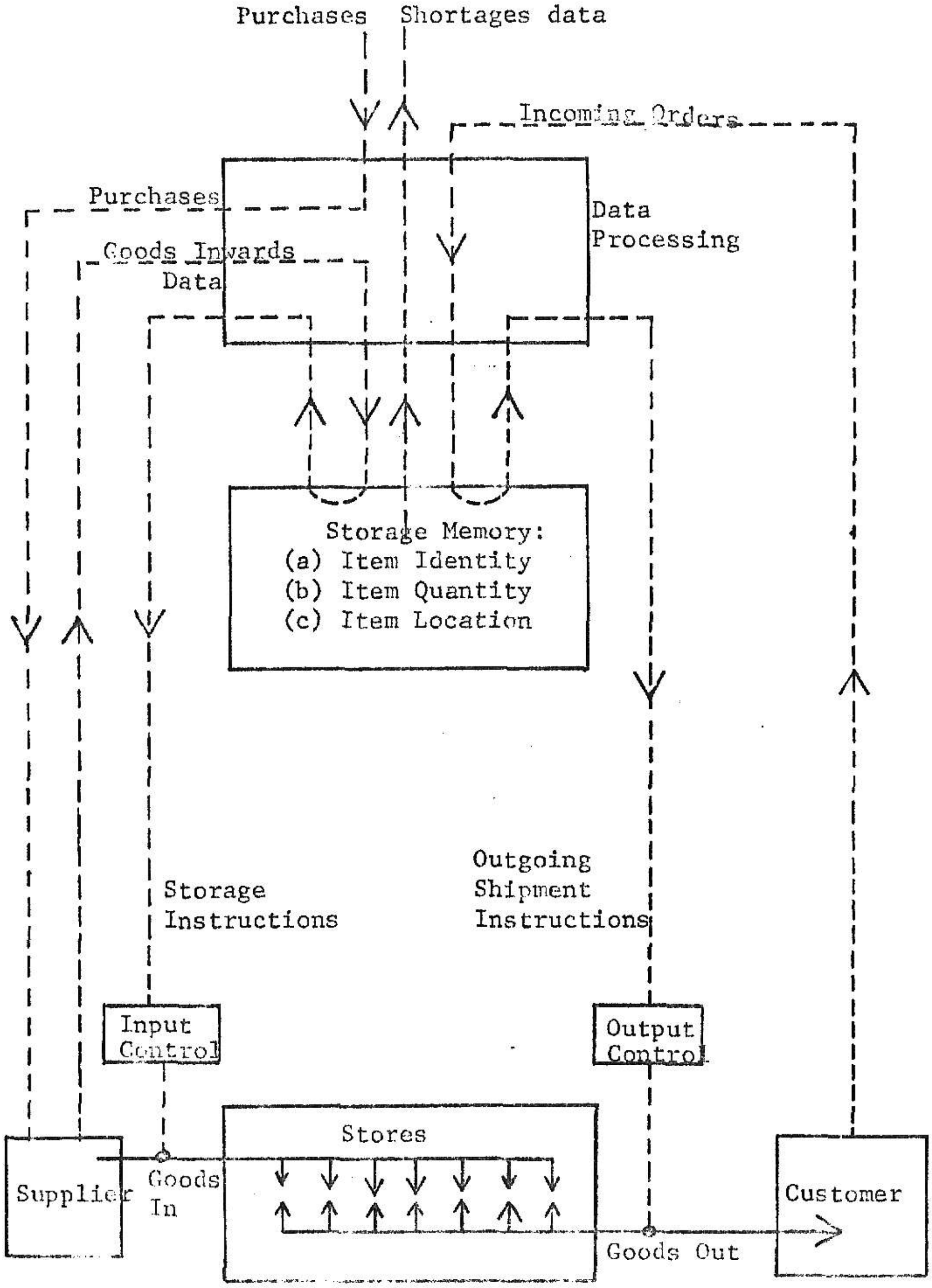

Figure [1]. Overall schematic of an automatic warehouse.

(Figure reprinted from Automation in Practice by David Foster).

output control device, and it signals the appropriate handling device for retrieving the material at the same time updating the information stored in its memory.

The computer apart from handling data and information and issuing signals to the interfaces for the physical movement can also group orders of similar type into picking lists, enabling the warehouse men to select goods with minimum wastage of effort. It can also forecast demand by screening the past demand and taking into account seasonal fluctuation and general trends and make input orders automatically thus keeping the stock at the ideal minimum levels and ordering quantities according to the economic order quantity. Hence the routine paper work can be taken up completely and more efficiently by the computer.

The second part of the automated warehouse is the physical handling of materials by a set of mechanism controlled by the central controller in accordance to the instruction received through the various input-output channels. This set of mechanism ensures the following:

1. On receipt of notification by the controller that an incoming item is to be stored in a given location, the item is moved automatically into that location.
2. On receipt of notification by the controller that a given item is to be extracted from the stores (Retrieval or order picking), the item is automatically extracted from its location and taken to the goods outwards area [31].

The set of mechanism to ensure this may be stackers, cranes, conveyors, chutes or any other equipment, depending on the type and the state of automation of the warehouse.

The material handling function of the automated warehouse can be considered to be two functions:

1. Storage functions
2. Sorting functions [98]

Some warehouses have just one of the above functions and some have both combined. Figure [2] shows a generalized scheme of a complex automated warehouse, which has both the storage and sorting function.

Warehouses which are mainly for storage will have the input and output functions and the actual storage as its main functions. Figure [3] gives a general idea of a pigeonhole type warehouse, which is generally used for storage functions. Part A in Figure [2] denotes storage functions.

Some warehouses have in addition the sorting function, which may be the main function of the warehouse or a subsidiary function depending on the warehousing system. Sorting function includes the picking of the material according to the customer orders, sorting them according to the customers, packaging, labelling, and dispatching. Part B in Figure [2] denotes the sorting function. Sorting is discussed under the heading of "order picking".

2.1.3. <u>Types of Control:</u> All automated warehouses need not have the computer as the main controller. The computer controlled warehouse is the ultimate. It gives the highest sophistication to automation in warehousing. But in small warehouses, or in places where computers are inflexible and uneconomical the main controller is generally a human being. He controls the movement in the warehouse with the help of the set of mechanism he has under his command.

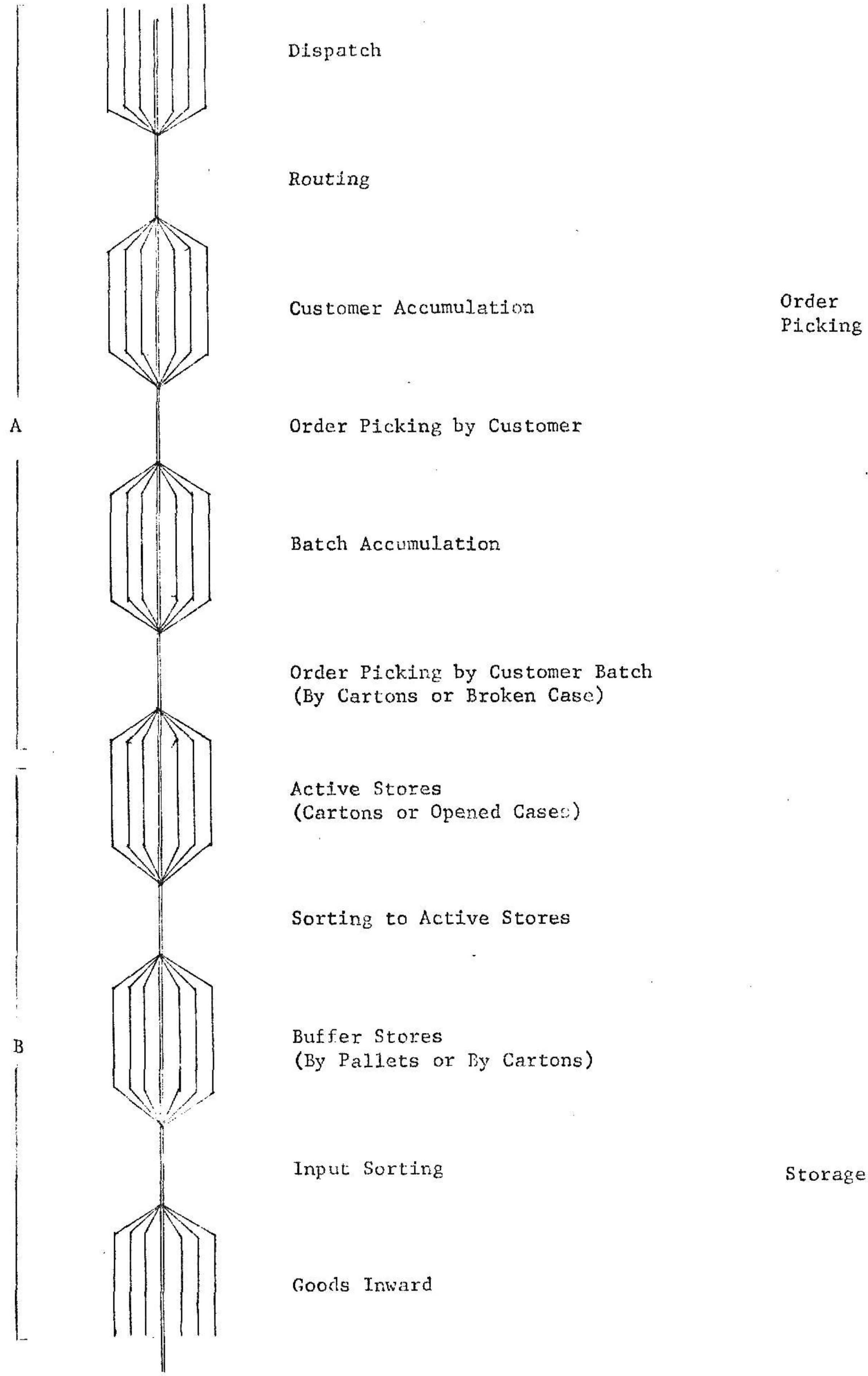

Figure [2]. Main activities of a completely automated warehouse.

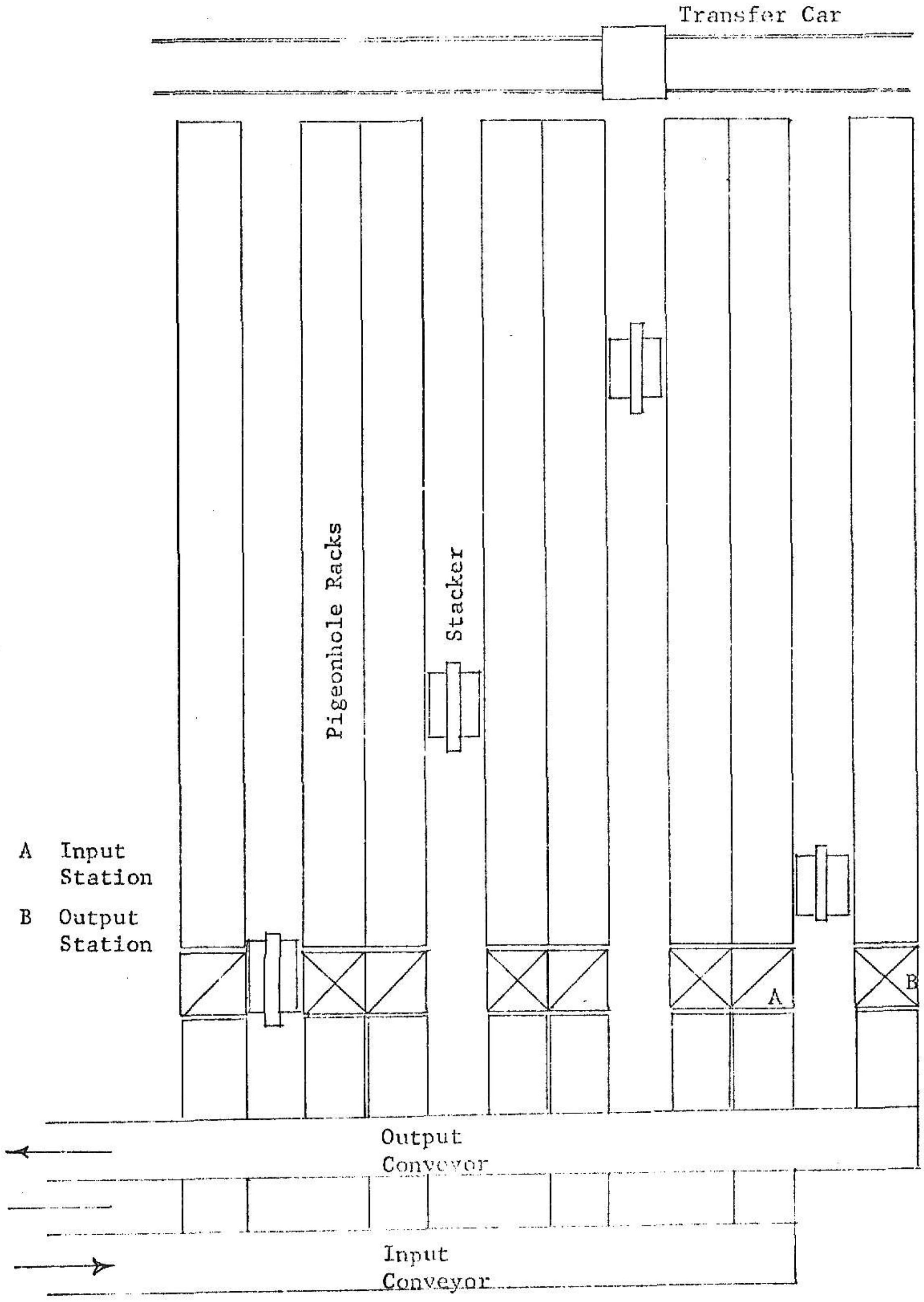

Figure [3]. A pigeonhole type automated warehouse.

Card Activated Control: A simple card file can be used to identify the items stored at random. The controller has on one side the empty location file consisting of appropriate punched cards for each location. Whenever an item enters the warehouse, he identifies the item and prepares an order card which has the type, number and other characteristics of the item to be stored, as well as the empty location punched card superimposed on this. Hence this card for each item will have information on the item coming in and where the item has to be stored. The controller then inserts the prepared card into a card reader, which reads the card and actuates the set of mechanism for the necessary storage operation. The controller then places the prepared card and the empty location card, together, in another file which has the information on the items in storage.

Whenever an output order comes in the reverse process takes place. This type of system is used for smaller installations. The complete record of the inventory is only the simple card file.

Pushbutton Programming: This is similar to the previous method, but instead of the punched cards being read by a card reader, the controller uses a set of pushbuttons to programme the stacker or any other set of mechanics, which have to be used in the process of storing the item. There are a few instances in which the controller has to program each stacker individually, whenever an item enters the system. This is an old method and not very popular at present.

Some of the other methods of control are by punched tape, magnetic tape and automatic identification (Discussed later); but the interest here is in the computer controlled automatic warehouse, because as said earlier, this type of warehousing is the modern trend in warehousing.

2.1.4 Computer Warehouse Control: The following is a brief explanation of the computer controlled automated warehouse operation [12]. It also gives the relationship between the functions and the equipment.

The heart of the automated warehouse is the warehouse controller usually a small process control computer, which controls both the materials flow and the information flow. Figure (4) shows the general configuration of an automatic control system in the warehouse. Communication with the controller can be achieved through a receiving station keyboard/display panel at an input/output control device. The former being an on line device used to inform the controller through a keyboard of the receipt of the material at the warehouse input station. Acknowledgements and/or special instruction are relayed to the receiving station by the controller through a display panel, an off-line device. This display panel is also used to transfer large amounts of information such as picking schedules or inventory records in or out of the system. The latest trend is the image of recorded messages so that the computer can "talk" to the operators. Provision for program adjustments or special instructions is made at the input/output control through a typewriter keyboard.

Based on the inputs it receives and the appropriate programs (instructions) it has in its memory. The controller issues commands to actuate the various warehouse equipment. The output of the controller is converted by various interfaces into the type of signals required by the handling equipment. Communication is a two way street. Whenever an operation is performed by any equipment, it signals a controller through the interfaces that the operation is done. This is necessary for its controller to give

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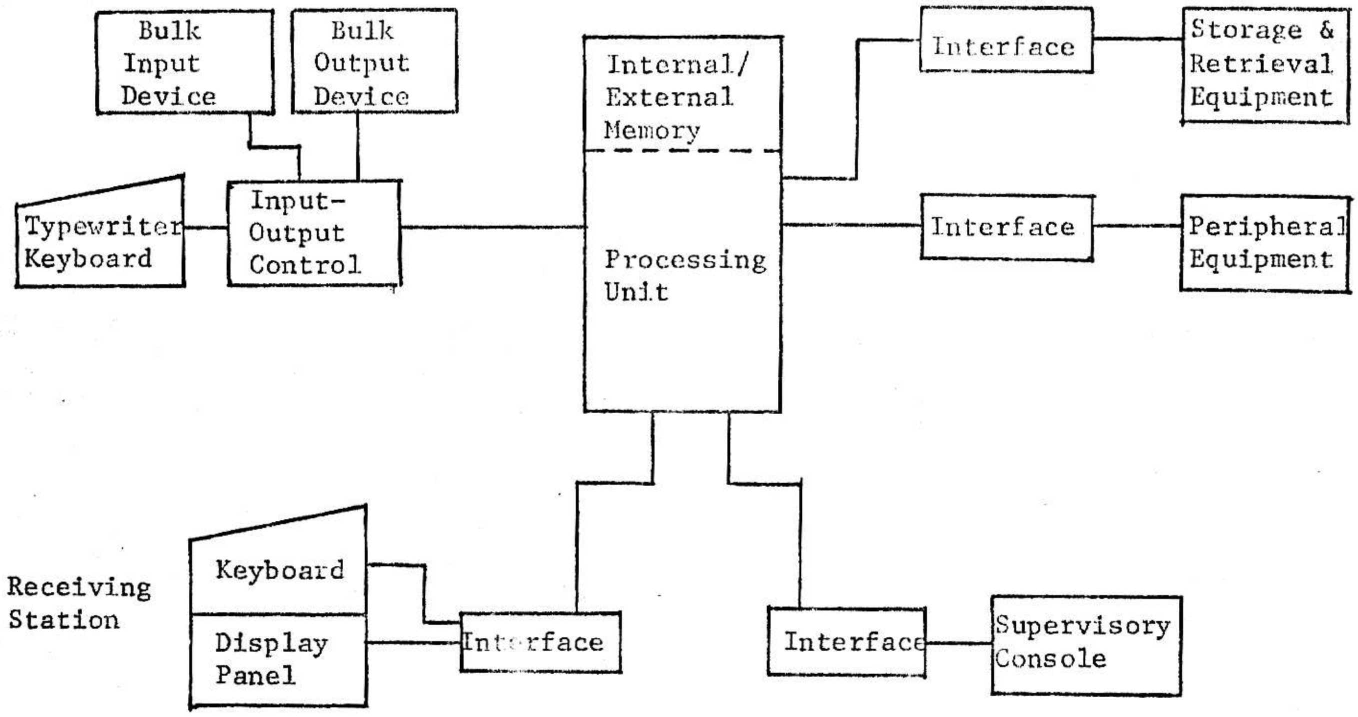

Figure [4a]. Relationship of handling equipment to controller.

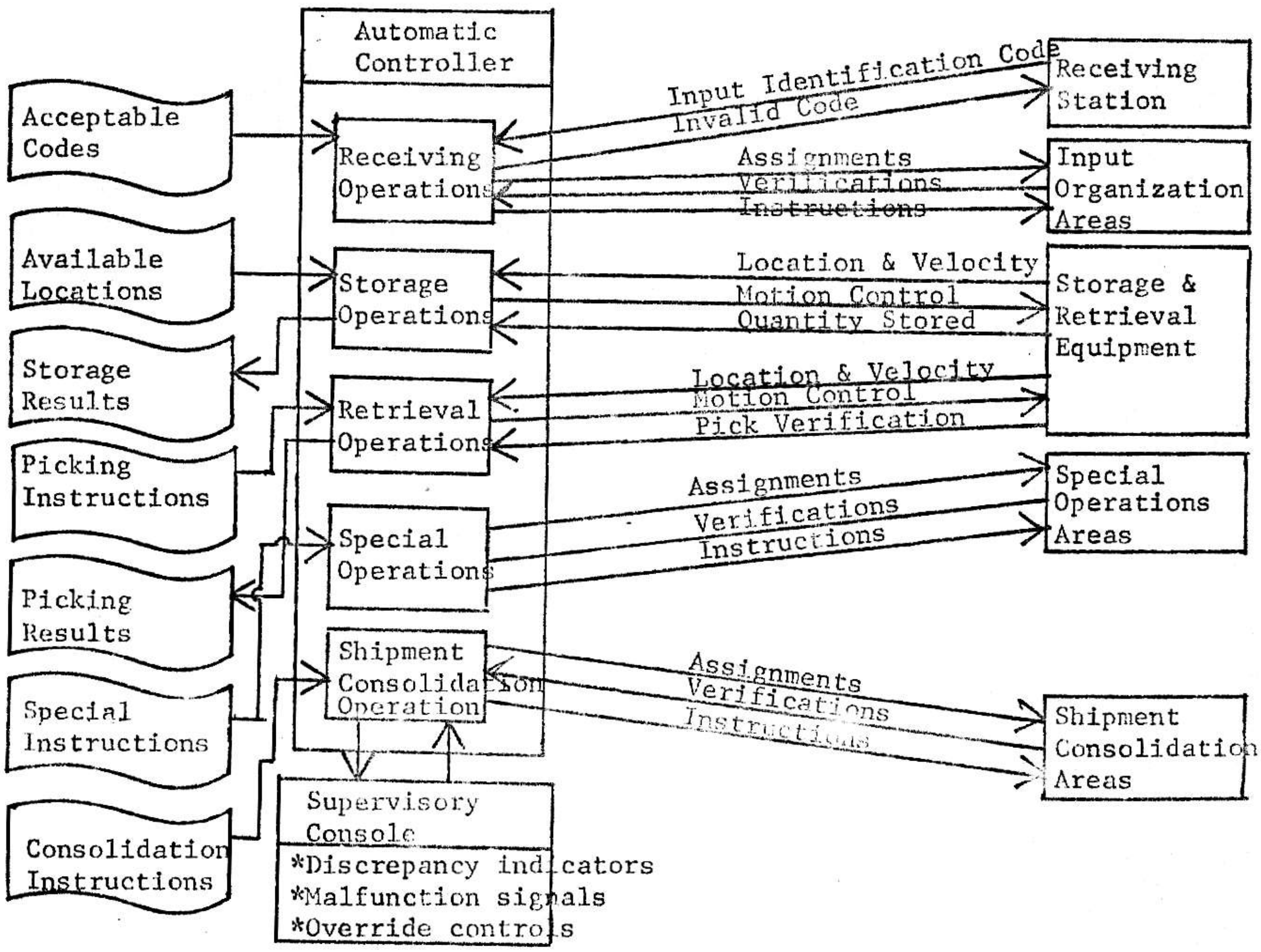

Figure [4b]. Information linkages between the automatic controller and the various materials-handling and supervisory operations.

(Figures reprinted from "Automatic warehouse operation: what it's all about" by Gary M. Barrett).

further orders and/or for error checking.

When a material enters the receiving station the material is identified manually and the information is relayed to the controller through a keyboard, or it can be identified and the message sent to the controller automatically. (Automatic input output control is discussed later). Upon receipt of the information the controller checks it against the acceptable codes which have been placed in its memory through the bulk input device. If invalid, then will be a programmed response from the controller to the receiving station and/or the Supervisory controls. This might be a reject signal, a "try again" signal or request for supervisory assistance. Once the material is deemed acceptable the controller proceeds to bring it into the system according to the previously programmed instructions.

If there is an input consolidation area, to accumulate the material prior to actual storage, the controller signals the appropriate mechanical equipment (Conveyors, tow-carts, etc) to move the material to the appropriate input consolidation area. The receipt of material is signalled by the various summing devices, to the controller.

When the controller is ready to store the material it instructs the input organization area to release the material and then routes the material to the appropriate storage equipment. Simultaneously the controller searches its memory for available storage location. Suitable for the material it wishes to store, selects a specific location at random, and instructs the storage equipment (conveyors, stackers, cranes, etc) to store the material. During storage the controller monitors the position of the material and ultimately receives conformation that storage was achieved in the selected location. Any deviation from instructions will cause the controller to take corrective action.

Retrieval operations are functionally the reverse of the storage operations. Upon leaving the storage area the controller directs the material according to the appropriate program, through any special operations (marking, painting, etc.), and ultimately reaches the shipping point, through various handling equipment. The controllers receive verification that the instructions have been carried out.

The controllers constantly update the information and data in its memory, and provides, as a by-product, whenever requested, all the information necessary for inventory and sales records.

As said earlier the total system approach is the present trend. In this case a giant computer controls all the activities and operations of the manufacturing system. The computer instructs the smaller warehouse computer of the arrivals of material and instructs the warehouse computer. Whenever an order for output comes in. The warehouse computer in this case is used just for instructing the various handling equipment and other warehouse details. The main information and records is stored by the central computer, and can be taken out whenever needed.

2.2. OBJECTIVES OF THE AUTOMATED WAREHOUSE:

The main objects of a warehouse is to provide a warehousing service for sales, production and the corporation. The automated warehouse goes one step ahead. It's main objective is to reduce or stabilize the total cost of distribution by saving in wages, land costs, stock levels and other overheads.

The other main objective of the automated warehouse is a fast and more accurate data processing and information system. The computer memory has all the facts and figures on the activities of the automated warehouse and at any time the information can be retrieved. The paper work is vastly reduced, or in some cases completely eliminated. Whenever an order comes in, the memory can be checked for availability of the material and if available, the item can be retrieved in minutes. Hence the other objects of the automated warehouse are to raise customer service in a competitive market by prompter delivery and improved order filling.

Lastly, the objective of the automated warehouse is to attain more control over distribution operations - i.e. achieve the most profitable one of any given level of inventory [67] [44].

2.3. TYPES OF AUTOMATED WAREHOUSING:

According to Dr. David Foster, the Consultant on Automated Warehousing, from Great Britain [31], there are three major techniques used in Automated warehouses.

1. Pigeon hole Warehouses - Items of stock are placed in separate compartments called pigeon holes and it involves manual or automatic order picking by traversing the face of the pigeon holes.
2. Product Lane Warehouses - Here, each item type is stored in a particular lane in line astern and the retrieval is done on a first in - first out basis. Gravity lanes are frequently employed in this technique of warehousing.
3. Rotating Stock Warehouses - When the number of product lines is high and order picking has to be done manually, instead of the man going to the products the products come to him. Here, the stock is rotated before a fixed order picking or stock placing position.

Within these broad divisions, there are about nine distinct practical types of automated warehouse. [31]

1. Pigeon hole warehouses for pallet loads:

   When the items coming in on the pallets are unit loads, this type of warehouse construction is often employed. The items are stored in separate compartments or bins called a pigeonhole, on a static framework 60 to 80 feet high - as high as 120 feet in Europe. A stacker both deposits and extracts the goods as and where required. This type of warehouse is appropriate for high flow rate of goods of either consumable or capital nature. The kitchens of Sara Lee Warehouse at Chicago, one of the first automated warehouses in the world is of this type.

2. Pigeon hole warehouse for standard packaged items

   This is similar to group 1, but instead of pallet loads the products are stored in individual boxes. The pigeonholes are serviced by a picking machine which extracts a box at a time, removes it into a vertically compartmented conveyor to take it to ground level and to the delivery point on a ground level conveyor. These are similar to vending machines. Men's shirts are stored in this fashion.

3. Pigeon hole warehouses with travelling picking car:

   The picking of goods from the pigeon hole is not automatic. The picking is done normally and pickers ride in a travelling car, which can scan the whole of the goods picking face. Such cars can be automatically programmed to go to the next picking point, and may have an illuminated legend board informing the human pickers of which item to pick.

4. Multi-lane Warehouses for Pallet Loads:

When dealing with a few varieties of products, all stored in pallets, this type of storage is ideal. Each type of product is stored in one particular lane. The lanes may have rollers and each lane may accommodate between twenty to fifty pallets, so that when one is extracted from the front picking face, those behind roll down the lanes ready for a further pick. The problem here is when one pallet is extracted, some forty of the following pallets roll down, having been set in motion by gravity. If one pallet weighs one ton, then about forty tons has to be halted at the picking face. For this, specially designed braking rollers and other devices which develop a high friction to stop the pallets, have been developed. Union Carbides' South Charleston warehouse is of this type. The chemicals (items) are arrive in drums and each type is stored in one particular lane, and whenever one drum is picked, the following drum will roll down for further picking. In this type of system, there is usually one picking machine, operating in between the two lanes. The stock is pulled from the back of the gravity lanes.

5. Multi-lane warehouses for cartons:

When there are about 200 product varieties with high flow rates of 1000 to 5000 cartons per lane, then for order picking this type of warehouse is used. Each lane holds about 50 cartons in line astern, and mechanical escapements in front of each lane allow one carton at a time to be deposited onto a transverse conveyor, which takes them to a delivery point. The order is set with an electronic card reader or any such device. This operates the lane escapements, accelerating the type and number of item required. These items fall into one or many transverse conveyors which conveys a point and each order can be routed to any destination. Routing to each required destination is accomplished by the train of cartons corresponding to an order being led by a pathfinder to a box which has a photoelectric escort memory coded on its side to operate different points of the conveyors. (This will be discussed in detail later). Example of this type of order packing is the Colgate-Palmolive Company warehouses at Kansas City, Jeffersonville, and Jersey City.

6. Multi-lane warehouses for unpacked goods:

Only one warehouse of this type was in commission, which is now abandoned. The Brunswig Drug Company, in Los Angeles dispensed 1500 different unpackaged items, such as tooth brushes and face cream bottles. The problem of making special arrangements for handling so many varieties of goods is formidable. This requires 1500 sets of mechanics and control gear for automated order picking and since some of the items are slow movers, they can hardly justify the cost of the associated mechanics and control gear. Dr. David Foster suggests that in future for varieties up to 500, it will be better to have a super vending machine storing unpackaged products in pockets to be dispensed on to a moving conveyor.

7. Multi-Handpick system with converging marshalling:
   The Oakland Navy base warehouse which services the whole U.S. Pacific Fleet, has about 1,250,000 different items in stock. In emergencies it may require 350,000 different items for one aircraft carrier to be loaded in a short time. The problem here is concerned with order picking a very large variety of items for a few or even one destination. With such enormous product variety the goods must be picked by hand, and the results of such hand picking, by perhaps 100 pickers in different buildings, must be quickly marshalled in one output lane.

   In the Oakland Navy warehouse the order picking is in plastic tote boxes, with the order picking area covering 10 floors in two buildings. When the picker has filled the tote box he sets a photoelectric destination code into the side of the tote box. This tote box, on any outgoing conveyor line, will automatically find its correct destination by photoelectric reading of the codes at junctions.

8. Handpick by batch with automatic resort by customer:
   The Genesco installation at Nashville, Tennessee involves picking 40,000 different pairs of shoes from 15,000 varieties daily for several hundred customers. For such order picking, a variety of goods for many customers, it is best to pick common items for a batch of customers, and automatically resort the batch by individual customer identity. Such systems are particularly suited to mail order warehouses.

9. Rotating stock systems:

Instead of the picker going to the stock for picking, the total stock in the warehouse is rotated before a stationary manual picker, who has a take away conveyor for dispatch. One variant is known as the "carousel" in which huge bins containing goods, arranged on rollers, are pulled round a flattened loop so that, in turn, each picker is scanned by the whole of the stock. Since the whole store has to be moved this is more expensive than moving the man to the store, but since this system is equally suited for input placing and order picking, the cost may be offset by simplicity. This type of storage is not popular in the U.S.A., but seems to be gaining popularity in Europe [78].

2.4. ORDER PICKING:

This is a fascinating part of automated warehousing which in recent years has attracted the most attention in automation. Order picking is an old term in warehousing meaning the process of filling orders for shipment. It means the filling of single or multi item orders in single case or broken case lots. In general it refers to any order filling regardless of order size. In other words it means retrieving from a large quantity of goods, those required for dispatch against a particular order. Order picking is the most time consuming of all warehouse work and is an important area for possible savings in warehouse work. Over half the floor personnel is generally employed as pickers, because of the time required for picking. The outbound shipments are in much smaller lots and with greater variety of items in each order than the incoming shipments. Hence the time and energy required to consolidate such orders is more, and the number of errors made in doing this is also very high. Part b of Figure [2] denotes the order picking function. Figure [5] gives the general idea of the order picking operation in the warehouse.

The conventional method of picking goods for an order is for an operator to circulate within a racking system picking for one order at a time. 90% of the operators time may be spent unproductively in walking from one location to the next, with the result that only a comparatively small amount of the total available time is actually spent in picking goods. A large number of orders can be picked together, but this is impossible to be done by a human being because of the speed and memory limitations. Where such a variety of items has to be picked from a large number of customers, the task of consolidating these orders becomes laborious. The labor content of the store is directly related to the number of times the operator has to visit a given location in a warehouse. The larger the store and the greater the number of product lines the greater is the labour content of the store.

The two main factors controlling the automated warehouse design and the different techniques employed are related essentially to:

1. Product variety,

2. Customer variety [90].

The actual picking of the material depends on the product variety and the sorting and consolidation operations depend on the customer variety. With increased customer orders the sorting of the materials according to each order becomes more and more complicated.

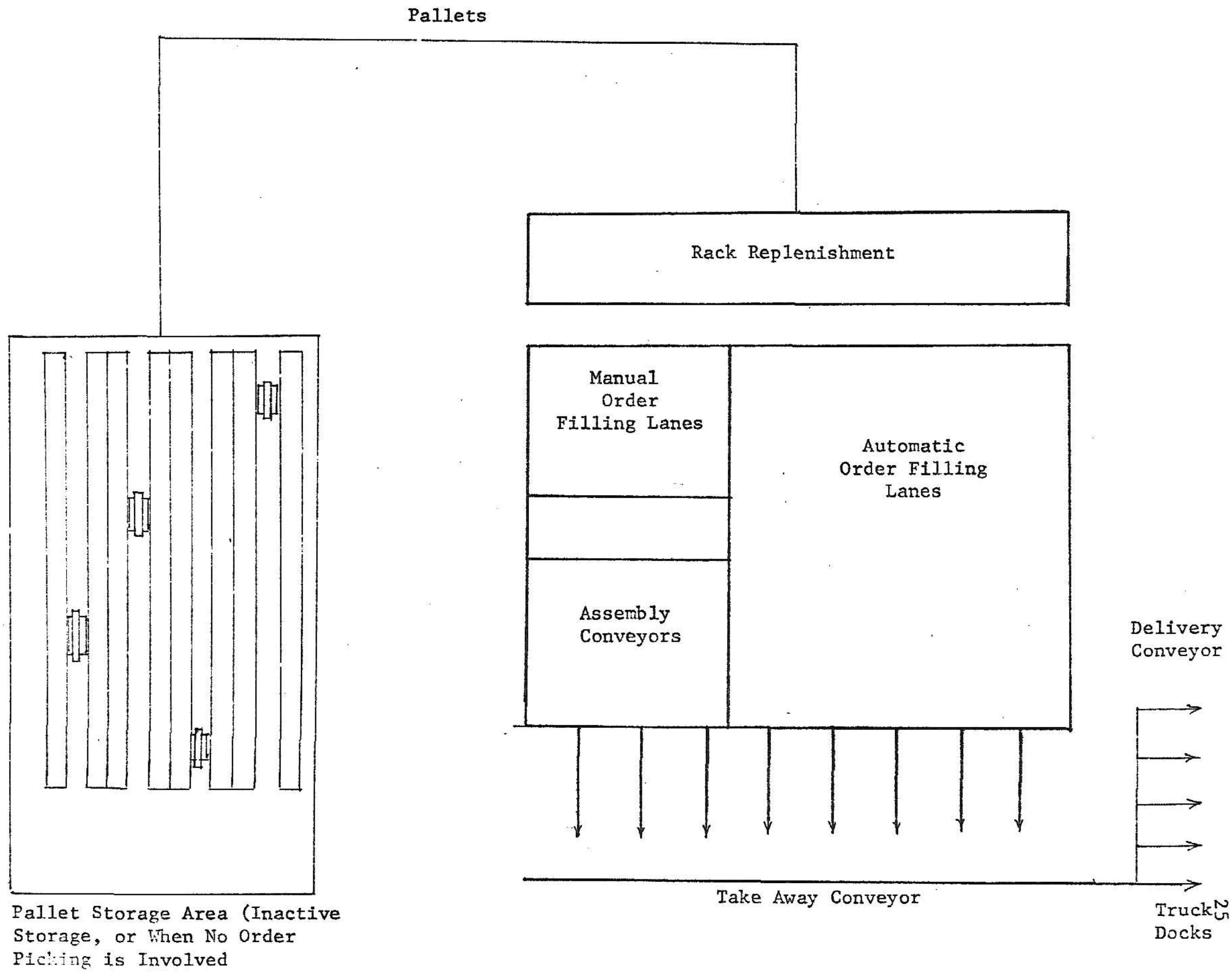

Figure [5]. An order picking and storage warehouse.

Automated order picking and computer assisted order picking have been developed in recent years, which have greatly improved the efficiency and time taken for order picking. Completely automated selection requires the following conditions: very high flow rate; relatively small number of items; regular shapes with few variations in size or weight; large number of small orders. With a flow rate of 10,000 cartons per day and with less than 100 product lines automated order picking becomes feasible. In an automated order picking system the information system keeps tabs on the actual physical flow of the material through the network of handling equipment. The information system actuates the appropriate handling equipment at the correct time, to get the order out automatically.

With a greater variety of goods, with more than a hundred product lines it becomes infeasible to have completely automated order picking. If there are 1000 product lines, then for true order picking 1000 sets of machines are needed. Some of the product lines may be "slow movers" and so the particular sets of machines may be underloaded and hence uneconomical, apart from the fantastic capital investment that is needed initially. For a larger number of product lines, computer assisted order picking can be employed. Computers can be used to help normal order picking. The main duty of the computer is to make picking lists from the different orders from the various customers. Each picking list is sequenced according to the product lines in the warehouse and their location. This enables easier order picking. If picker A is working on aisle 1, then his picking list will be for the items stored in aisle 1. The picking list is made out in a picking sequence so that "backtracking" by the picker is eliminated. That is if the picker starts from one end of the aisle picking the material according to the list, he will reach the end of both the list and the aisle without having to retrace his steps for any item. This reduces human effort.

As the items are being picked, the picker places them on a conveyor, which in most order picking systems is the main type of handling equipment. The conveyor usually runs in between the aisles. The picker forms some sort of a goods train on the conveyor and at the head of the train he places a tote box with photoelectric tapes (destination and material code) on its side. When he has completely picked the list he puts the list in the tote box and signals the main controller that the picking is done. The train then finds the way towards its destination, usually the order consolidation area, where the items are divided automatically according to the customer orders.

When making out the picking list initially, the computer also takes into account the picking and walking speed of the manual pickers, the speeds of the conveying and handling equipment. It makes different picking lists for each picker in the different parts of the warehouse. The picking lists are made such that the pickers are neither idle nor overworked. Collision between each goods train is avoided, by photoelectric sensing devices, which stop and start sections of the handling equipment, as required.

The order consolidation depends on customer variety. Consolidation becomes complicated as the number of customers increase. The number of diverters, transfer points, etc. through which the items have to travel, to get into the right accumulation zone, will be more and complicated sorting equipment will be required.

An important principle of efficient order picking is to separate high and low volume items into separate picking zones, so that appropriate picking methods may be used. By using this "split flow" system, incoming items go into the right storage areas - tailored for high or low volume order picking as the case may be. Appropriate order picking systems are used - high volume items may be stored in gravity lanes or other automated picking systems may be employed, whereas low volume items may be stored in shelves and hand picking or any other such system may be used.

Some Observations in Order Picking:

Some of the features that are apparent in the computer assisted order picking system are: [67]

1. Classification of the stock into fast, medium and slow movers. This helps to get priorities right, in terms of space utilization and order picking.
2. Faster moving items are kept closer to the picking points than slow movers.
3. When palletload storage and less than pallet load storage are combined a different classification can be used. A bulk or buffer storage, a reserve store and a picking store. The latter is usually for fast moving items. In some cases the reserve store is left out, but the effect is the same. The fast moving items from the picking store are hand picked, and

the stock is replenished from the bulk store automatically. The Dr. Maag, Zurich and Suchard, Paris are examples of this type of stores.

4. A third method is picking by batch and not by order as is the general merchandise system.
5. Another method is using "carousels" - bringing the stock to the pickers, rather than taking the pickers to the stock.

Most of the order picking installations follow generally the same principle. The difference is usually in the complex sorting and diverting mechanisms, which are usually tailor made for each installation.

Order Picking Innovations: [67]

As less than pallet load picking systems become integrated with automatic pallet stores new order picking methods to speed the removal of stock after picking and to fit into a computer controlled order picking sequence, have to be derived. Some of the innovations have been discussed here.

Gathering Tower: It moves between the racks and has access to either side of the aisle and the picking platform moves up and down. Route instructions are fed into the machine by the main computer. At each pallet position the number of items called for, is flashed on a screen inside the tower. The order pickers withdraw the cartons, or less than pallet load orders from the storage and transfer them to conveyors. A third man sweeps them one by one onto the trays of the moving elevator, which deposits them on to a takeaway conveyor. This system is used in the Boots Warehouse, Noltingham, U.K. A maximum of 5000 cartons/hr. can be gathered.

ORDAMATA - Smaller and simpler version of the gathering tower. Usually the takeaway conveyor, in this case is in the aisle itself. The ordamata rides over the conveyor, with wheels on either side. A simple elevator brings down the items collected onto the takeaway conveyor.

Some of the other sophisticated developments are the tilt tray system as in the General Merchandise Co., the cartrac system in which carts loaded with picked items move on tracks and automatically find their destination, driverless tugs and tractors and tilted band conveyors. In all these cases the conveyors or tractors or whatever innovation it is, they can all be controlled automatically and with remote control.

2.5. COMPONENTS OF AN AUTOMATED WAREHOUSE:

A number of components make up an automated warehouse, whether it is used just for storage and/or for order picking, and all are equally important for the warehouse to work as an integrated system.

Some of the main components are:

1. Conveyors, accumulating conveyors and other conveying devices,
2. Stacker cranes,
3. Transfer cars,
4. Automatic divertors and other equipment for sorting operations

5. Automatic identification devices,

6. Computers, card readers, printers and interfaces,

7. Storage racks, pallets, and other miscellaneous equipment, like palletizers, depalletizers, etc.

All these equipment will not be discussed here, but some of the main components like stackers, transfer cars, and the new topic of automatic identification will be discussed in brief. The rest of the equipment are generally not specialized and so they are not detailed in this chapter.

Stacker Cranes: One of the most important components of an automated warehouse, the stacker crane provides very efficient, fast and automatic storage at very high levels with minimum aisle space and with high degree of safety. The stacker crane operates in a narrow aisle, which is only 4" wider than the largest load which the stacker can carry. No maneuvering and turning is required since the stacker pushes the load into the pigeon hole sideways, on both sides of the aisle.

Between each pair of racks the stacker travels two and fro and stacks or retrieves items into or from the pigeon holes as directed by the central controller. The stacker automatically picks up an incoming load from the input station, where the load is squared and placed in the right position for the stacker to lift the load, then moves it diagonally down the aisle to a selected opening, gently places it in the pigeonhole and returns to the home base for further instructions. The retrieval operation is the reverse of this, and the pallet load is placed on the output station. The stacker can be given the following commands:

1. Single command - Store: Pick up load from the input station and deposit at the programmed address.

2. Single command - Retrieve: Travel to programmed address, pick up load and deposit at the output station.
3. Dual command - A combination of store and retrieve commands, storing one load and retrieving other without reprogramming.
4. Double Command - Perform two store and two retrieve commands without reprogramming.
5. Single command - To transfer a load from one location to another.

If by chance the location is filled or if the load is too big, then the stacker returns the load to the home station. (Before a load comes to the input station, the load is checked for the weight and size, and if found not suitable for storage, will be rejected).

The stackers consists of a rigid hoisting column with a top running, under running or floor running trolley. This column is equipped with a carriage, which is filled with load-carrying telescopic forks powered for both right and left motion.

The control for the stacker can be different. The control console for programming the stacker can be mounted on the stacker itself, or if many stackers are employed, the controls can be in a central place. The ultimate is the central computer control.

The stacker speeds are generally 125 to 400 fpm horizontal and 40 to 100 fpm veritcal.[44].

Transfer cars: When the number of aisles are more than the number of stackers, a transfer car is used to move the stacker units from one aisle to another.

Depending on whether the stacker is top running or floor running, the transfer car will be on the top or the bottom. In these cases the transfer car will be an overhead bridge or movable low flat car capable of supporting the stacker during transfer.

Depending on such factors as the warehouse volume, activity rate, uptime value, cost and available storage the benefits of using a transfer device are:

1. In a low volume storage installation the transverse car can be used to transfer one stacker so that it can service a number of aisles. Since the transfer car is less expensive than the stacker, there is an overall cost reduction.
2. The transfer car improves system reliability, when the system uptime is imperative. The transfer car enables the inoperative stacker to be moved and a spare stacker brought in, or a stacker from another aisle to be brought in to the particular aisle.
3. In low volume installations the future expansion costs are greatly reduced, since all it needs is extra racks. The same number of original stackers can operate in the newly added aisles also.
4. Some floor space is taken up by the transfer car, but if the load and unload stations are placed on the transfer cars, then there is actually a saving in space.

For a warehouse with high flow, the transfer cars are useless, in fact they become very uneconomical. The speeds of the transfer car are anywhere between 20 to 100 fpm, whereas the horizontal speed of the stacker is 125 to 400 feet. In a high flow warehouse, if a transfer car is used then the high flow materials and the low flow materials have to be stored in different racks, so that there is very little movement of the transfer car.

Load accumulation conveyors can also be located across from the end of each aisle. Thus the storage/retrieval unit can complete several cycles in a single aisle before transferring to another.

But generally the transfer cars are not used in high flow warehouses. In these cases they are used only for emergencies or for service or repair.

Automatic Identification: The input data to the controller comes in through various input channels. This data can be fed in manually through a keyboard or through a telephone or any other such device. These manual operations can be eliminated by using automatic identification systems. These automatic identification methods can be used not only to feed in data to the controller, it can also be used for automatic sorting operations, thus eliminating the need for manual handling and sorting. They are a means of getting greater efficiency and accuracy. These automatic identifications controls are mostly used in systems with high flow rate and where diversion, rejection and sorting is done during storage or processing.

Some of the automatic identification techniques are given below:

1. Mechanical methods: Such systems may be based on tote boxes or other carriers with adjustable code pegs which engage with fixed ploughs to divert the box from or to the conveyor at the appropriate point.
2. Electro-mechanical methods: Adjustable code pegs operate combinations of limit switches to operate the appropriate diverting or identification mechanism. This method is more flexible than the completely mechanical method.
3. Pneumatic methods: These logic systems are still in the early stages of development. Code perforations on carton flaps or code plates on conveyances are detected pneumatically.

4. Electro-conductive methods: Carbon lines or wire staples, etc. set in a code pattern on a carton or a package, can be electrically sensed by electrical contacts to provide the coding signal to operate the equipment. Reading punched cards pasted on the cartons or pallets also comes under this classification.

5. Photoelectric methods: This is a very versatile method and allows good mechanical tolerances in the system. They do the job by sensing an interruption in an electromagnetic field or by beam interruption or reflection of materials printed or pasted on a container.

Magnetic markings can be used, so that magnetic pickups can read the identity of the goods as they pass by.

Color marking can be read by several photocells wired to combination logic circuits. Black markings are preferred on buff cartons, but flourescent inks (illuminated by ultra-violet light) can also be used with appropriately sensitive photocell assays. Flourescent ink loding can be picked up and analyzed at a distance without the need for close registration.

"Lock-on" identifiers read moving messages by automatically locking on to the moving light marks. The optronscope, which is a cathode ray photo multiplier system, is one such device.

Proximity detection of codes: Magnets are fastened to an object that must be detected for some given reason. The magnet on the conveyed object will cause a metallic wand to move, thus opening and closing a circuit. This action causes a signal to be sent or a switch to close.

Ultrasonic code readers: Can be used where movement is continuous; or on in-the-floor driverless tractors where they secure obstructions. They are good when large objects are involved and where light is poor.

Infrared sensors: They do the same job as photoelectric cells, but in this infra red light is used instead of ordinary light. They can detect items having a very high temperature or where ambient light is inadequate.

Photochemical methods: Phosphor coding techniques are nowadays being used, increasingly within postal automation [29], [55], [89].

2.6. ECONOMICS OF THE AUTOMATED WAREHOUSE:

An automated warehouse is a very expensive and complicated mechanical and electronic system. A number of factors have to be carefully assessed before a decision can be made to install one. A modest warehouse may cost about $300,000 usually 70% for the mechanics and 30% for the control hardware. If the warehouse works according to specifications, that is if the warehouse is capable of handling the managements operating policies then in most cases the investment on the warehouse ought to be paid off between three to four years after commissioning.

To make sure that the warehouse makes sense economically careful planning and feasibility studies have to be undertaken. The objectives of the automated warehouse and its principle functions in relation to the companies operating policy have to be defined explicitly. The various advantages and benefits of installing an automated warehouse (better distribution, better customer service, etc.) have to be compared with the existing system to determine whether there is a sufficient margin to justify the capital investment required for an automated system.

The present system as such has to be studied thoroughly. Facts, figures and statistics on the products produced, the number of product lines, the production rate, the relative popularity of each product in the market, the through-put of each product, the type of storage necessary, number of customers and the average number of orders per customer have to be collected and verified. The method of storage - unit storage as in cartons, or pallets or broken case storage or unit grouping, has to be decided. The management has to take a long sighted approach and it has to be sure that its warehousing and the physical distribution policy is fixed for quite a few years ahead, as regards to geographical and physical stability, lest it should have to write off an expensive piece of equipment.

The type of warehouse depends on the physical form and variety of goods received, the number of customers requiring the material in one day and the typical number of items ordered by each customer in one day. For unit loads such as pallets or cartons of high flow rate of either consumable or capital nature and few product lines, the pigeonhole warehouse is appropriate. Pigeon hole warehouses are truly automatic in the sense that very little or no manual work is involved in most cases. In addition standardizing the products in pallets, cartons or in unit grouping, i.e. within a tote box or container, will be better for progress in automated storage. A high utilization is obtained from the mechanics, in the pigeonhole warehouse.

When dealing with an intermediate number of product lines (25 to 100) and when the question of order picking comes in, the product lane warehouses are more appropriate. About 100 different product lines appear to be the upper limit of true automatic order picking. For more than 100 product lines, it is more economical to use hand picking. If there are 10,000 product lines, then for true automatic order picking, 10,000 sets of mechanics are needed. Some of these items may be slow movers and so many of the mechanics may be underloaded. Hence there should be a strict discrimination between fast and slow moving items and only the fast movers have to be picked automatically, and the slow movers should be left out of the automated system.

When very great varieties of product lines are involved, such as in Genesco (50,000 pairs of shoes a day spread over 15,000 varieties), or as in the Oakland warehouse of the U.S. Navy (1,250,000 items in stock, or when less-than-pallet load orders for high variety of fast moving items are involved as in the Brunswig Drug Company (1500 pharmaceutical items like tooth paste, bottles, etc.), product lane warehouses are inefficient and costly. Manual order picking is the most efficient in these cases. Hence when it comes to high flow rates with high product varieties the order picking should be by hand and order consolidation to be done with the help of automation.

The economics of the automated warehouse depends on the load factor, which can be brought to bear on the equipment. The load factor is not sheer machines in motion but rather in terms of the loading of useful function related to the maximum possible useful function which can be loaded onto the system [31]. In the U.S.A., with the labor rates very high in relation to the cost of capitol machinery, a load factor of 50% is required to justify the installation of an automated warehouse.

Lastly the economics of the automated warehouse turns simply on the amount of effective use made of the capital invested. In general a high flow of goods, is required to make warehouses economically feasible, this high flow meaning the total weight moved per unit time, and not the number of items moved. As a rule, automatic warehouses are financially viable if they move not less than 10,000 lb. of product an hour [31].

Another problem faced in deciding on an automated warehouse, is how high is the automated warehouse going to be. The conventional warehouse is about 10 to 15 feet high, as high as a man could reach or can safely manipulate the conventional handling equipment like a fork lift. Nowadays with highly sophisticated automatic handling equipment and automatic control, automatic warehouses reach for the "clouds". On an average the height of an automated warehouse in the U.S.A., is about 40 to 60'. In Europe it is higher and warehouses are built up to 100'. The automated warehouse at the Ford's warenham Plant in England is 110' high.

The reasons for this 45-60' height in the U.S.A., says Mike Rowan, editor of Modern Materials Handling, are numerous and they vary according to the situation. Some of them are equipment speed, architectural problems, need to adopt to existing facilities and equipment availability. The equipment speed factor is an important one. In most of the automatic stacking and retrieval units the horizontal speed is higher than the vertical speeds. A common ratio is 300-330 fpm horizontally and 60 to 70 fpm vertically.

When relatively few items are stored and FIFO arrangement is not used, then the height is no problem. Lower loads can be retrieved when time is a problem and higher loads can be taken out when there is no rush or hurry. But when there are many items and time response is an important criterion, then the speed of the equipment is critical. In this case more floor space, lower racks and more retrieval units have to be used to make best use of the faster horizontal travel.

The equipment availability is another important problem. The industrial designers tend to plan around existing equipment types to avoid the time and cost of planning new tailor made equipment. The equipment and storage rack strength is another criterion. The higher the warehouse the sturdier and more costlier the equipment becomes.

In Europe the cost of space is a big factor. In USA with the cost of land not as high as in Europe, a height of 45 to 60' more or less tends to balance against the cost of movement or of throughput per unit.

Some of the other points are increased fire hazards in higher systems and the architectural problem. While they are not the main consideration, they may, when certain other factors are equal, tip the scales because of the safety policies and because of the higher construction costs [30][31][67].

2.7. WHY AN AUTOMATIC WAREHOUSE:

During the last decade with the tremendous increase in competition for marketing a product, several techniques and methods of reducing the product cost were developed. The physical distribution was considered as the strategic weapon in marketing. Several new developments like the centralized data processing to sales offices and plants, new telephone and teletype equipment that makes networks possible, a greater number of transportation options and a more sophisticated material handling technology, have made physical distribution an important factor in cost reduction.

Warehousing is one of the main functions in physical distribution and perhaps the biggest time and profit consuming function. It is a non-productive function and is essentially costly, the costs being borne by each product using the facilities and the labor in the warehousing operations. The costs associated with warehousing have prompted the companies to invest in sophisticated electronic and mechanical systems, which when applied correctly have resulted in all round savings. Another important reason for efficient warehousing operation is the customers attitude. With the neck to neck competition the customers have turned around and have forced the manufacturer or the wholesaler to take the whole burden of warehousing. This coming in as an added expense, had to be taken care of by such efficient methods as automated warehousing.

The last decade has seen two significant developments in the computing field [104].

1. The introduction of small special purpose computers for stock control.
2. A great reduction in the cost of larger computers, and at the same time an increase in their ability to store and handle data of all kinds at high speeds.

With these developments there has been a tremendous increase in the use of computers for data processing operations, and for stock recording purposes. With just a slight addition to the capital expenditure the same computer can be used to control the physical distribution too. An automated warehouse requires computer control of records, and having installed a computer for data processing, why not use for controlling the warehouse mechanics?

The computer of the automated warehouse, whether it is the central computer in the main office or the specialized small warehouse computer has the complete and up to date information of the warehouse operation in its memory at any time. Basically the computer does the following stock control jobs: it receives orders from sales offices, selects the warehouse from which to ship, updates the inventory, makes out the necessary shipping orders, and transmits to the selected warehouse the documents needed to make the shipment. It reviews the stock position of the warehouse daily, determines, what is needed to replenish the stock according to seasonal and other conditions and based on its instructions it decides whether to replenish the stocks. With the computer controlled warehouse the inventory is always kept at the optimum level, without the danger of overstock or understock. The paperwork is vastly reduced, which in turn reduces the costly labor required and also minimizes the errors involved in this sort of laborious paperwork. Apart from the time savings gained by less supervision, inventory control, productions control and record keeping, this type of automated stock control makes rapid auditing possible.

The automated warehouse is a significant contributor in physical distribution. With the total systems approach, taking the whole distribution cycle as a system, the warehouse has to be highly sensitive to the changes in sales and marketing. The automated warehouse has great sensitivity of changes in the value of sales. The response time is fast. With automated operations along the line and with the operations controlled directly by the information system, the ability of the system to react is greatly improved. Errors can be anticipated before they can affect response time. Forecasting and scheduling can be built into the information system to eliminate guesswork and put new reliability into decision making.

The automated order picking and sorting functions of the warehouse, ensures prompter customer service, and in case of a works store a more efficient one to assembly lines, getting greater accuracy in order filling and stock figures. The customer orders are reconciled with optimum methods of goods retrieved, like constructing picking lists which can usually account for 20% of total picking time, automating diverting and sorting operations and ultimately the accumulation of orders according to the customer. The time between goods entering the warehouse and dispatch of orders is reduced and hence the delivery to the customer is fast and efficient.

The work load variability is reduced and the physical difficulty in complex case handling functions are greatly simplified. One of the prime benefits of an automated warehouse is that the work pace can be built into the system, with less or no dependence on human factors. With a properly designed warehouse a balanced flow without any bottlenecks can be achieved. The management's control over a large and highly variable area of company cost, is increased.

The automated warehouse which is used just for storage purposes like the pigeonhole type warehouse has in addition few other advantages. It assures optimum utilization of space. Until recently storage areas have been considered in terms of square footage, despite the fact that loads are usually stored one on top of another. But with space today at a premium, management must think in terms of cubic feet - i.e. considering the height as well as the lateral dimensions of a storage facility. A very significant advantage of the automated warehouse is space saving, through more efficient, high density use of cubic space. Every cubic foot from the roof downward can be utilized, since no manual operations is involved, the height of the warehouse is increased considerably to utilize the cube to the utmost extent. Hence there is a tremendous savings in land area, which forms a substantial part of the capital expenditure. Up to 75% of the storage area can be saved.

The automated warehouse permits a decrease in warehouse size by facilitating random storage. Another savings in space comes from the fact that the aisles are much narrower than the regular aisles. They are just an inch or two more than the size of the load. This allows maximum space utilization.

The storage racks of the automated warehouses are slightly larger than the pallet load themselves. Since the items are automatically centered and loaded by the stacker, the racks can be made just an inch or two larger than the laod. Movement of racking under the load or due to settlement does not affect the operation of the warehouse. Electronic controls can enable racks to be erected to better tolerances and hence more economically.

There is 100% accessibility to every load stored in the warehouse. Due to automation, there is high "turnaround" efficiency - loads are stored and retrieved in seconds. There is no waiting because of materials, parts in process or tools are lost or buried beneath a stock. Inventories are easily "turned over" on a first in first out basis to minimize deterioration and avoid obsolescence.

Another important advantage of an automated warehouse is the tremendous savings in manpower required. More than 50% labor savings is assured by an automated warehouse. Since there is no human element involved in storage, the systems can operate in the dark and at less than comfort heating temperatures, which means that there is a saving on lighting and heating requirements.

Gentle handling reduces damage and pays off in customer goodwill and fewer returned products. Since employees do not do the heavy lifting, or ride moving equipment, or enter the aisle between the material banks, the insurance claims can be reduced. Due to a reduction of labor and due to the construction of the warehouse, pilferage is reduced to a great extent.

CHAPTER 3

LITERATURE REVIEW

Literature pertaining to the automated warehouse, has been discussed in Chapters 1 and 2. This chapter reviews some literature available on the simulation of the various aspects of an automated warehouse. Literature on the cost aspects of the automated warehouse has also been discussed.

The National Joint Council on Materials Handling, U.K., in their report on automatic warehousing [90] have classified automatic warehouses according to customer variety and product variety. They have also identified the main variables that are relevent to choice of technique and to the costliness of an installation.

N = The number of articles in stores at anytime. For a given volume, the greater is N the more costly the stores.

M = The average "mobility" of the goods in the warehouse expressed in units such as feet per day. The greater the "mobility" the more use is made of the installation and thus the capital return per item is improved.

Sv = Shape variety of the goods. The greater the shape variety the higher the cost of the handling variations.

d = The density of the product.

V = The average size of the product in cubic feet.

Gv = Variety of goods

Cv = Variety of customers

With these variables the costs and complications of an installation are related in a logical equation:

$$\text{COST VALUE} = \frac{N \cdot Sv \cdot d \cdot V \cdot Gv \cdot Cv}{M}$$

This is a logical equation and not an arithmatic equation. It is useful in coming to a first approximation as to whether an automatic stores is financially viable or not.

Kay [45] has developed mathematical models for various types of handling in a warehouse. For conventional warehouses, he has assumed that the handling effort in a function of the average distance over which one unit has to be moved during the storage process. In the automated warehouse it is different. Pure handling cost, i.e. costs dependent on the distance, are only part of the total handling cost. Due to the higher capital investment needed, there are other costs, which are time dependent, such as amortization rates of building and capital equipment. Hence he says, that the total handling cost per time unit will be

$$H(T) = A + B,$$

where A represents amortisation of capital and B is given by

$$B = \frac{M}{2}\,(ax + gy + dz),$$

where a, g and d are the efforts required tohandle the respective directions, and $\frac{M}{2}$ is the average rate of throughput in the warehouse. As A increases B will have an increasingly smaller effect on H(T). A will increase according to the maximum distance over which an item has to be moved; in other words automated handling equipment must be able to operate over the entire length of the warehouse and it's cost increases with increased warehouse capacity. It is then more important to minimize the maximum required warehouse capacity than to minimize handling effort.

Critchlow [19] has brought out a total cost equation for a warehouse, using "Microcosting", which allows microscopic details to be analyzed. The parameters he has included in the equation are:

B = Building cost, as affected by total storage required, height, area, etc.

E = Education and training costs.

I = Insurance costs

R = Racking and binning equipment cost, as it varies with depth and size of racks and bins etc.

S = Storage and selecting equipment cost, as a function of the total storage required, building area, height, throughput, weight and size of the objects stored, etc.

O = Operating costs and labor costs.

M = Maintenance and Repair costs

C = Cost of money in interest, taxes and loss of other investment opportunities.

D = Associated Data Processing costs.

G = Cost of poor customer service; late deliveries, shipping errors, inaccurate invoices and loss of customer goodwill.

The total cost equation is just the sum of all the separate costs listed above:

$$\text{Total Cost, } K = B + E + I + R + S + O + M + C + D + G.$$

Not very many papers or articles have been found on simulation of an automated warehouse. Sundstrom [103] has discussed how simulation can be used for solving material handling problems. A conveyor problem has been simulated using GPSS. The modeling has been discussed, though the program and the results have not been included in the discussion.

Brantly [14] has developed a simulation model for analyzing the behavior of a manufacturing system. A batch-production operation that manufactured several sizes of a product consisting of a number of parts was examined. These parts were produced on separate machines, stored in a finished products inventory and assembled again on customer demand. Several distributions, including a truncated normal distribution were priced, but an empirical distribution was found to be the most efficient. An iterative simulation procedure has been developed to determine economical safety stocks.

Hillman [41] has used discrete event simulation to aid in designing an enlarged order picking and shipping system. A tow line system was simulated with the objectives of work flow control, to achieve better labor productivity, and the flexibility of handling a variety of order types, so that customer service may be improved. The model was also used to compare the capacity effects of various conveyor configurations, to test the assumptions of systems design and to arrive at an estimate of overall system capacity expansion of the revised system.

Dhanda [24] has applied simulation to design an order picking system. He says using simulation one can be absolutely sure before committing capital on a new concept or design. The order pickers were timed during their picking operation and accurate timings were employed during the simulation. Two simulations were made - one to determine the physical characteristics of the conveyors and the other to determine how the pickers will cope with

with the system.

GASP IIA has been used as the language for this simulation. Pritsker and Kiviat [94] discuss GASP II and IIA thoroughly and have applied both to several problems to determine the worthiness of the language. They say why GASP is attractive for educational institutions and for industrial users with small or medium size computers:

1. GASP is FORTRAN based and requires no separate compiler.
2. GASP is modular and can be made to fit on most machines that have FORTRAN compiler.
3. GASP is easy to learn, since it is FORTRAN and only the simulation concepts have to be mastered.
4. GASP can be implemented immediately on new computing systems.
5. Since GASP concepts are similar to those employed in other languages such as SIMSCRIPT, programs written in GASP can be easily converted to other simulation languages.
6. GASP is easily modified and extended.

Much literature is available on simulation and it's applications. Though they were not very directly connected with the simulation of an automated warehouse, some of the ideas and concepts behind them, were helpful in completing this simulation study.

CHAPTER 4

MODELLING USING GASP IIA

4.1. SIMULATION AND GASP IIA:

Digital simulation has been applied to study a particular automated warehousing system. Complicated mathematical tools can be used to study and design warehousing operations but the time and effort involved is too much for mathematical modelling to be acceptable. In fact in some cases mathematical models become so complicated that a solution is not possible. To get over these drawbacks, and to get a closer and a complete look into the continuous operation of the warehouse, digital simulation has been used.

Simulation is the use of a model (physical, analytical, computer) to study a system. It is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a business or economic system (or some component thereof) over extended periods of real time [91].

GASP IIA (General Activity Simulation Program) has been used on the simulation language in this problem. GASP IIA offers next event type simulation in which the logic of simulation moves from event to event and the measures of performance are taken at discrete-event times. A very brief introduction of GASP IIA is given here.

GASP IIA is a set of 26 Fortran subprograms organized to assist in performing simulation studies. Common elements of simulation studies that are independent of the particular problems, have been specified and subprograms have been provided to perform these specialized tasks. GASP IIA performs the following operations - data collection, statistical computing and reporting, monitoring and error reporting, random variate generation and all this are linked and organized by a main program known as the GASP executive - Subroutine GASP.

GASP IIA views the world as composed of entities, that are described by attributes. The specification of the attributes of a permanent element is equivalent to naming a FORTRAN variable with one to three subscripts [94]. These entities and their attributes are related through files. The entities interact with other entities through events. Events occur at points in time at which any system state change takes place. A system state can be changed if the entities are created or destroyed, attribute values changed or if file contents altered.

"The events and their effects upon system elements take place over time through the media of logical decision rules and physical process. These rules and processes depend on the state of the system in time, that is on the particular values of the element attributes and on various logical and physical parameters that characterize the system. As the model progresses through time, certain events generate data that represent changes in the system resulting from the particular data characterization and logical structure of the model. After a period of simulated time the simulation is terminated and the data examined to evaluate the performance of the model."[91]

GASP IIA is an improved version of GASP II and it has been tried for the first time in this university. In GASP II the filing array NSET is used for storing events and their attributes and entities and their attributes. Since NSET is a fixed point array, the attribute values have to be scaled to be stored in the array. The scaling causes truncation errors and limits the magnitude of the attributes stored in the filing array. NSET can be made a floating point array to resolve this difficulty. This procedure increases the storage requirements for those machines that use two memory words for floating point variables and one word for fixed point variables and the pointers used in the filing array should be integer values for efficiency and to avoid truncation difficulties [94]. This difficulty does not arise in the IBM 360/50, because in the 360 both the fixed point and floating point words are the same length. GASP IIA circumvents these difficulties by dividing the filing array into a floating point array and a fixed point array. The floating point attributes are stored in the one dimensional array QSET and the fixed point attributes are stored in the one dimensional array NSET. The array pointers are maintained in the array NSET.

GASP IIA like GASP II maintains multiple files and the ranking procedures are similar. The ranking attribute has been altered so that a KRANK value of less than 100 indicates that the ranking attribute stored in QSET and a KRANK value of greater than 100 specifies a ranking attribute stored in NSET. Another change in GASP IIA is that the time of the event is stored as the first attribute in QSET and the event code is stored as the first attribute in NSET. In GASP IIA there are two buffer storage vectors: ATRIB for floating point attribures and JTRIB for fixed point attributes. The number of floating point and fixed point attributes are specified by the GASP IIA variables IMM and IM, respectively.

The FIND subroutine in GASP II is split up in GASP IIA as FINDQ and FINDN. Subroutine FINDQ is used to search the floating point array and FINDN to search the fixed point array. A new subroutine LOCAT has been added to enable the programmer to convert from column and row designation to call number designation.

Both the files NSET and QSET are printed in the output.

4.2. THE SPECIFIC PROBLEM

Description: The skeleton of the problem was taken from a local automated warehouse of a leading manufacturing corporation. The warehouse, though not a highly sophisticated one, served the purpose, because the data collected from this warehouse was the only one available. The warehouse size has been reduced considerably to make simulation studies less laborious.

The following is a description of the warehouse which has been used in this simulation, and which the author had the opportunity to visit. The automated warehouse is a multiple aisle pigeonhole type unit load installation. The unit loads are materials on pallets. There are three aisles with racks on both sides. Two stacker cranes service two aisles at a time. A transfer car is used to shift the stackers from one aisle to another. The stacker services both sides of the aisle. Each aisle has 360 pigeonholes, 180 in each rack, arrayed 30 deep and 6 high. The dimensions of each pigeonhole are 6' x 5' x 8'4" deep.

Each aisle has an input station and an output station on the same end of the racks, both stations being serviced by conveyors. The input conveyor carries the pallet loads from the unit load forming operation to the input station. The pallet load is perfectly squared and aligned at the input station to be picked up by the stacker. The stacker, in accordance with the instructions it receives picks up the load, deposits the load into the appropriate address and returns to the "home base" for further instructions.

While retrieving, the stacker picks the load from the pigeonhole, returns to the "home base" and places the load on the output station, from where the load is conveyed to the appropriate destination.

The palletizing process is not considered in the simulation. The material is assumed to come into the system in palletized form. The conveyor speeds are also not taken into consideration.

Production Cycles: Eight varieties of tube lights are manufactured. This includes four different colors - A, B, C and D and in each color two different sizes - 4' and 8' lengths. There are four parallel production lines in the manufacturing section. Two lines for the 4' lengths and the other two for the 8' lengths. Only one color of tube light is manufactured at a time. For example if Color A is being manufactured, then all the lines will be producing Color A - the first two lines producing the 8' lengths and the other two producing the 4' lengths of Color A.

Each line produces 100 boxes of tube lights per hour, each box containing 12 tube lights. The manufacturing section works on a two shift basis, each shift being 8 hours. Hence each line will be producing 1600 boxes per day. On the whole 3200 boxes of 4' lengths and 3200 boxes of 8' lengths of the same product is manufactured per day, by the whole manufacturing section. 128 boxes of the 4' lengths or 60 boxes of the 8' lengths make up a pallet load. Hence 25 pallet loads of the 4' lengths and 53.3 (can be approximated to 53) pallet loads of 8' lengths are manufactured per day. Each pallet load weighs about 1150 lbs.

Storage: The pallet loads produced go into the automated store for a certain period of storage. This period of storage is necessary to enable the quality control department to run a series of tests on the particular batches of tube lights manufactured. If they come up with some flaw or defect in the tube lights, then that particular batch of tube lights is removed from the storage and scrapped. The probability of the batch being scrapped is negligible and hence in this simulation it is assumed that there is no defect in the production and hence no scrappage.

Interarrival Times: Table [1] gives the types of tube lights manufactured and the rate of production per day.

Types 1 and 2, both being of the same color are produced simultaneously, 50% of the time. After types 1 and 2 are produced, then type 3 and 4 are produced together, 25% of the time. Similarly type 5 and 6 and type 7 and 8. By 50%, 25% and 12.5% it means that if types 1 and 2 are produced for say 64 hours, then types 3 and 4 are produced for the next 32 hours, then types 5 and 6 are manufactured for 16 hours and lastly 7 and 8 are manufactured for 16 hours. The cycle repeats itself again. The change over time from the production of one type of material to another is negligible, but in this simulation it is taken to be the average of the rates of production of each length.

The 4' lengths are produced at a rate of 25 pallets per day. Hence the interarrival time into the store will be 38.8 minutes [(16 hours/25)*60]. Similarly the interarrival time for the 8' lengths will be 18.1 minutes. Since the production lines are all automated, the rate of production is almost constant. Hence the variation of the interarrival times is very small. The interarrival times are approximated by a truncated normal distribution with a mean of either 18.1 minutes or 38.8 minutes and $\pm$ 3 standard deviations. The variability is 5% of the mean, for both interarrival times.

Type	Length	Color	Percentage Production %	Production Per Day Pallets/Day
Type 1	4'	A	50	25
Type 2	8'	A		53.3
Type 3	4'	B	25	25
Type 4	8'	B		53.3
Type 5	4'	C	$12\frac{1}{2}$	25
Type 6	8'	C		53
Type 7	4'	D	$12\frac{1}{2}$	25
Type 8	8'	D		53

Table [1] Types of material and their rate of production.

The rate of input to the warehouse will be 25 + 53.3 = 78.3 pallets per day. The output and the input of the warehouse are balanced. Hence the time between each output will be [(16 hours/78.3)*60] = 12.13 minutes. The time between each output is also assumed to be normally distributed with a mean of 12.13 minutes $\pm$ 3 standard deviations. The variability is 5% of the mean. The output interarrival times is assumed to be normally distributed to be in balance with the input.

The interarrival times change according to the rate of input and output, or the rates of throughput in the warehouse. The changeover time TCH, is an average between the interarrival times of the 4' length and the 8' length. Table [2] gives the interarrival times and changeover times.

4.3. FORMULATION OF THE MODEL USING GASP IIA:

4.3.1. Subroutines and Events:

Fig [6] gives a general idea of the system which is simulated. The size of the warehouse has been reduced to one aisle with one stacker servicing just two racks on either sides of the aisle. The main events are formed as shown in Fig. [7]. The main subroutines used in the simulation, apart from the GASP subprograms are discussed below:

1. ARRIVE: This event subroutine simulates the arrival of the pallet load into the warehouse. The simulation is started with the arrival of types 1 and 2 material, these two initial arrivals being the initial events in the data. When a particular type arrives, the arrival subroutine checks the type of material and if the production time for that particular material is over, it

Table [2]. Interarrival times for various rates of throughput.

Rate of Throughput	Type	Mean (Hours)	Std. Deviation (Hours)	TCH (Hours)
	4' lengths	.6400	.0320	
78 Pallets/Day	8' lengths	.3002	.0150	0.42
	Output	.2030	.0106	
	4' lengths	.5012	.0250	
100 Pallets/Day	8' lengths	.2352	.0117	0.37
	Output	.1600	.0080	
	4' lengths	.4005	.0200	
125 Pallets/Day	8' lengths	.1881	.0094	0.34
	Output	.1280	.0064	
	4' lengths	.3200	.0160	
150 Pallets/Day	8' lengths	.1501	.0075	0.21
	Output	.1022	.0051	

4' lengths are Types 1, 3, 5 and 7.

8' lengths are Types 2, 4, 6 and 8.

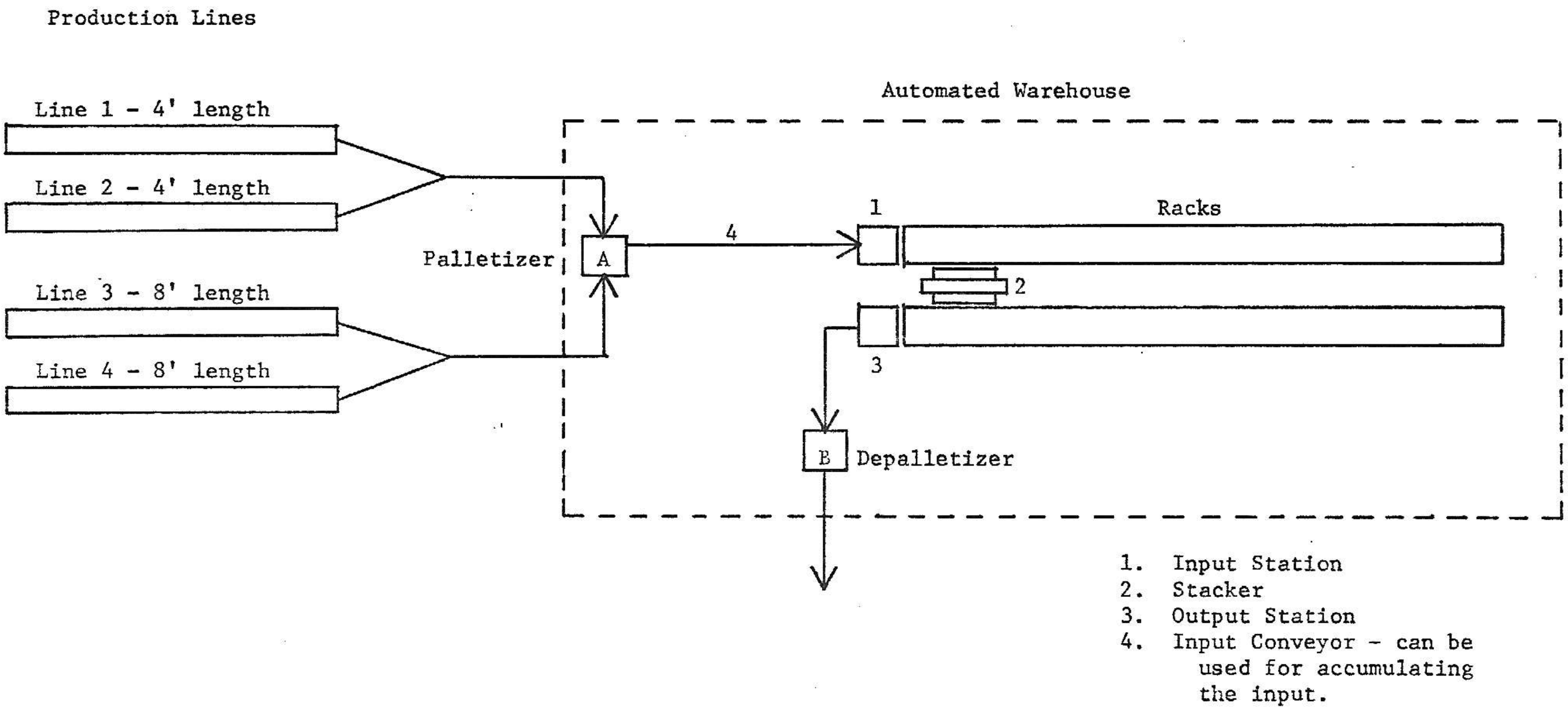

Figure [6]. The manufacturing and warehousing system.

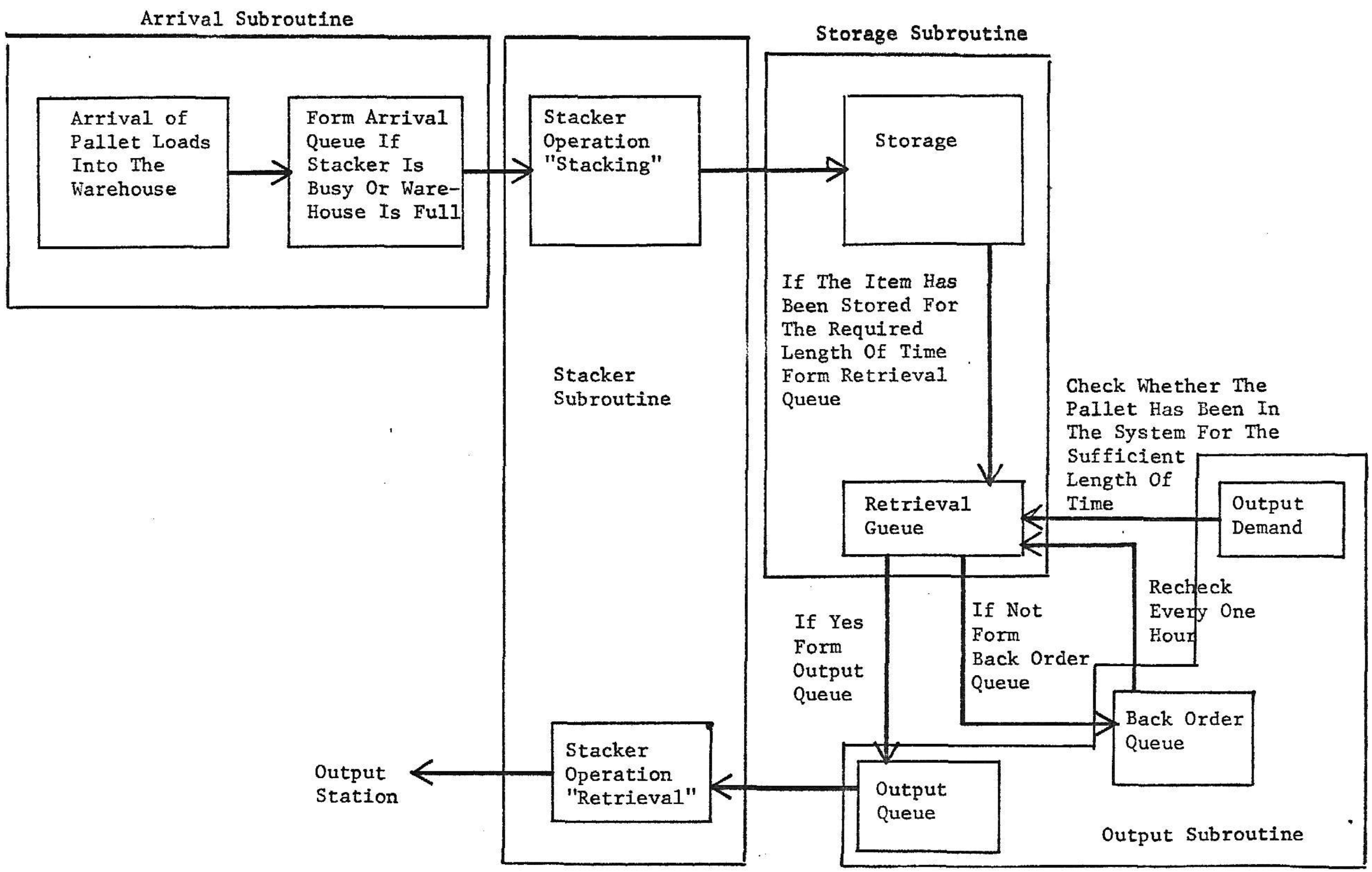

Figure [7]. Formulation of Subroutines.

will schedule the next type of material to arrive at TNOW + TCH, where TNOW is the current time and TCH is the changeover time. If the production time for that particular type material is not over, the program will schedule the same type to arrive at TNOW + X, where $X = N(38.8, 3\sigma)$ for 4' lengths and $X = N(18.1, 3\sigma)$ for 8' lengths and in both cases $\sigma = 0.05$ of the mean.

The arriving material is then formed into an arrival queue. The stacker is checked whether it is busy or idle. If idle, the stacker is called.

2. STACKER: This event subroutine simulates the stacker operation. The stacker event has been modelled in two different ways. In Model 1, the stacker operates only on a single command. The stacker subroutine can be called by both the arrival and output subroutines. The pallets waiting in the arrival queue are given the first preference, because it is not desirable to build up a long arrival queue. Hence when the stacker subroutine is called, it first checks whether there is any arrival waiting in the arrival queue. If so, it then checks whether there are any empty pigeonholes available and if there are vacant pigeonholes, it places the load in the pigeonhole, at the same time updating the file of the particular type of material (Files are maintained for each type of material in the system).

If there is no arrival waiting or if there are no empty locations, the subroutine checks if there is any pallet load to be retrieved. If there is any pallet load waiting in the output queue, it removes the pallet from the system at the sametime updating the file of the particular material.

The second model of the stacker can operate on dual commands also. The stacker, in other words, places the load in the pigeon-hole and retrieves a particular load in the same cycle.

Calculation of Stacker Cycle time:

Cycle time of stacker = stacker constant + stacker time.

Calculation of the constant:

FT = Fork cycle times to extend forks, lift or lower load and retract load = 0.232 minutes.

AT = Time to accelerate from start to travel speed = 0.067 min.

TS = Slow down travel time prior to stopping at bin = 0.067 min.

TS' = Slow down travel time prior to stopping at home station = 0.067 minutes.

K = 0.25 min., a constant for the particular stacker considered in the simulation, to allow for malfunction, deterioration, etc.

Stacker Constant = 2FT + 2AT + TS + TS' + K

= 2*0 232 + 2* 0.067 + 0.067 + 0.067 + 0.25

= 0.982 minutes

Cycle time of a Single Command Stacker:

XDIST = Total horizontal travel

YDIST = Total vertical lift

XSP = Horizontal travel speed (200 fpm)

YSP = Vertical travel speed (40 fpm)

XTIME = Travel time in the X direction = XDIST/XSP

YTIME = Travel time in the Y direction = YDIST/YSP

STIME = Maximum (XTIME, YTIME)

(YTI = Cycle time = (0.982 + 2*STIME) minutes

<u>Cycle time of a Dual Command Stacker:</u>

X1 = Horizontal travel distance to the pigeonhole to be loaded.

X2 = Horizontal travel distance to the pigeonhole to be emptied.

XDIST = Maximum horizontal travel.

Y1 = Vertical lift to the pigeonhole to be loaded.

Y2 = Vertical lift to the pigeonhole to be emptied.

YDIST = Maximum vertical lift

XTIME = = Travel time in the X direction = XDIST/XSP

YTIME = Travel time in the Y direction = YDIST/YSP

STIME = Maximum of XTIME, YTIME.

Stacker Constant (Dual) = 4FT + 3AT + 2TS + TS' +2K

= 4*0.232 + 3*0.067 + 2*0.067 + 0.067 + 0.5

= <u>1.838</u> minutes

CYIT = Cycle time = (1.838 + 2*STIME) minutes.

(The calculation of the stacker cycle time, has been taken from the A.R. Pabich's article in Plant Engineering on Planning Automatic Storage and Retrieval Systems).

3. OUTPUT: This event subroutine generates the outputs and determines what type of pallet load has to be retrieved. The initial output is given by the data. When an output event occurs this subroutine

schedules the next output at TNOW + X, X = N(12.13, 3). The type of material scheduled is generated from the probability distribution shown by Table [3].

After scheduling the next output event, the subroutine checks whether the particular material to be retrieved, is in the retrieval queue. If so, it removes the material from the retrieval queue and forms an output queue, which is the queue of the materials waiting for the stacker. If the stacker is idle, it calls the stacker. If the material to be removed is not in the retrieval queue, it is filed into the back order queue. At intervals of one hour (TRCHK), the first entry in the back order queue is removed and the retrieval queue is rechecked to see if the particular material is available. If not, then the material is again filed into the back order queue to be rechecked again.

A second model of the output subroutine has been tried. When an output event occurs, the first entry in the file of the particular material is removed and checked whether it has been in the system for the sufficient length of time. If it has been in the system for the required time, it is retrieved. If not, the order is filed into a back order queue, to be rechecked at time TNOW + the remaining length time it has to be in the system.

The retrieval queue is eliminated in this case, hence the FINDN subroutine is not used. The FINDN subroutine takes up a considerable amount of computer time. Though FINDN is not used in this model, the computing time is very high. This is due to the increased rechecking operations involved in the model. Model 1 was found to be more efficient, and so it has been used throughout the simulation.

Type	Pallets Per Day	Ratio	Percentage Production	Probability	Cumulative Probability
Type 1	25	.47	50%	0.1599	0.1599
Type 2	53.3	1		0.3401	0.5000
Type 3	25	.47	25%	0.0799	0.5799
Type 4	53.3	1		0.1701	0.7500
Type 5	25	.47	12.5%	0.0399	0.7899
Type 6	53.3	1		0.0851	0.8750
Type 7	25	.47	12.5%	0.0399	0.9149
Type 8	53.3	1		0.0851	1.0000

Table [3]. Probabilities per output sampling.

4. STORE: This event subroutine makes available the material for retrieval after the required holding time.

5. RCHECK: This event subroutine is scheduled for rechecking operations. The first entry filed in the back order queue is removed and OUTPT is scheduled.

6. OUTPT: This entry point in the OUTPUT subroutine is used to recheck the retrieval queue.

7. INTTAL: This event subroutine initializes the locations of the pigeonholes in the warehouse. Each pigeonhole is given it's co-ordinate distances.

   The preloading of the warehouse is also taken care of by the subroutine.

8. INITAL: Initizlizes the statistics on the total time in the system and the total time in the retrieval queue of a pallet, at 64.0 hours.

9. REPORT: This event subroutine produces the complete information of the system at fixed intervals of time. It calls the subroutine <u>OTPUT</u>, which brings out certain statistics which is not collected by GASP subroutine SUMRY, and the GASP subroutine SUMRY which outputs the various statistics collected through the simulation. SUMRY in turn calls the GASP subroutine PRNTQ, which outputs the information on the various GASP files.

10. SELECT: This subroutine from a discrete probability distribution and determines the type of material to enter and leave the system.

The event subroutine is given below according to their event numbers:

Event Number	Event Name
1	Arrive
2	Staker
3	Store
4	Output
5	Outpt
6	Report
7	Intial
8	Rcheck
9	Inital

4.3.2. Record Keeping:

Multiple files had to be used for record keeping purposes. A total of fourteen files are used in the simulation. Each file, their attributes and their routing procedure, have been shown below:

FILE 1: Event file

ATRIB(1) = Event time

JTRIB(1) = Event code

JTRIB(2) = Type of material on pallet (For events 1, 2, 4 and 5)

Ranked FIFO on ATRIB(1)

FILE 2: File of the Pigeonholes with Type 1 material.

ATRIB(1) = Time at which the pallet load enters the system.

ATRIB(2) = Time at which the pallet is loaded into the pigeonhole.

JTRIB(2) = Pigeonhole number.

JTRIB(3) = Distance of the pigeonhole from the input-output station, in the "X" direction.

JTRIB(4) = Height of the pigeonhole.

Ranked FIFO on ATRIB(2).

FILE 3: File of the pigeonholes with Type 2 material

[File 3 to File 9 are files of the pigeonholes with various types of the material. The ATRIBS and JTRIBS are same].

FILE 10: File of the empty pigeonholes.

ATRIB(2)= Time at which the pigeonholes became empty.

JTRIB(2)= Pigeonhole number.

JTRIB(3)= Distance of the pigeonholes from the input-output station.

JTRIB(4)= Height of the pigeonhole.

Ranked FIFO on JTRIB(2).

FILE 11: File of the pallets waiting in the arrival queue for the stacker.

ATRIB(1)= Time at which the pallet enters the system.

ATRIB(2)= Time at which the material entered the queue.

JTRIB(2)= Type of load

Ranked FIFO on ATRIB(2).

FILE 12: Retrieval Queue: Pallets ready for retrieval.

ATRIB(2)= Time at which the pallet entered the queue.

JTRIB(2) = Type of load

Ranked FIFO on ATRIB(2).

FILE 13: File of the pallets waiting in the output queue for the stacker

ATRIB(2) = Time at which the pallet entered the queue.

JTRIB(2) = Type of load.

Ranked FIFO on ATRIB(2).

FILE 14: Back order file

ATRIB(2) = Time at which the pallet entered the queue.

JTRIB(2) = Type of load.

JTRIB(3) = Ranking number.

Ranked FIFO on JTRIB(3).

4.3.3. Statistics Collected:

The GASP subroutine COLCT and HISTO have been used to collect the statistics.

SUBROUTINE	CODE	STATISTICS COLLECTED
COLCT	1	Time spent by the pallet in the retrieval queue.
COLCT	2	Waiting time in the arrival queue.
COLCT	3	Waiting time in the output queue.
COLCT	4	Waiting time in the back order queue.
COLCT	5	Cycle time of stacker.
COLCT	6	Average time spent in the system by a pallet load.
HISTO	1	Histogram of the time in the retrieval queue.
HISTO	2	Histogram of the waiting time in the output aueue.
HISTO	3	Histogram of the waiting time in the back order queue.
HISTO	4	Histogram of the waiting time in the arrival queue.

4.3.4. Assumptions and Rules of Operation:

1. The manufacturing department and the automated warehouse both work two eight hour shifts per day, without any breakdowns. No overtime

is allowed.

2. Rate of production of the various types of materials is the same for a particular production cycle.
3. The production runs are continuous without any interruption. All production lines work at equal rates and pace. There is no in-process inventory.
4. The boxes are assumed to be palletized when they enter the store. The palletizing operation has not been considered in the simulation to reduce computing time. Similarly when a pallet goes out of storage it is assumed to be depalletized.
5. The time taken for the control operation, such as card reading, or push button programming, etc. is assumed to be negligible.
6. The random storage system has been adopted. By this it is meant that there is no specific location for a specific material type.
7. The pigeonholes nearer to the input-output stations are serviced first. Figure [8] shows how the pigeonholes have been numbered. The pigeonholes are used according to their numbers in ascending order. All the racks are of equal dimensions.

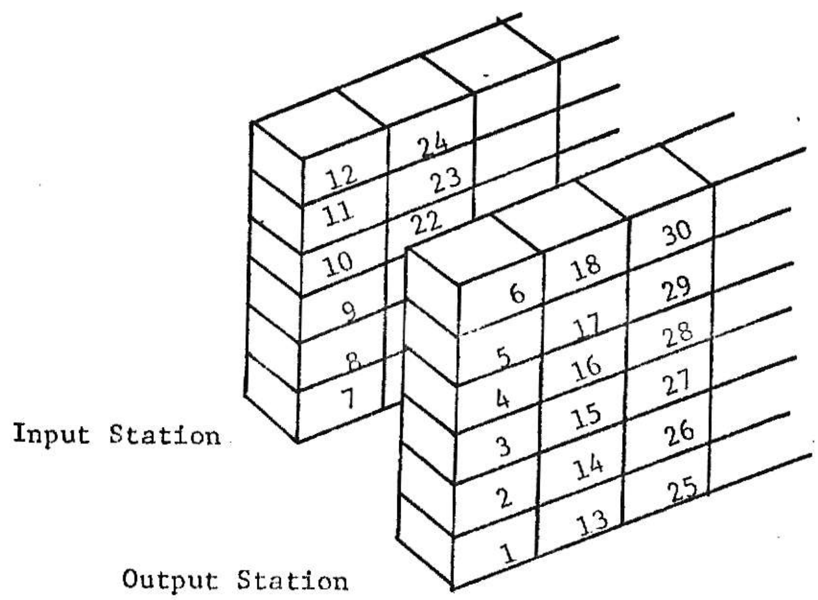

Figure [8]. Method of Numbering Pigeonholes

8. In practice, the hoist travels in the "Y" direction concurrent with the stacker movement in the "X" direction. The stacker trolley speeds is 200 feet per minute and the hoist speed is 40 feet per minute. The travel time of the stacker is the "X" direction or in the "Y" direction, whichever is greater is considered to calculate stacker cycle time.
9. The materials are stored in the warehouse for a particular length of time for quality control purposes. It is assumed that there are no rejections due to lack of quality.
10. The pallet loads are all assumed to be of correct size and weight, and there is no rejection due to discrepancy in dimensions of the pallet load. No overcharging of the pigeonholes are allowed.
11. The arriving pallet loads are given preference for the stacker operation.
12. The automated warehouse in this simulation is used just for the purpose of storage. The output and inputs are generated; hence there is no ordering cycle or any inventory control as such.
13. All the pallet loads are assumed to be full and there is no less than pallet load or broken-case storage.

CHAPTER 5

DISCUSSION OF THE RESULTS

5.1. OBJECTIVES: The objectives of this simulation have been threefold:

1. To develop a simulation model of an automated warehouse using GASP IIA and to study the behavior of the storage process. The model has been discussed in the previous chapter. During the simulation, the effects of certain variables on the stochastic nature of the storage process have been analyzed.
   a. The effect of varying the rate of throughput in the warehouse.
   b. The effect of multi-item production with varying production times, on the warehouse operation.
   c. The effect of varying the storage times on the warehouse operation, and the interrelated effects of all these variables.
2. The second objective was to determine the right amount of preload necessary for a balanced warehouse operation in the long run. The preload is the number of pallet loads already stored in the warehouse at the start of the warehouse operation. The ratio of the different material types in the preload has to be calculated so that the back orders, in the back order queue is within the operating policy of management. Various methods of preloading have also been studied. A formula has been developed to determine the amount of preload.

   The capacity of the storage system required for the process, considering the rates and lengths of production and storage times, has been determined.

The other features of the simulation discussed are:

1. The effects of the two types of stacker commands - dual command and single command, and
2. The capabilities of the system.

3. The third objective is to make a concise report on the features of the automated warehouse. Chapter two deals with this aspect of the objective.

5.2. MODEL NOTATION: A number of simulation runs have been made with different models, and a considerable amount of data has been gathered. To identify the different models used in the simulation a particular notation has been followed throughout this discussion. This notation identifies the pertinent variables in the model. By model M1(32, 16, 78) it is meant model number 1 with 32 hours production cycle, each pallet being stored in the warehouse for at least 16 hours and the throughput rate is 78 pallets/day. The changes in the other variables in the model have been discussed as and when required. Table [4] shows the notation for some of the important models used in the simulation.

5.3. THE BEHAVIOUR OF THE STORAGE PROCESS:

The automated warehouse considered in this simulation is assumed to be used for the purpose of storage. There is no ordering cycle for the goods stored in the warehouse and there is no inventory control as such. The main interest however, is to study the characteristics of the warehouse at different times for any stochastic process. The process being the arrival of a pallet load into the warehouse, storage of the material for

THIS BOOK CONTAINS NUMEROUS PAGES THAT HAVE INK SPLOTCHES IN THE MIDDLE OF THE TEXT. THIS IS AS RECEIVED FROM CUSTOMER.

THESE ARE THE BEST IMAGES AVAILABLE.

Table [4]. Model notations for the various simulation runs.

Model	Rate TPUT	TONE	TTWO	TTHRE	TCH	NPX	NPHI	PRELOAD	SAFETY STOCK	TSTOR	TRCHK	Length of Sim. (Hrs)	Remarks
M1(32,16,78)	78	16.0	8.0	4.0	.42	30	6	150	-	16.0	2.0	48.0	
M2(32,16,78)	78	16.0	8.0	4.0	.42	30	6	150	-	16.0	2.0	16.0	Method II - No retrieval queue
M3(32,16,78)	78	16.0	8.0	4.0	.42	30	6	150	-	16.0	2.0	40.0	Stacker - Dual command
M4(128,32,78)	78	64.0	32.0	16.0	.42	30	6	150	-	32.0	2.0	112.0	
M5(64,16,78)	78	32.0	16.0	8.0	.42	30	6	150	-	16.0	2.0	256	
M6(32,16,78)	78	16.0	8.0	4.0	.42	30	6	150	-	16.0	2.0	256	
M7(32,16,150)	150	16.0	8.0	4.0	.235	30	6	150	-	16.0	2.0	104	NOFIL, introduced
M8(32,16,100)	100	16.0	8.0	4.0	.37	30	6	150	-	16.0	2.0	256	
M9(32,16,125)	125	16.0	8.0	4.0	.34	30	6	150	-	16.0	2.0	224	
M10(32,16,125)	78	16.0	8.0	4.0	.42	30	6	75	-	16.0	2.0	256	
M11(32,32,78)	78	16.0	8.0	4.0	.42	30	6	150	-	32.0	1.0	156	
M12(32,32,150)	150	16.0	8.0	4.0	.42	30	6	150	-	32.0	0.5	64	
M13(32,24,100)	100	16.0	8.0	4.0	.37	30	6	300	-	24.0	1.0	256	Initialized statistics
M14(64,16,78)	78	32.0	16.0	8.0	.25	30	6	240	-	16.0	1.0	256	WTR Histogram cell width changed
M15(64,32,78)	78	32.0	16.0	8.0	.42	30	6	315	-	32.0	1.0	256	
M16(128,32,78)	78	64.0	32.0	16.0	.42	30	12	475	-	32.0	1.0	352	
M17(64,16,78)	78	32.0	16.0	8.0	.42	30	6	176	78	16.0	1.0	448	Improved preloading method
M18(64,32,78)	78	32.0	16.0	8.0	.42	30	6	257	78	32.0	1.0	448	Improved preloading method
M19(64,32,78)	78	32.0	16.0	8.0	.42	30	6	257	78	32.0	1.0	448	Preloaded directly into retrieval file, Improved preloading
M20(64,32,78)	78	32.0	16.0	8.0	.42	30	6	257	78	32.0	1.0	448	Truncation of input distribution at 3 on both sides. Imp. preloading.
M21(64,32,78)	78	32.0	16.0	8.0	.42	30	6	116	0	16.0	1.0	256	Stacker - Dual command. Improved preloading
M22(64,32,78)	78	32.0	16.0	8.0	.42	30	6	276	0	32.0	1.0	256	Improved preloading. No safety stock.

a particular length of time and the retrieval and output of the material.

Model M5(64, 16, 78) is used to study the warehouse operation. A 64 hour production cycle produces eight types of materials - Types 1 and 2 produced during the first 32 hours (TONE), types 3 and 4 produced in the following 16 hours (TTWO), types 5 and 6 in the next 8 hours (TTHRE) and types 7 and 8 in the last 8 hours (TTHRE) of the production cycle. The complete production cycle repeats itself again. The interarrival times of the 4' pallet loads and 8' pallet loads are both truncated normal distributions with means of 38.8 minutes and 18.1 minutes respectively. The products come out of automated production lines, where the machines being driven by synchronous motors run at constant speeds. Hence the products cannot be produced faster than a particular limit. The production rate can be slowed down due to breakdowns, breakages, etc. Hence the interarrival times are truncated at 1 on the lower side and 3 on the higher side.

The throughput in the warehouse is 78 pallets per day (RATE), and each pallet load has to be in storage for at least 16 hours (TSTOR). The output of the warehouse is also stochastic, the outputs being sampled from a particular discrete probability distribution. The time between each outputs follows a truncated normal distribution with a mean of 12.13 minutes and the truncation at 3σ on both the sides.

The number of pigeonholes in the warehouse is 360 - 180 on each side of the aisle, the racks being built 6 high. 150 pallet loads comprising different types of materials have been preloaded into the warehouse. (One of the reasons for including this model is to study the process effects due to improper preloading). The amount of the different types of materials that form the preload are determined according to the output probability distribution. Table [3] shows this discrete distribution. The preloaded items are available for retrieval at intervals of 0.1 hours from TBEG, the time at which they are preloaded, which is the start of the simulation.

Figures [9] and [10] show the number of different pallet loads in the warehouse at various periods of time. The total number of pallets in the system is also shown. The variations in types 2, 4, 6 and 8 are more because of their higher rate of 53 pallets per day, which is more than double the rate of types 1, 3, 5 and 7. A certain number of types 1 and 2 material are always stacked in the warehouse. This is due to the longer production runs for these two types, which is responsible for a larger number of types 1 and 2 coming into the warehouse.

As an example consider type 2 material. Type 2 is produced for a length of 32 hours, the storage time being at least 16.0 hours. Hence the material will be available for output at the end of 16.0 hours of simulation time. From TBEG to 32.0, the number of type 2 in the system increases, due to the production. After 32.0 hours a different material type is produced and the demand for type 2 has to be satisfied by the material in storage. This is the reason why the number of type 2 in the system reduces from 32.0 to 64.0 hours, at which time the production of type 2 starts again, due to the production cycle being repeated.

Types 3, 4, 5, 6, 7 and 8 are not in storage at sometime or other. This is due to the lower amounts of production of these types, compared to type 1 and 2. When a demand for a particular material occurs, and if that material is not in storage, or if it has not yet completed the period of

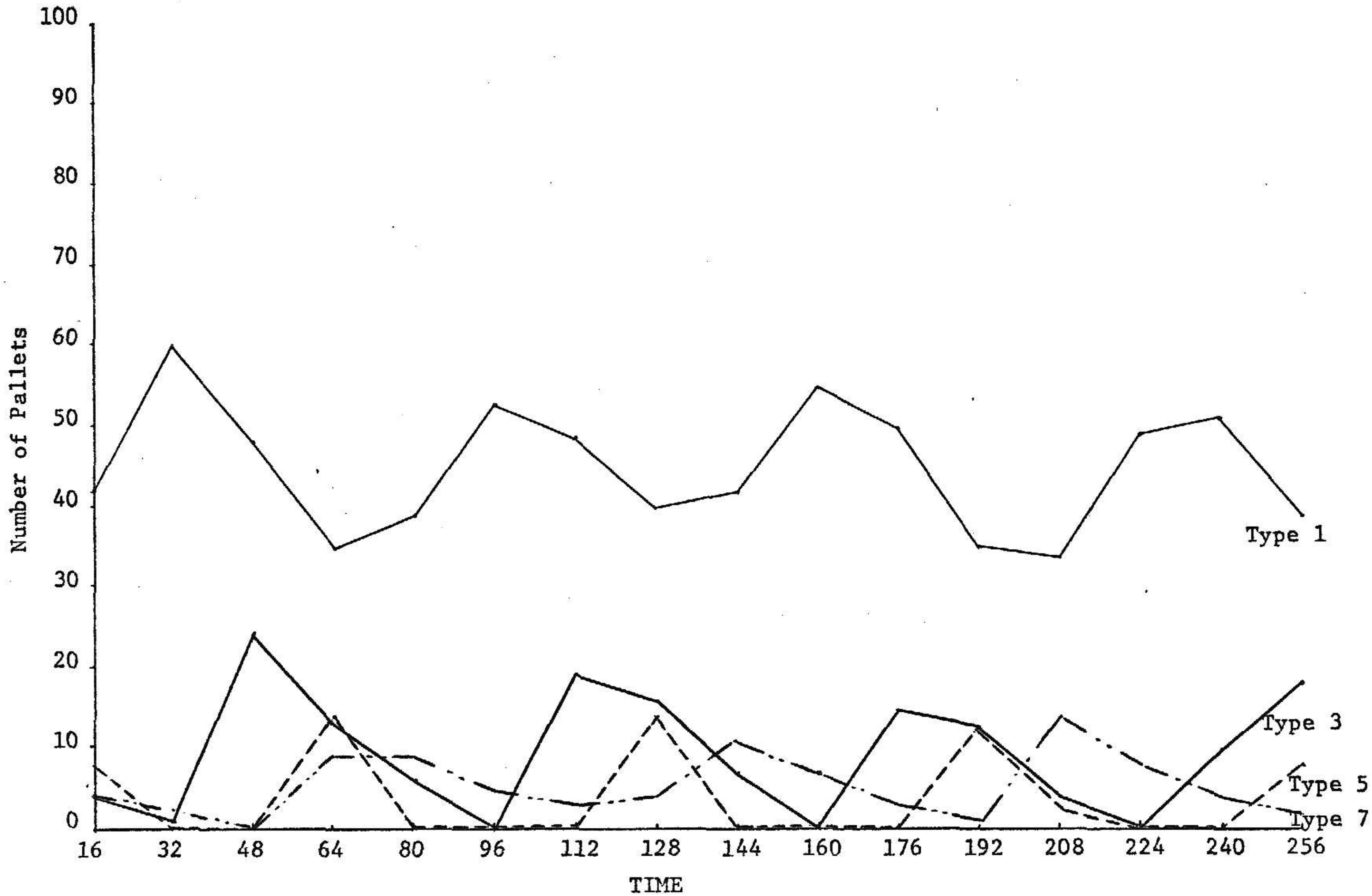

Figure [9]. Variation of types 1, 3, 5 and 7 in the system.

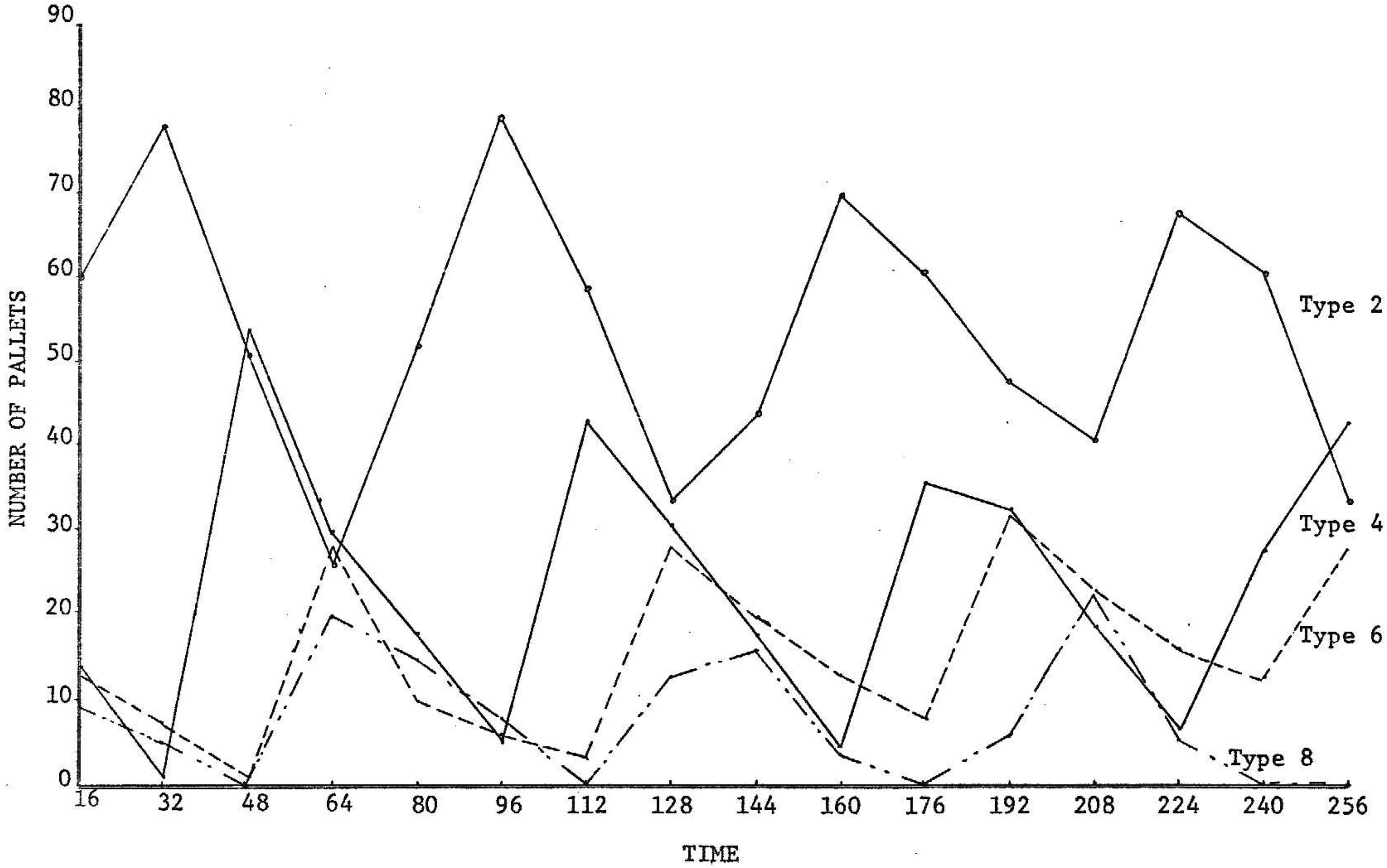

Figure [10]. Variation of types 2, 4, 6 and 8 in the system.

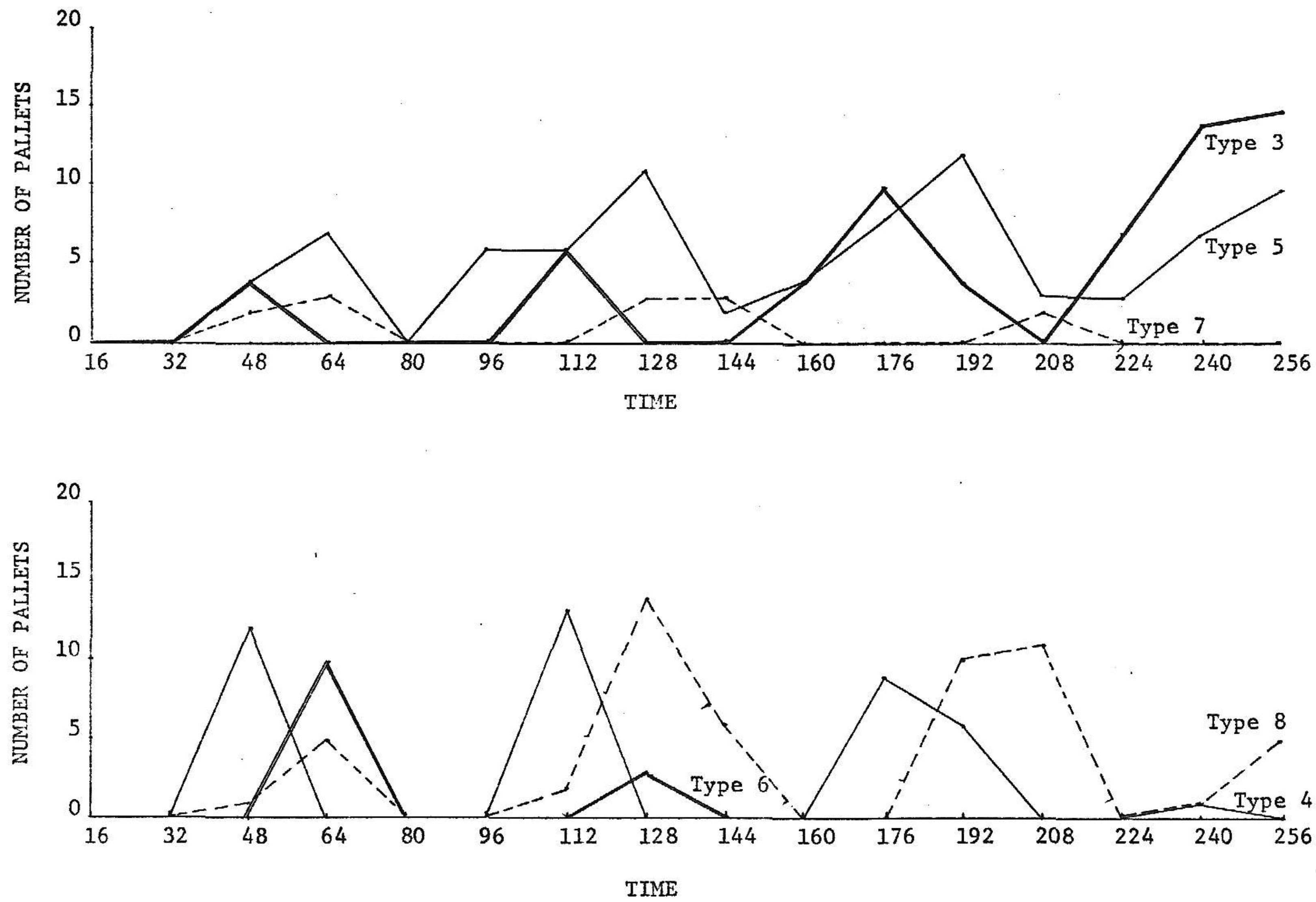

Figure [11]. Number of orders in the back order queue.

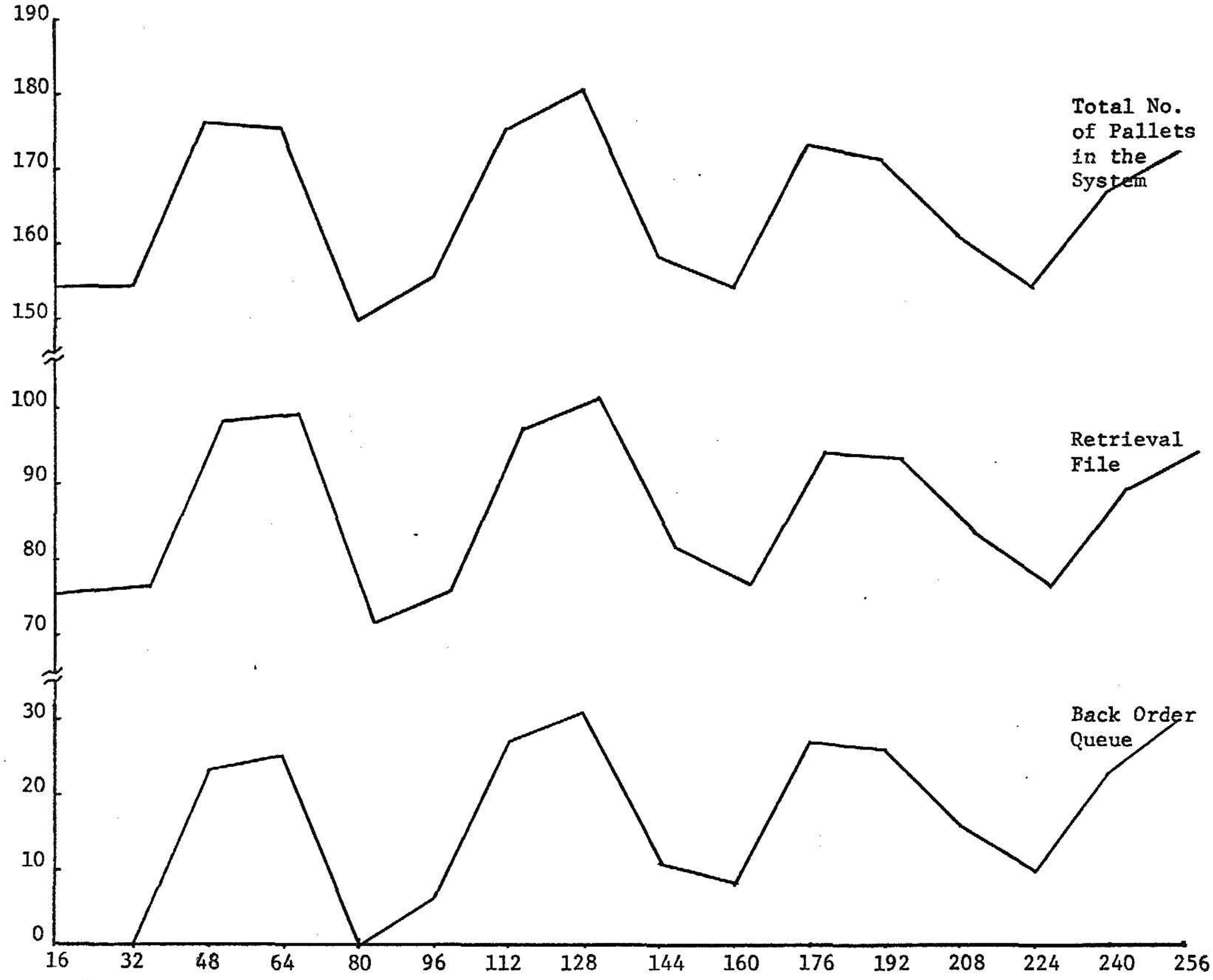

Figure [12]. Relationship between the total number in the systems, the retrieval queue and the back order queue.

storage, then a back-order queue is formed. Figure [11] shows the numbers of the various materials in the back order queue. Since the production of Types 1 and 2 are more than enough to satisfy the demand for those items, there is no back order of types 1 and 2. It is seen by comparing the Figures [10] and [11] as the number of items of type 4 in the system increases, the back order for that type also increases. Up to a simulation time of 32.0 hours the output demand for type 4 was satisfied by the preload, which was 150, a two days stock. After 32 hours the demand has to be satisfied by the item of type 4 coming into storage. But type 4 item comes into storage only at 32.0 hours, the production time being up to 48 hours. Since each pallet load has to be in storage for at least 16.0 hours, the first pallet of type 4 material is available only after 48 hours. Hence the back order of type 4 also builds up simultaneously. Similar explanations can be given to the other variation in the back-order queue.

This process of the different items being out of stock at specific times, is the cause for the cyclic back-order queue shown in Figure [12]. Cyclic back-orders are notpalatable for efficient warehouse operations, because it means that at regular intervals of time, customer orders are not satisfied. For balanced warehouse operations without customer back-log, the back order queue has to be reduced as much as possible. The cyclic effect in the back order queue affects the retrieval queue in the same manner. The retrieval queue is a file of materials that have been in the storage for the retrieval length of time and so are ready for retrieval. If an order for a material comes in and is not available in the retrieval queue, then it is added to the back order queue. The back order queue builds up. Since at that time no items have been removed from the retrieval queue and due to the regular additions of the materials available for retrieval into this queue, the retrieval queue also builds up. Hence, it is seen that the retrieval queue and the back order queue are related to each other as shown in Figure [12]. Since the total number in the system includes the retrieval queue, the total pallets in the system are also affected in the same way as the retrieval queue. The main influence here is that the back order queue, the retrieval queue and the total number of pallets in the system are all related to each other and any discrepancy in the back-order queue affects the whole system in the same way.

Improper preloading is the main cause for the cycle back order queue. The preloading aspect has been discussed later in this chapter. To summarize, the study of the storage process has given an insight on the following:

1. The range and frequency of variation of each type of material in the warehouse.
2. The relationship of the back-order queue with the total number of pallets in the warehouse.
3. The cyclic variation of the back-order queue, which is caused by improper preloading.

5.4. EFFECT OF VARYING THE THROUGHPUT IN THE WAREHOUSE:

The throughput of the warehouse is the rate of flow of the pallets per working day through the warehouse. Various throughputs have been tried in the simulation studies. Figure [13] shows the effect of varying the throughput, on the total number of pallet loads in the warehouse and the back-order queue. Figure [14] shows the average time spent in the system by a pallet load. Tables [4] and [5] provide other relevant statistics of the different models.

Five models have been compared. The feature that strikes the eye, is the varying degree of fluctuation; in the total number of pallets in each system. As the throughput rate increases the fluctuations tend to increase. The fluctuations also become cyclic with increased throughput. The main reason for this cyclic variation is the improper and insufficient preloading in different models. Except for M9(32, 16, 78), the preloads for all the other models are 150 pallets, which is not sufficient for higher rates of production as in M7(32, 16, 150). In M7 this is the very prominent cyclic back order queue and the total pallets in the system.

Models M9(32, 16, 78) and M8(32, 16, 100) have been compared to show that the rate of throughput is also the cause for the fluctuations, though not in the same intensity of preloads. M9 has a preload of 78, which is just a days stock. Model M8 has a preload of 150 which for this model is more than a days stock. Curve of the total pallets in the system of both the models have been compared in figure [13]. It is seen that the curve of M9 is smoother than M8, M8 having a higher throughput rate it goes to show that the rate of throughput is also a cause for fluctuations in the system.

Some other observations made, on varying the throughput are:

1. The stacker utilization is a maximum in M7(32, 16, 150), which has a rate of 150 p/day. M6(32, 16, 78) and M7(32, 16, 78) have low stacker utilization because their low rates of throughput. It is seen from Table [6] that the stacker cycle time does not vary much. This is because the cycle time of the stacker does not depend on the rate of throughput, but on the number of pigeon-

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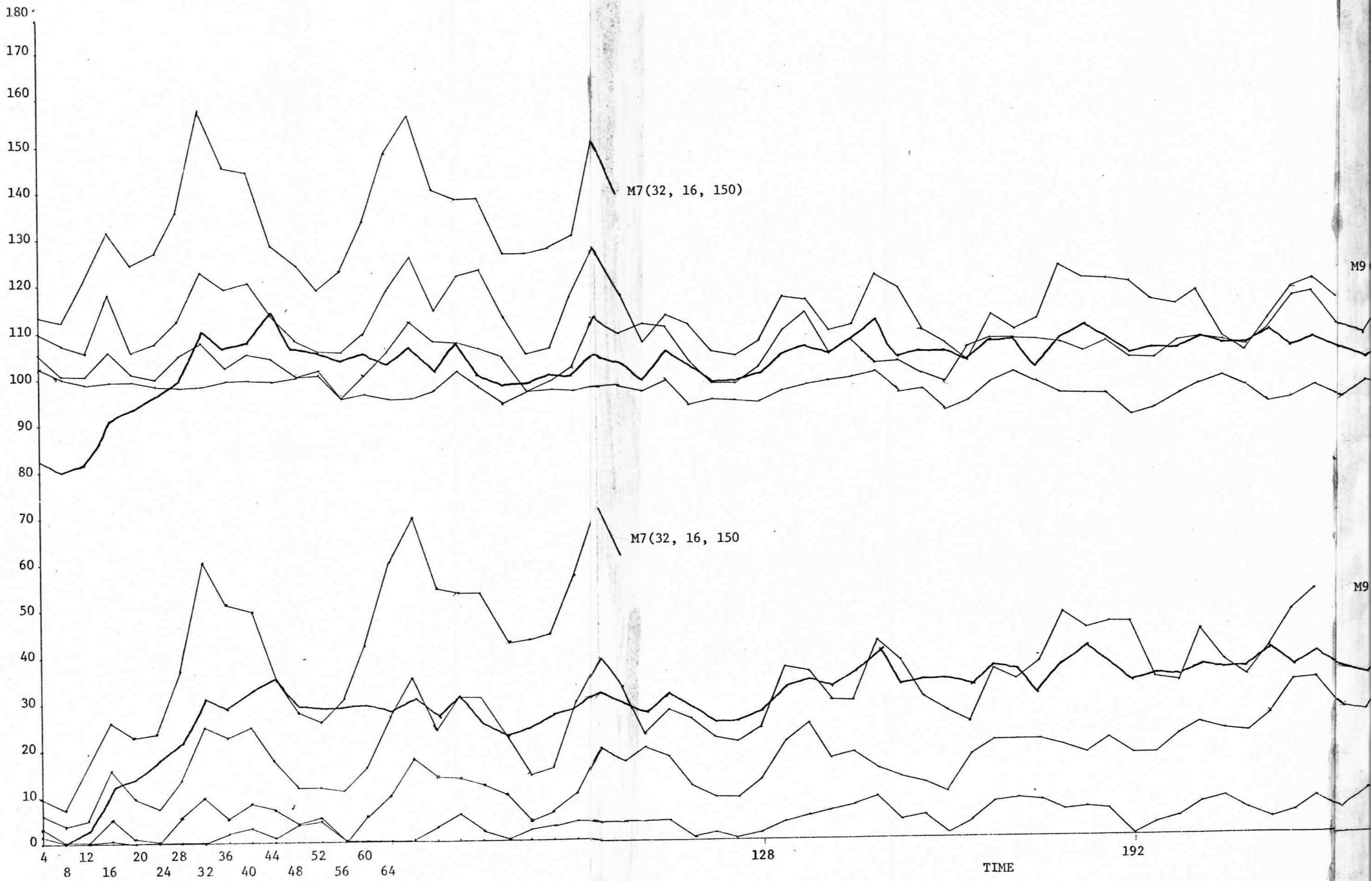

Figure [13]. Effects of varying the rates of throughput.

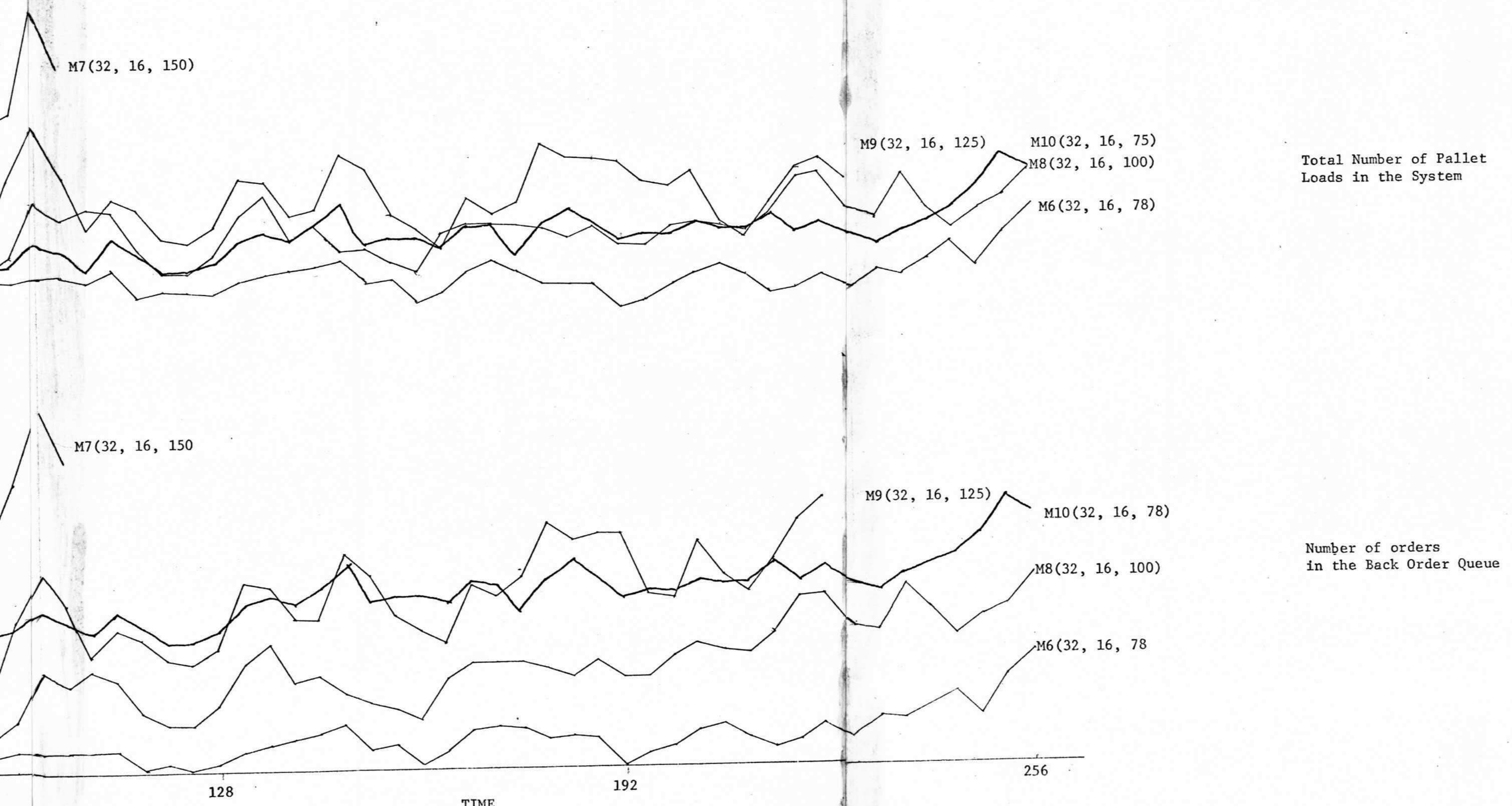

Figure [13]. Effects of varying the rates of throughput.

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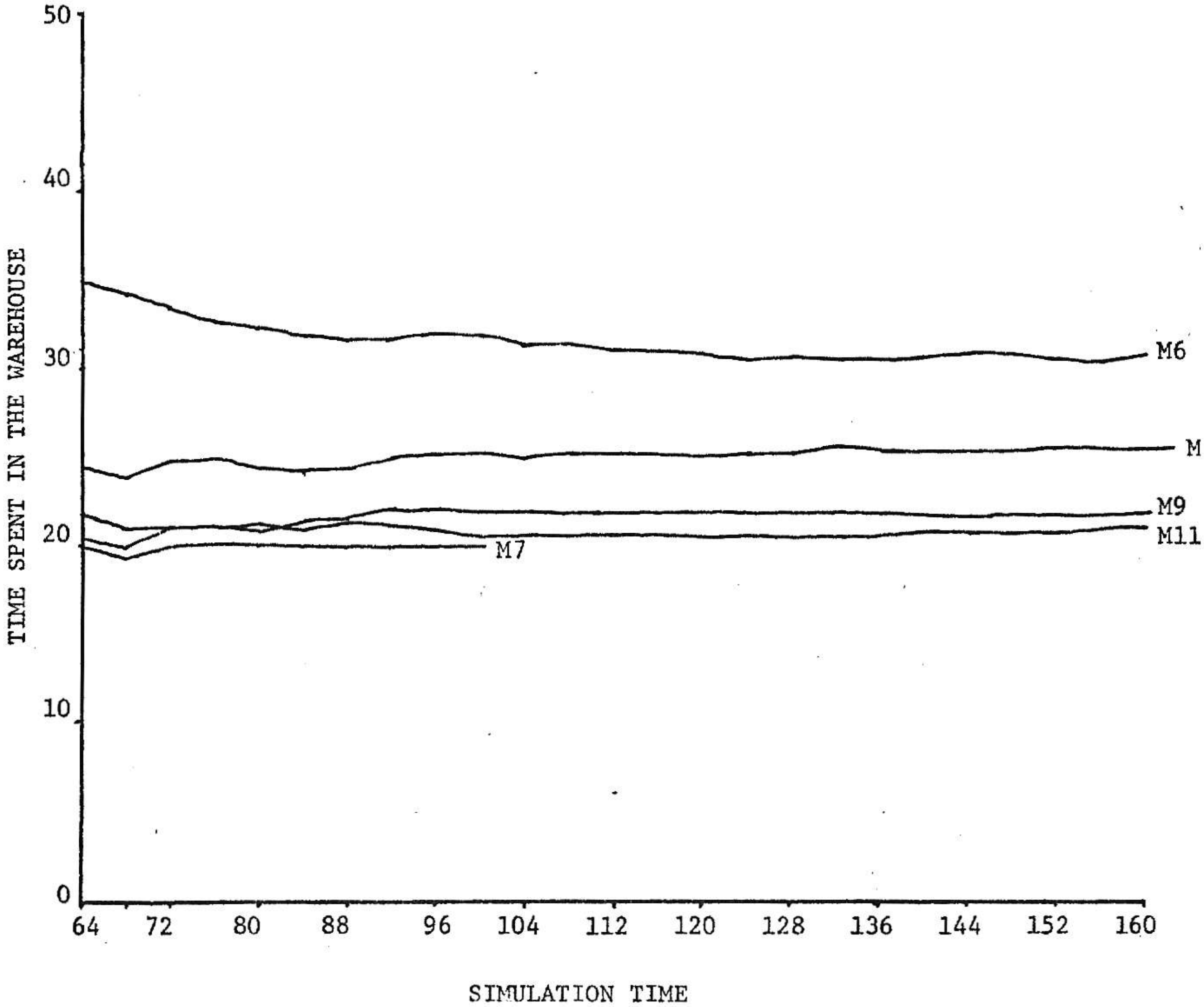

Figure [14]. Total time spent in the warehouse for various throughputs (Statistics initialized at 64.0 hours).

Table [5]. Statistics on the retrieval and back orders queues.

Model	Waiting Time In Retrieval Queue (Hours)		Waiting Time in the Back Order Queue (Hours)		Total No. of Obser. Taken in the Back-Order Queue	Maximum Number of Orders In The Back Order Queue		Statistics Recorded At Time (Hours)
	Mean	Max.	Mean	Max.		No.	At Time	
M6(32, 16, 78)	13.58	61.13	7.33	26.00	98	9	148	224
M8(32, 16, 100)	9.04	42.87	8.81	90.00	295	34	224	224
M9(32, 16, 125)	5.60	36.21	10.17	128.00	566	48	224	224
M7(32, 16, 150)	3.58	23.29	9.66	58.00	355	71	100	104
M10(32, 16, 78)	5.12	41.87	12.38	134.00	485	41	148	224
(Preload 75)								

Table [6]. Stacker and pigeonhole statistics and the total time spent in the system.

Model	Average Stacker-Cycle Time (Minutes)	Stacker Utilization %	Average Pigeon-Hole Utilization %	Max. No. of Pigeonholes Used		Average Time Spent in the Warehouse By a Pallet Load (Hours)		Total No. Of Pallets That Have Been Handled	Stats. Record. At Time (HRS)
				No.	At Time	Mean	Max.		
M6(32, 16, 78)	1.83	29.7	41	157	4	30.63	77.13	1092	224
M8(32, 16, 100)	1.84	37.5	44	171	220	25.52	58.87	1381	224
M9(32, 16, 125)	1.85	46.8	46	182	100	21.79	52.22	1715	224
M7(32, 16, 150)	1.86	57.7	53	212	32	19.98	39.29	990	104
M10(32, 16, 78) (Preload-75)	1.79	28.6	29	114	44	21.16	57.87	1092	224

holes utilized for storage. This fact is shown by Model M7(32, 16, 150) which uses the maximum number of pigeonholes for storage. The stacker cycle time is maximum for this model, the time being 1.86 minutes. The more pigeonholes used, the more the stacker has to travel from the home station. Due to this longer travel time the stacker cycle time increases.

The stacker utilization for M7(32, 16, 50) is 57.7% which is the maximum among the various models compared. M6(32, 16, 78) and M7(32, 16, 78) have the lowest stacker utilization because of their low rates. In short the stacker utilization depends more on the rate of throughput and the stacker cycle time on the number of pigeonholes utilized. It should be noted that the rate of utilization and the number of pigeonholes used for storage are both related to each other, in the higher throughput models the fluctuation are more, which means that on the average more pigeonholes are utilized:

2. Another important observation is the total time spent by the pallets in the system in different models. From Table [5] it is seen that M7(32, 16, 150) has the lowest time in the retrieval queue. This is due to the rate of demand which is more in M7, 150 pallets per day. Due to insufficient preload there is a large back order. Hence as and when the pallets become available for retrieval they are taken out. So the time spent in the retireval queue is only 3.88 hours as compared to 13.58 hours spent by a pallet in the retrieval queue of M6(32, 16, 78). M6 has a rate of 78 pallets per day. The preload/rate ratio is

very high as compared to M7. The back order is less. Hence a greater number of items are available for retrieval for a particular demand. So the time spent in the retrieval queue is more. Since the total time spent in the system depends on time spent in the retrieval queue, the average time spent in the warehouse by a pallet is M7(32, 16, 150) is 19.98 has much less than 30.63 hours in M6(32, 16, 78).

As said earlier improper and insufficient preloading and the high throughput rate has caused the cyclic back-order in M7. The maximum number of orders in the back order queue was 71 in M7 which has a low preload/rate ratio. M6 which has the highest preload/rate ratio has only a minimum of 9 orders waiting in the back-order queue at any instant.

The main features that have come to light by varying the rates of throughput are:

1. The rate of throughput contributes to the fluctuations in the system.
2. Improper preloading affects the system with higher throughput rate to a greater extent than one with a lower throughput rate. The fluctuations tend to become cyclic as the throughput increases.
3. Stacker utilization is more in the case of higher throughput models, due to the increased number of pallet loads handled in the warehouse.
4. The average time spent in the warehouse by a pallet load, depends primarily on the time spent by the pallet load in the retrieval queue, which on the other hand depends on the preload.

5.5. EFFECT OF PRODUCTION CYCLES ON WAREHOUSE OPERATION:

Figure [15] is a comparison of the simulation run of two models M6(32, 16, 78) and M5(64, 16, 78), with different production cycles. For a preload of 150 pallets a two days stock, M5 tends to be cyclic, the cyclic period being one production cycle. Tables [7] and [8] give the statistics of both the models taken at the end of 224 simulation hours.

The maximum number of orders in the back order queue for M5 is 30 and 9 for M6. The back order queue of M5 which is cyclic is obviously due to the nonavailability of the right material at the right time. This in turn is due to the preload. The number of each item in the preload was not sufficient to satisfy the demands for the various items during the 64 hours production cycle. Figure [11] shows the type and amount of materials that are out of stock.

The total number of pallets in the system for model M5(64, 16, 78) varies from about 150 to 180 pallets, due to the cyclic nature of the system. The average pigeonhole utilization is 46%. In model M6(32, 16, 78) the variation is neither cyclic, nor is there any real fluctuation in the system, hence the pigeonhole utilization is around 41%. The average time spent in the system by a pallet load is more in M5, 33.4 hours, than in M6 which has 30.63. The pallets stay in the warehouse for a longer time in M5 due to the cyclic back-orders. Back orders increase the entries in the retrieval queue, which means that more time is spent in the retrieval queue, which increases the time spent in the system.

Some features that are prominent due to the production cycle effect on the storage processes are:

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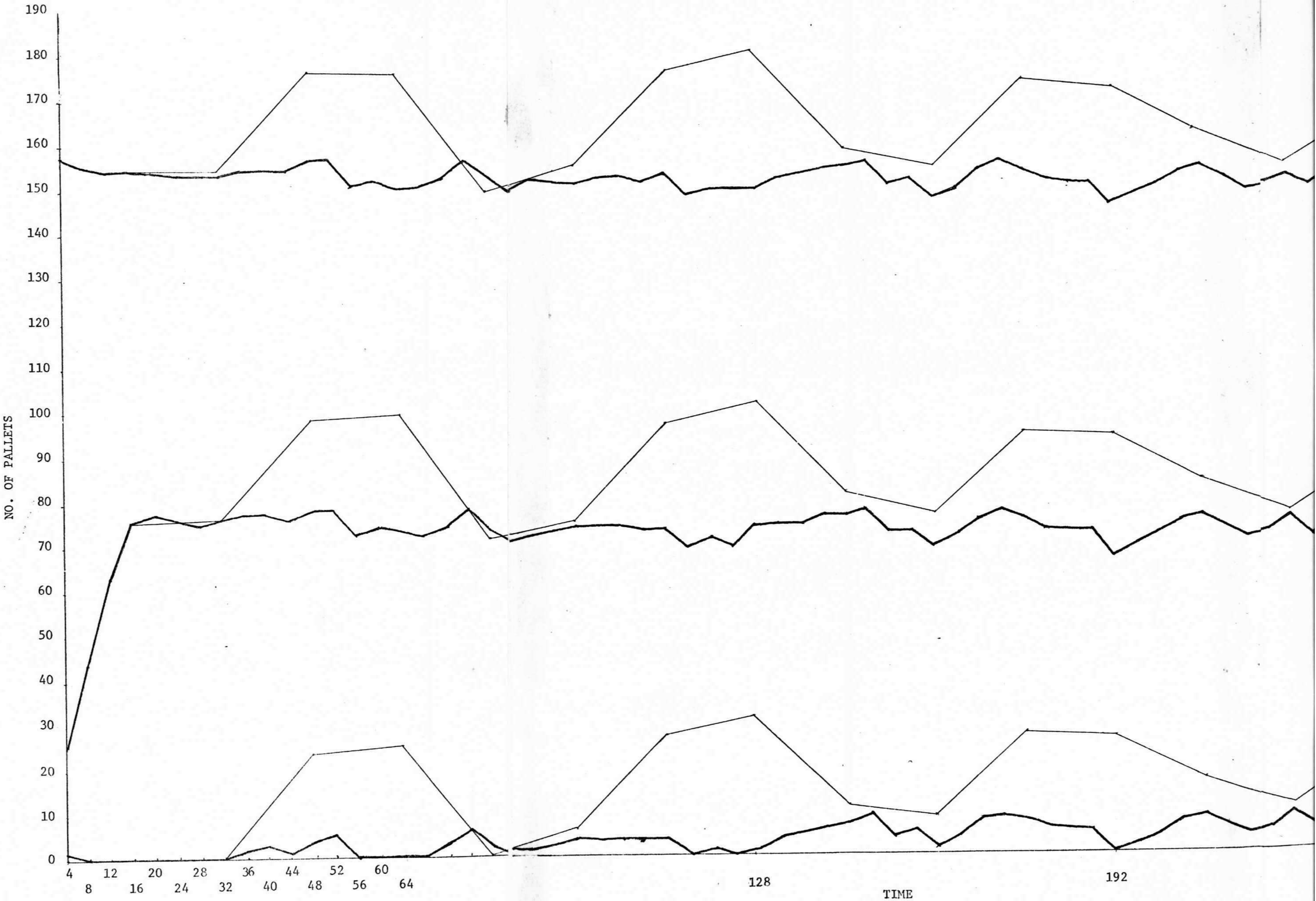

Figure [15]. Effect of production cycles.

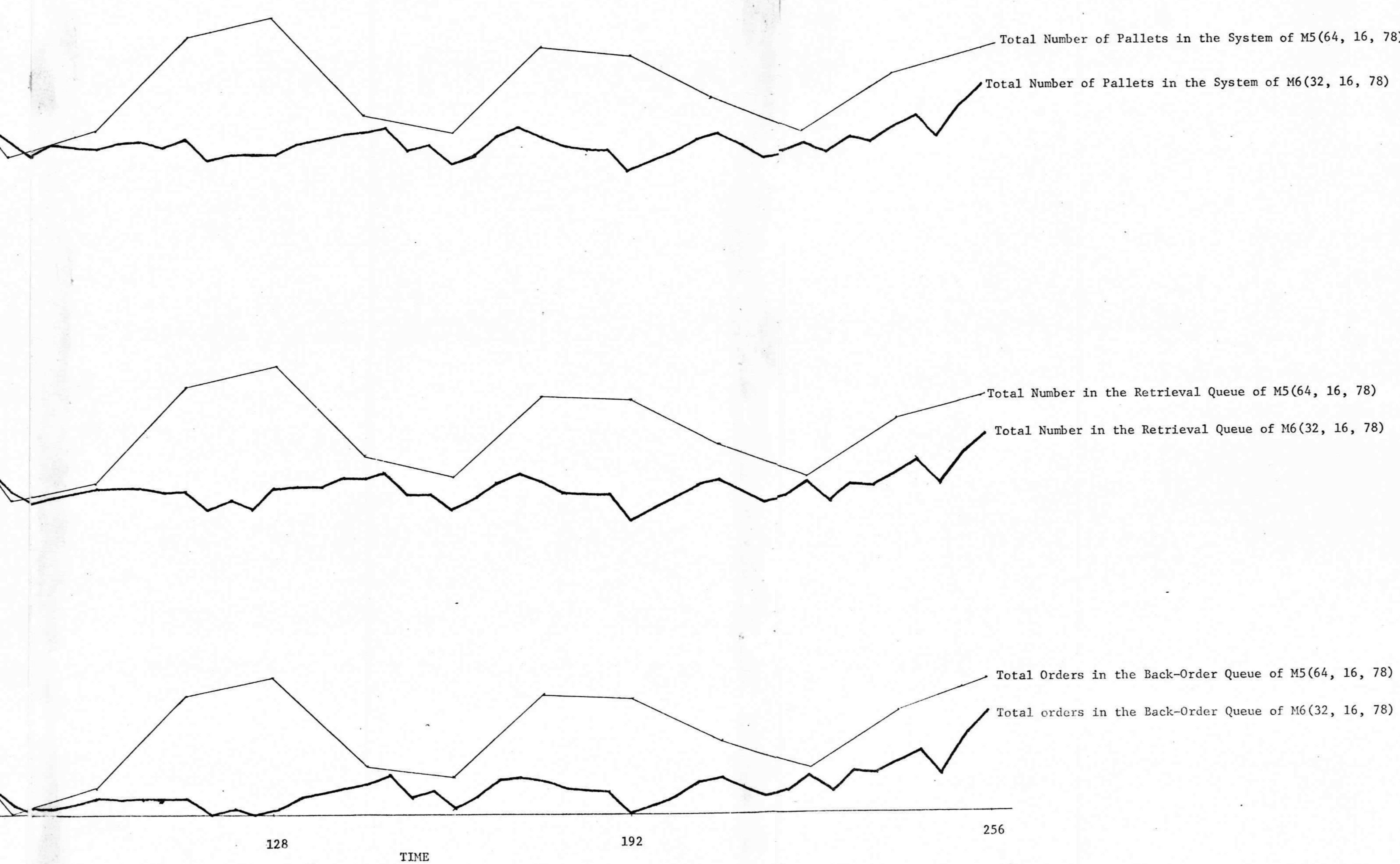

Figure [15]. Effect of production cycles.

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Table [7]. Statistics of M5(64, 16, 78) and M6(32, 16, 78) at 224 simulation hours.

	Waiting Time In the Retrieval Queue (Hours)		Waiting Time In the Back-Order Queue (Hours)		Total Number of Entries That Have Been in the Back-Order Queue	Maximum No. of Orders in the Back-Order Queue At Any Instant	
						Number	At Time
M6(32, 16, 78)	13.58	61.13	7.53	26.00	98	9	148
M5(64, 16, 78)	15.74	60.83	16.55	114.00	188	30	128

Table [8]. Stacker and pigeonhole statistics and total time in the system of M5(64, 16, 78) and M6(32, 16, 78).

	Average Stacker Cycle Time (MIN)	Stacker Utilization %	Average Pigeon-Hole Utilization %	Maximum Number of Pigeonholes Used		Total Time Spent In The Warehouse by a Pallet Load Hours		Total Pallets That Have Been Handled
				No.	At Time	Mean	Max.	
M6(32, 16, 78)	1.83	29.7	41	157	4	30.63	77.13	1092
M5(64, 16, 78)	-	-	46	180	128	33.4	76.86	1093

1. For a particular preload, as the production cycle increases, the number of pallets in the system tends to become cyclic, which is due to the cyclic nature of the back-order.
2. The number of pigeonholes required increases for larger production cycles due to the increased fluctuation range.

5.6. EFFECT OF STORAGE TIME:

Models M6(32, 16, 78) and M11(32, 32, 78) have been used to show the effects of storage time. Both the models have a preload of 150 pallets. Their rates of throughput are the same being 78 pallets/day, and the production cycle in both the cases is 32 hours. M11 has a storage time of 32 hours, double that of M6, which has a storage time of 16 hours.

The preloaded pallets are made available at time increments of 0.1 hours, in both the models. Hence the complete preload of 150 pallets (being a two days stock at the rate of 78 pallets per day) come into the retrieval queue by the end of 15 hours of warehouse operation. It is seen that at the end of 16.0 hours 75 pallets are waiting to be retrieved in the retrieval queue. This is so because about 75 pallet loads have been retrieved to satisfy the demands during the 16 hours (1 day) of warehouse operation. It should be noted that the output event have occurred only for the last 15 hours, since the first output event occurs at TBEG + 1.0 hours.

Figure [16] compares both the models. In model M6(32, 16, 78) the retrieval queue remains steady around 75, whereas it has reduced to 25 pallets in M11(32, 32, 78). This is due to the storage time in M11 being 32 hours, and only at 32.0 hours the first pallet load will be available for retrieval. (<u>Not</u> the preloaded pallet load) To satisfy the initial

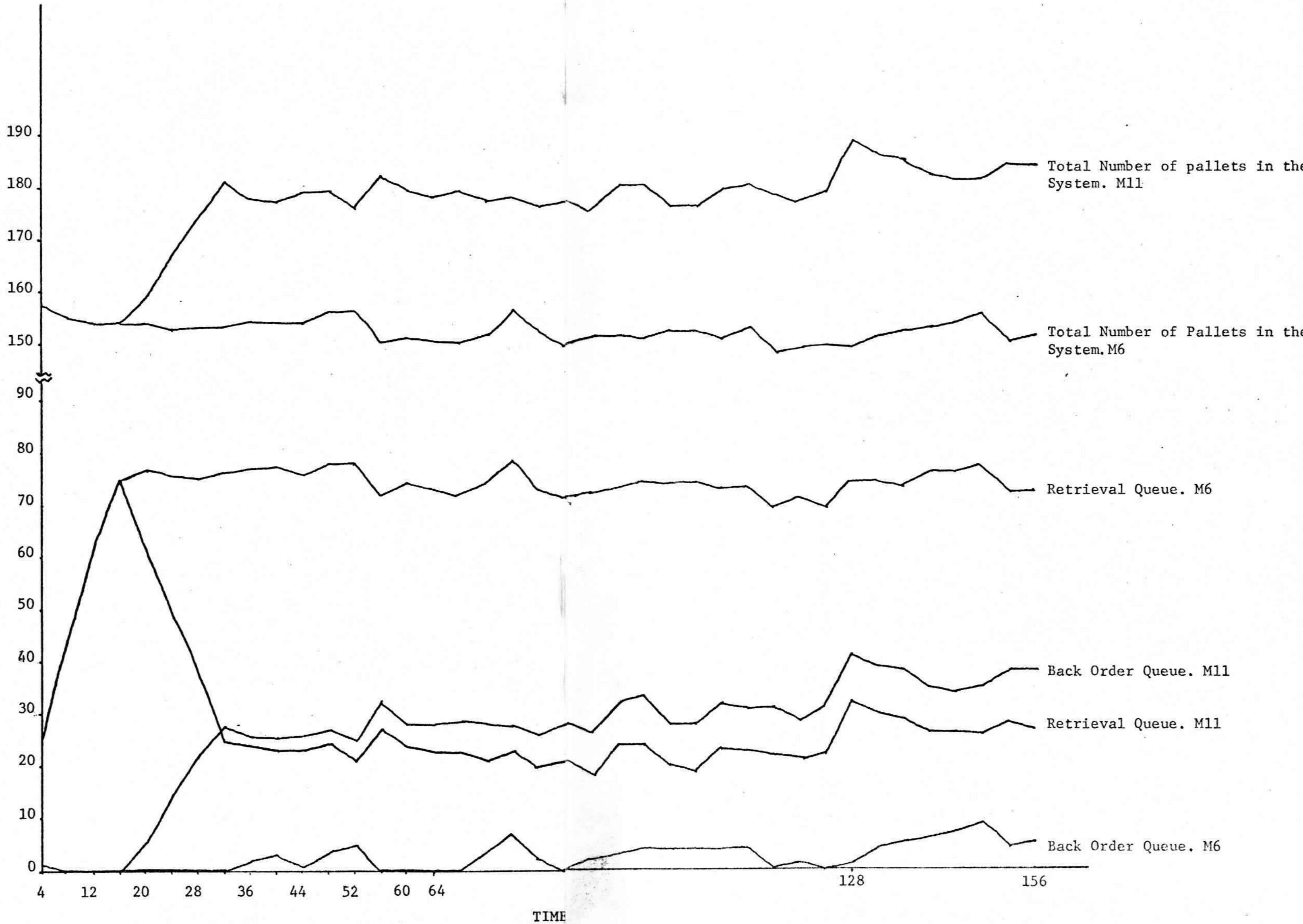

Figure [16]. Effect of storage time.

Table [9]. Statistics of M6(32, 16, 78) and M11(32, 32, 70) at 156 hours.

	Time in the Retrieval Queue HRS		Time in the Back Order Queue HRS		Total No. of Entries that have been in the B.O. Queue	Max. No. of Orders in the Back Order Queue at any Instant	
	Mean	Max	Mean	Max			At time
M6(32, 16, 78)	13.13	44.32	7.52	26.00	46	9	148
M11(32, 32, 78)	5.67	35.57	10.63	43.00	339	41	128

Table [10]. Statistics of M6(32, 16, 78) and M11(32, 32, 78) at 156 hours.(Stacker and Pigeonhole)

	Average Stacker Cycle Time (MIN)	Stacker Utilization %	Average Pigeonhole Utilization %	Maximum No. of Pigeonholes Used		Time Spent in the Warehouse by a Pallet (HOURS)		Total No. of Pallets That Have Been Handled
				No.	At Time	Mean	Max	
M6(32, 16, 78)	1.826	29.7	41	157	4	30.64	60.32	761
M11(32, 32, 78)	1.830	30.0	49	189	128	36.74	60.32	761

demand during the longer length of storage in M11, the preload has to be higher than that of M6. Since both the preloads are the same more demands are left unsatisfied in model M11, resulting in a sharp rise in the back-order queue during the first 16.0 to 32.0 hours of warehouse operation. Since the first pallet loads starts to be filed into the retrieval queue at 32.0 hours, some of the back-orders are satisfied and hence the back-order queue settles down around 30 orders. The total number in the system follows a similar pattern, due to it's relationship with the back-order queue.

It is seen from Figure [16] and Table [10] that the total time spent in the warehouse by a load is about the same in both the models. Though in M11 an item has to be in storage for 32.0 hours (TSTOR), double the time as in M6, which has a TSTOR of 16.0 hours, it is seen that the difference in the time spent in the system is only 6.0 hours. This is due to the fact that more time is spent by an item in the retrieval queue, waiting for retrieval, in Model M6. A larger number of pallets are in the retrieval queue, in M6 than in M11. The pallets wait at an average 13.13 hours after their 16.0 hour of storage for their retrieval. In M11 the pallets wait for retrieval only 5.67 hours, after their storage time of 32.0 hours. Since more pallets are waiting for retrieval in M6, they have to wait for a larger time for their turn.

The effect of storage time, hence, has shown that the total time spent in the system depends more on the total number of pallets in the system. The more the pallets, the higher will be the time spent in the warehouse.

5.7. PRELOADING AND ITS EFFECTS:

It has been seen from the previous discussions that for a particular preload, the rate of throughput, the length of the production cycle and the storage time have certain effects. These effects are mainly due to the orders for particular material types, not being satisfied, with the "right amount" of materials available at the right time, these effects can be removed. The quantity of material available in the warehouse at any instant depends on the preloaded amount and the ratio of the different types of preload.

The main objective is to get a steady and balanced warehouse operation with the minimum amount of preload. By steady and balanced operation we mean, any operation without cyclic or other abnormal fluctuations in the system. The following criterion can be used to determine whether the preload in the system is sufficient, and if the system is operating smoothly.

1. The fluctuations in the system.
2. Cyclic variations.
3. Number of orders in the back-order queue - It is preferable not to have any back orders, but due to the practicality of the simulation some back orders are bound to occur. The more numbers in the back-order queue should be within the operating level set by the management.
4. Number of pallets waiting in the arrival or output queues. The number waiting should be less than a certain predetermined number. The restriction on the arrival queue in this case is 10 pallets, which covers a length of about 10 feet on the input conveyor. A greater number of pallets in the arrival queue or the output

queue means that the system is not in balance - that is either the arrivals or outputs is greater than the other.

It was seen earlier from Figure [11] that for a preload of 150 and a production cycle of 64, the items being out of stock are types 2, 3, 4, 5, 6, 7 and 8. Figs. [9][10] show the actual numbers of the different types of materials in the system at any instant. These two figures give a better insight to understand preloading systems further.

Figure [13], which has been discussed earlier is a good example to show the effects of varying amounts of preloads. It is seen that M7(32, 16, 150) is not at all steady or balanced. With this high rate of throughput the cyclic imbalance in the system is very prominent. M6(32, 16, 78) on the same figure has the same preload as M7, but for a rate of 78 pallets/day, the preload is a 2 days stock. The back orders in this case has been reduced considerably. Though this is not the ideal case (in an ideal case the back order is zero), it is seen that as compared to M7, there are no cyclic fluctuations and the operation is steady.

Various preloads have been tried to determine the optimum preload amount. Models M14(64, 16, 78) and M15(64, 32, 78) have tried each with different preloads, Figure [18] shows model M14 with a preload of 240, a 3 days stock. Figure [19] shows M15 with a preload of 315 pallets, a 4 days stock, for a storage time of 2 days. It should be noted that the ratio of the types of materials in the preload is the same as the probabilities of output of the different materials.

Even with such large preloads it is seen from charts, that there is some back order in both the models, though the back orders are considerably less than that of the previous models. The back order queue has peaks at

64.0 hr. periods - the length of a production cycle, and the maximum number of back-orders is 14 for M14 and 17 for M15.

This type of preload calculated on the basis of the days of storage or the length of the production is not effective. It was seen from Figures [9], [10] and [11] that only certain types of materials are out of stock or not available for retrieval at certain periods of time, depending on the production and storage times. The preload has to cater to the demands for such materials at the times when they are not available for retrieval. Hence the ratio of the materials in the preload is not the same as the output probabilities. The ratio mainly depends on the length of production of each item and the length of storage, as shown in the following subdivision.

5.8. DETERMINATION OF THE PRELOAD RATIO:

Figure [17] shows the time at which each pallet load stored in the warehouse becomes available for retrieval. The warehouse operation starts at TBEG = 0, when the types 1 and 2 pallet load arrive. The first pallets of types 1 and 2 will be available for retrieval at TBEG + 16.0 hours, where 16.0 is TSTOR the storage time. Types 7 and 8 are the last to be produced in the production cycle and they arrive into the warehouse after all other materials have come in. Types 7 and 8 will be available then only at

$$TBEG + (TONE + TTWO + TTHRE + TSTOR) = TBEG + 72 \text{ hours},$$

as shown in the Figure [17]. The outputs or demands on the other hand,

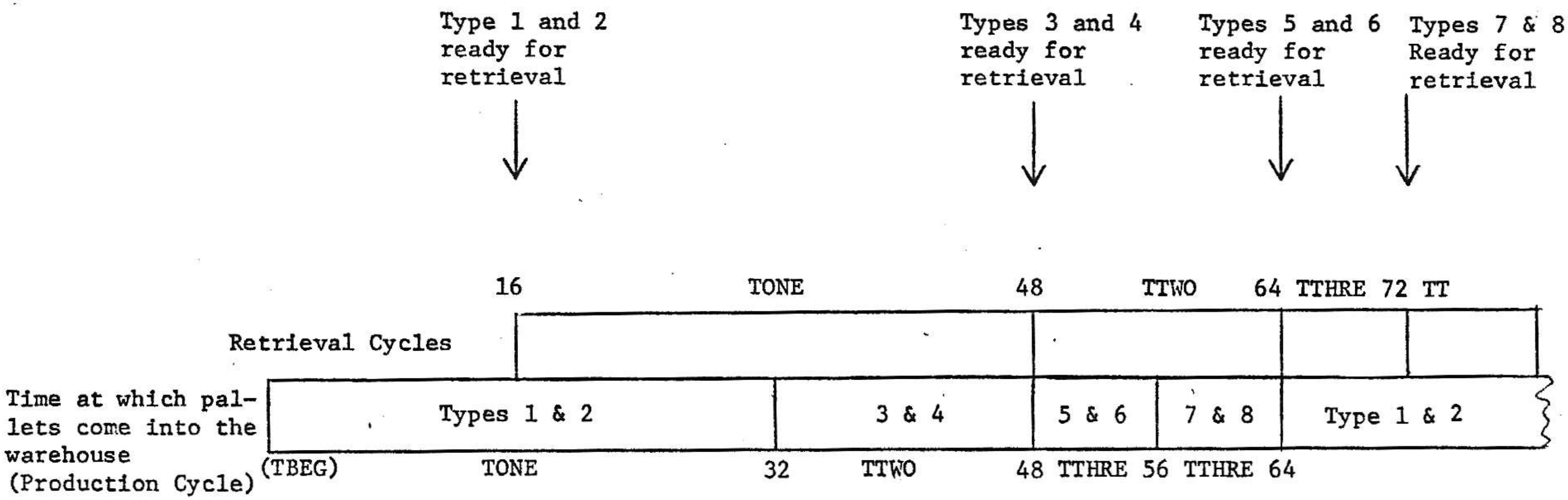

Figure [17]. Time at which each type of material becomes ready for retrieval, in M17(64,16,78) used to determine the preload ratio.

start to come in at TBEG + 10 hours. This demand also includes types 7 and 8. Since types 7 and 8 are available only after 72 hours of warehouse operation, a certain amount of types 7 and 8 have to be preloaded into the warehouse at the start of the operation. This preload has to cover the demand for types 7 and 8 for a period of 72 hours.

The preloads necessary for the other types have to be calculated in this way. In the previous preloading methods, the ratio of the various types in the preload was the same as the ratio of the types in the output probability distribution. The ratio of the various types is changed now because of the different method of calculating the preload. From Table [3] the probability of demand of a type of material is known. Using these probabilities the amount of a particular material necessary to satisfy the demand for a period of time can be calculated.

For example the probability of demand of type 8 is .0851 and the preload of 8 has to be calculated for a period of 72 hours. Hence the amount of type 8 necessary to cover 72 hours will be

$$(78 \times \frac{72}{16}) * .0851 = 29.87 \approx 30 \text{ pallets},$$

where 78 is the rate of throughput/day, and

16 is the working hours per day.

The total preload is calculated as follows:

Preload of type 8 = Number of type 8 material required to cover TONE + TTWO + TTHRE time periods plus TSTOR, the storage time.

= (TONE + TTWO + TTHRE + TSTOR) * RATE/HOUR * .0851

Preload of type 7 = Number of type 7 material required to cover the same length of time

= (TONE + TTWO + TTHRE + TSTOR) * RATE/HOUR * .0399

Similarly,

Preload of type 6 = (TONE + TTWO + TSTOR) * RATE/HOUR * .0851

Preload of type 5 = (TONE + TTWO + TSTOR) * RATE/HOUR * .0399

Preload of type 4 = (TONE + TSTOR) * RATE/HOUR * .1701

Preload of type 3 = (TONE + TSTOR) * RATE/HOUR * .0799

Preload of type 2 = (TSTOR) * RATE/HOUR * .3401

Preload of type 1 = (TSTOR) * RATE/HOUR * .1599.

The total preload will be the same of all of these preloads. Provision has also been made in the program to include a safety stock and other extra preloads.

Model M21(64, 32, 78) has a preload of 257 pallet loads, calculated as per the formula for preload. The statistics of M21 are shown in Tables [11] & [12]. It compares favorably with M15(64, 32, 78). The maximum number in the back order queue is 14 compared to 17 in M15. The waiting time in the back order queue is also reduced to 7.7 hours, which is much less than 15.51 hours of M15. Though it compares very well with M15, it is

Table [11]. Preload statistics

Model	Preload	Statistics Collected At Time	Waiting Time In The Retrieval Queue (hours)		Waiting Time In The Back-Order Queue (Hours)		Total No. of Entries That Have Been In Back Order	Max. No. of Orders in the Back-Order File	
			Mean	Max.	Mean	Max.		No.	At Time
M17(64,16,78)	176* + Safety Stock=78	256	31.27	102.60	9.50	32.00	30	8	132
		448	32.95	130.55	11.31	40.00	78	9	404
M14(64,16,78)	240	256	29.36	74.12	11.75	42.00	52	14	132
M18(64,32,78)	257* + Safety Stock=78	256	31.57	99.75	11.17	34.00	30	7	144
		448	33.11	131.37	13.53	52.00	76	12	388
M20(64,32,78)	257* + Safety Stock=78	256	40.71	118.78	16.06	33.00	17	7	148
		448	39.68	134.42	14.54	46.00	58	9	396
M15(64,32,78)	315	256	28.12	85.14	15.51	48.00	59	17	148
M21(64,32,78)	257*	256	23.32	112.47	7.70	43.00	122	14	32
M13(32,24,100)	300	256	20.54	68.55	8.14	23.00	83	12	248

*Preload calculated as per the equation.

Table [12]. Preload Statistics.

Model	Preload	Statis. Collected at Time	Average Utilization %	Stacker Utilization %	Avg. Pigeonhole Utilization %	Maximum No. of Pigeonholes Used		Time Spent In The Warehouse By A Pallet		Total No of Pallets Handled
						No.	At Time	Mean	St.Dev.	
M17(64,16,78)	176* + Safety Stock of 78	256	1.946	31.7	72.25	269	4.0	52.25	22.73	1253
		448	1.958	31.9	70.8	269	4.0	51.71	22.73	2195
M14(64,16,78)	240	256	1.934	31.6	68.0	258	132.0	49.58	90.10	1262
M18(64,32,78)	257* + Safety Stock of 78	256	2.078	33.9	95.25	350	4.0	68.77	19.18	1253
		448	2.078	33.8	94.0	350	4.0	67.95	22.65	2202
M20(64,32,78	257* + Safety Stock of 78	256	2.09	34.0	96.0	355	148.0	70.08	19.21	1245
		448	2.102	34.2	97.0	359	396.0	70.36	23.07	2195
M15(64,32,78)	315	256	2.042	33.2	89.0	328	148	64.07	17.74	1249
M21(64,32,78)	257*	256	1.962	31.9	75.0	284	32	54.39	17.59	1255
M13(64,32,78)	300	256	2.018	41.5	82.0	311	16	47.11	24.01	1592

*Preload calculated as per the equation

seen that the system seems to be fluctuating more than the other models. The preload in this case is calculated exactly as per the formula and no consideration has been given for randomness. The interarrival times and the outputs are all randomly generated and due to this, the arrivals of the eight types of materials may be less and the output may be slightly high. This randomness may cause back orders and slight fluctuations in the system. To accommodate this random variation a safety stock is introduced into the warehouse. The safety stock in this case is just a protection to allow for the randomness in the inputs and outputs of the different types of materials. Figure [20] compares models M20[64,32,78] and M21[64,32,78]

Figure [18] compares models M17(64, 16, 78) and M14(64, 16, 78). M14 has a preload of 240, which is a three day stock. The preload of M17 has been calculated according to the formula derived earlier. A safety stock of 78 pallets has been introduced in M17. It should be noted that the ratio of the types of materials in the safety stock is the same as the probability of demand of the particular types.

It is seen from the table [11] that due to the improved preloading the maximum number in the back order queue of M17 has been reduced considerably when compared to M14, (8 to 14). The average time in the back-order queue of M17 is 9.50 hours as compared to 11.75 hours of M14. These two statistics coupled with the smoothness of operations of M17 as seen from Figure [18] shows that the improved preloading system is very effective. The total time spent in the system by a pallet is 52.25 hours in model M17, which is more than 49.58 hours in M14. This is due to the fact that more pallets in M17 than M14. M17 has in addition to the calculated preload, a safety stock of 78 pallets. The extra pallets in M17 increases the waiting time in the retrieval queue, which is responsible for the longer

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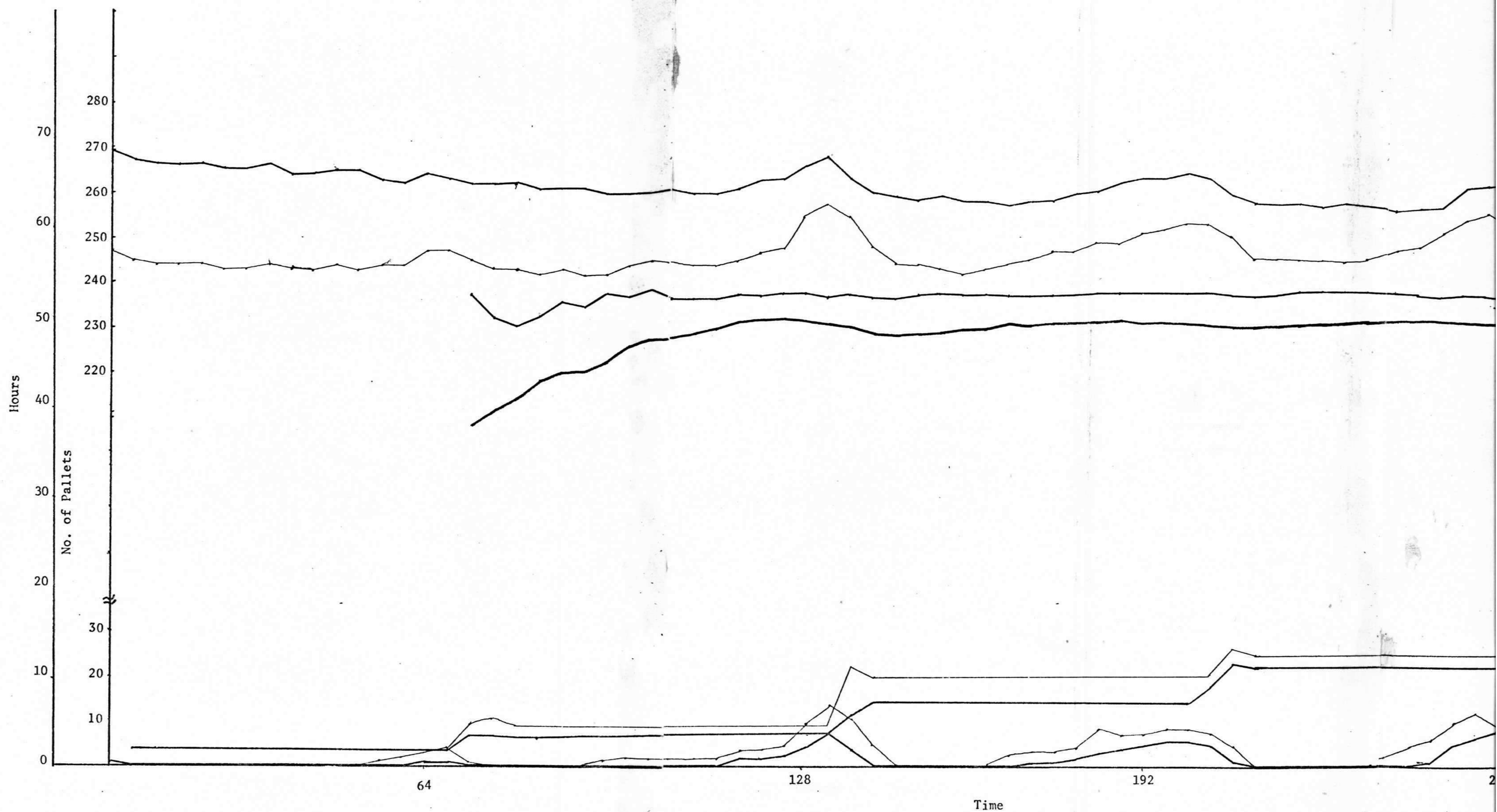


Hours
No. of Pallets
70
60
50
40
30
20
10
0
280
270
260
250
240
230
220
30
20
10
0
64
128
192
Time

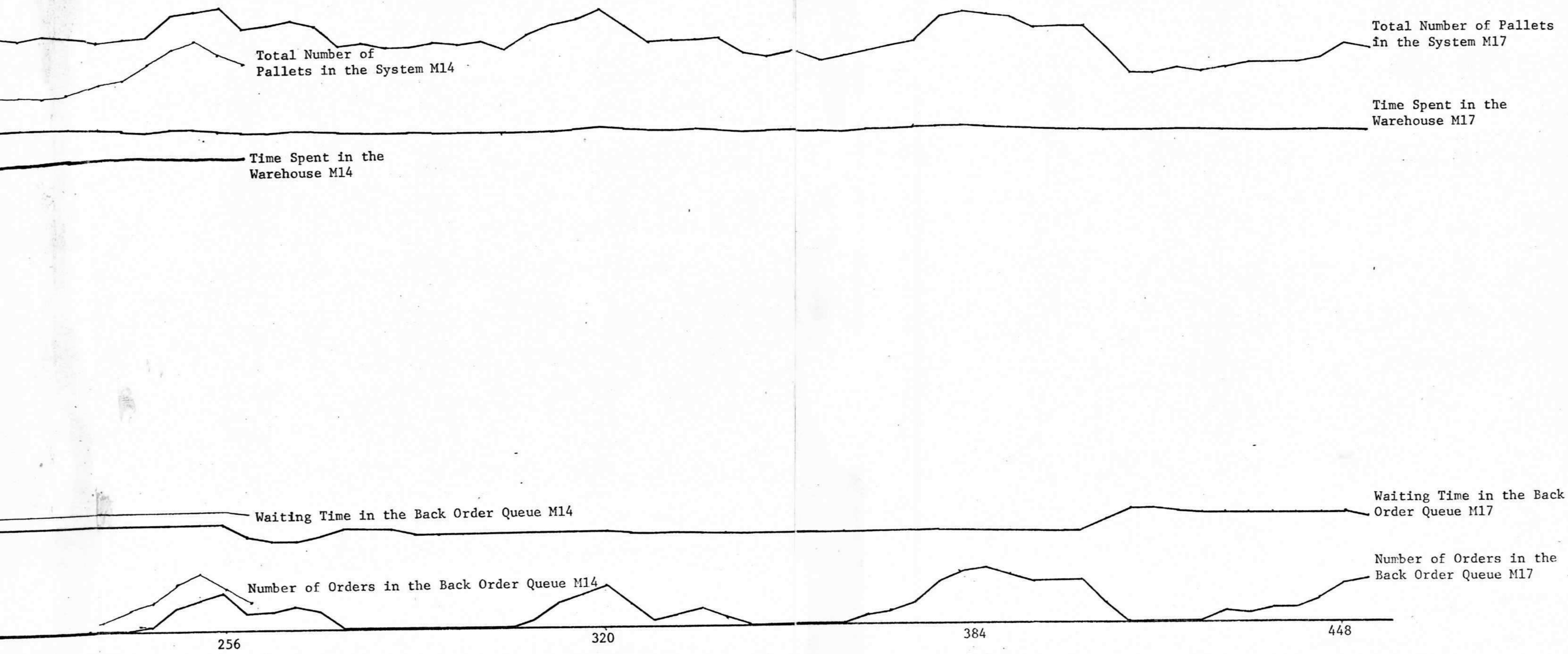


Figure [18]. Model M17(64, 16, 78) and M14(64, 16, 78).

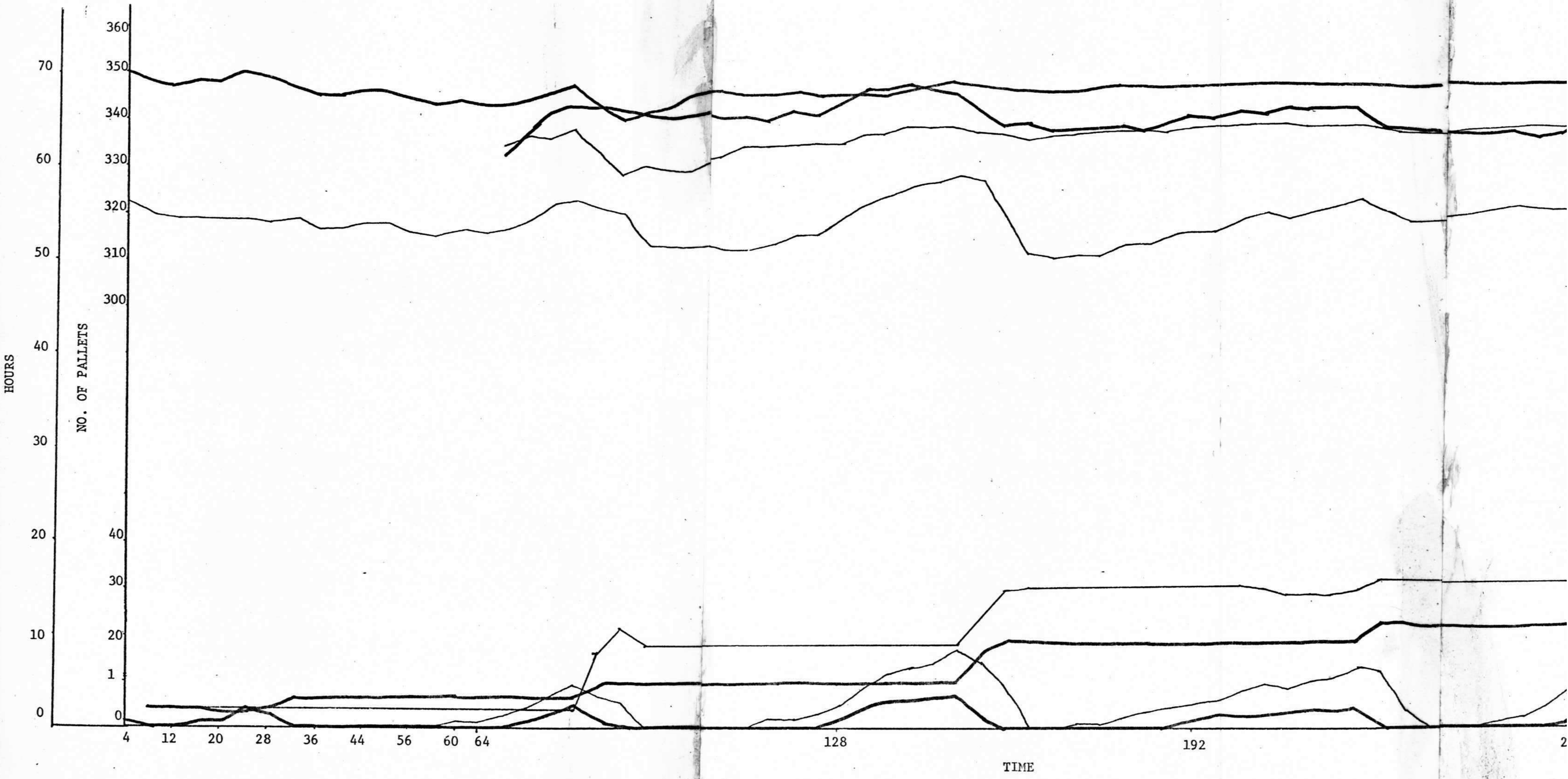
the system.

Models M18(64, 32, 78) and M15(64, 32, 78) have been compared in Figure [19]. Both the models have TSTOR = 32 hours, but M18 has been preloaded by the preload formula. M15 has a preload of 315, a ten days stock. The number in the back order queue of M18 is 7 orders compared to 17 orders in M15. The time spent in the back order queue of M18 is 11.17 hours which is much less than 15.51 hours in M15. The effectiveness of the preload formula is shown by these two criterions. The overall performance of the operation is smooth and balanced in M18.

It is seen from the Figures that time of the total number of pallets in the system of M17 and M18 is seen to droop as the simulation progresses. This may be due to the interarrival times. The interarrival times have been approximated by a truncated normal distribution, truncated at 1 std. deviation on the lower side and 3 std. deviation on the higher side, whereas the output has been approximated by truncated normal distribution with 3 standard deviations on both sides. Hence the input may not be in balance with the output - it may be slightly lower. The effect of this inbalance has not been felt till now, because it is very slight and due to the excessive back order and fluctuations in the previous models, it had been covered up.

In the models M17 and M18 the preloads are exact and accurate, which minimizes the back order. The system is very steady and the effects of the various variables have been removed. Hence when simulated to a longer period of 28 days, the slight effect is brought to light.

To show that this does not affect the preload or the back orders model M20(64, 32, 78) has been simulated. Figure [20] shows the characteristics of the model. The number in the back order is 7 as compared to 17 in M15.



HOURS
NO. OF PALLETS
70
60
50
40
30
20
10
0
360
350
340
330
320
310
300
40
30
20
1
0
4
12
20
28
36
44
56
60
64
128
192
TIME

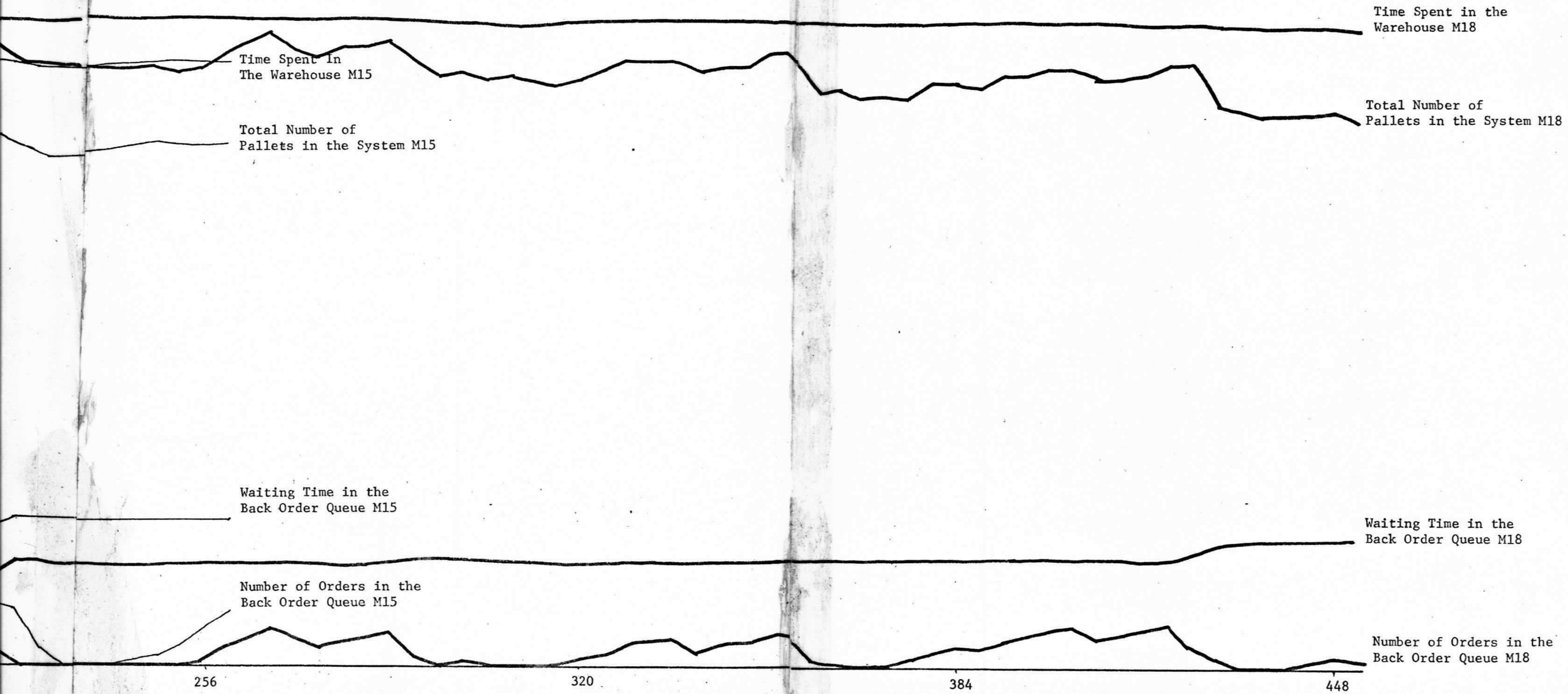
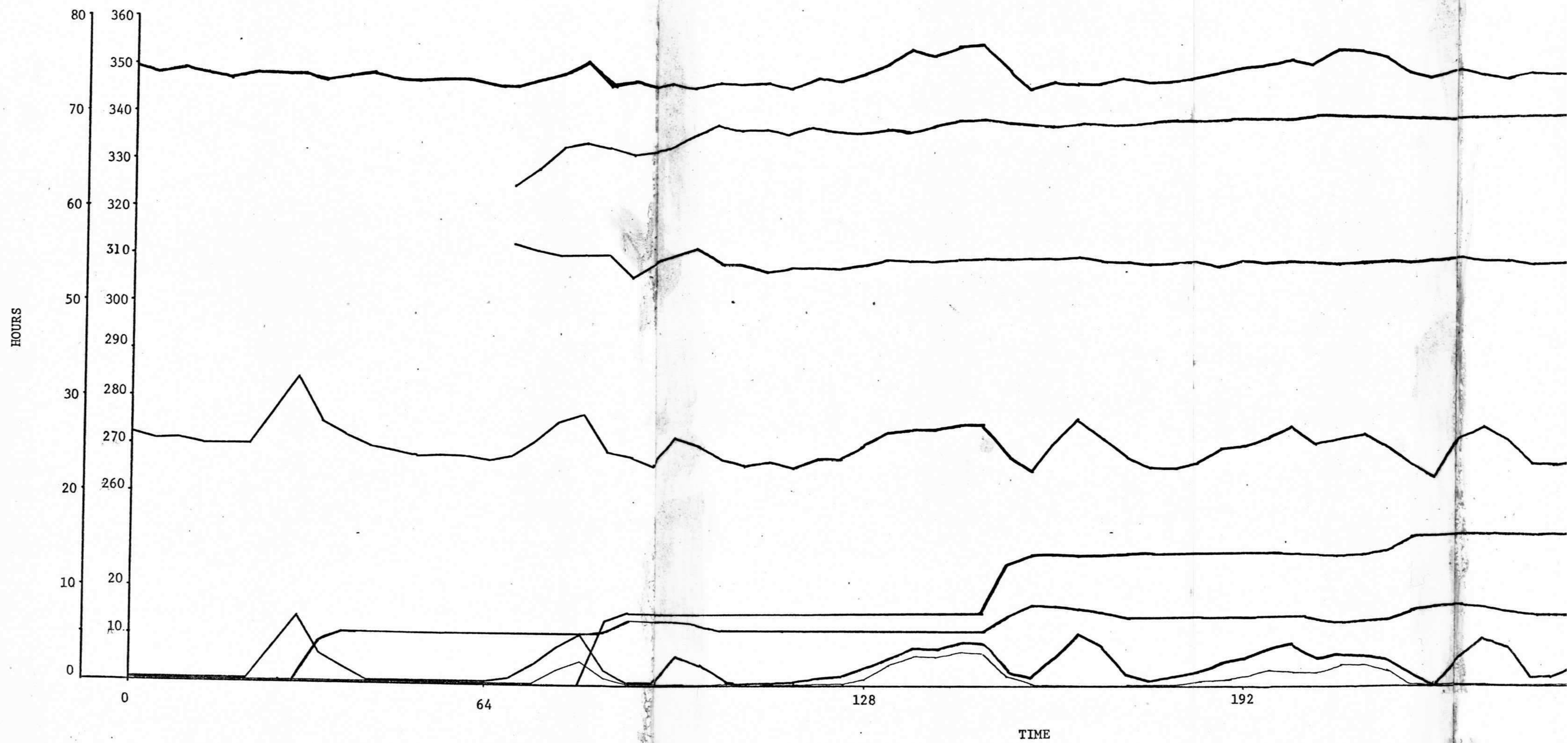


Figure [19]. Models M18(64, 32, 78) and M15(64, 32, 78).



HOURS
80
70
60
50
30
20
10
0
360
350
340
330
320
310
300
290
280
270
260
20
10
0
64
128
192
TIME

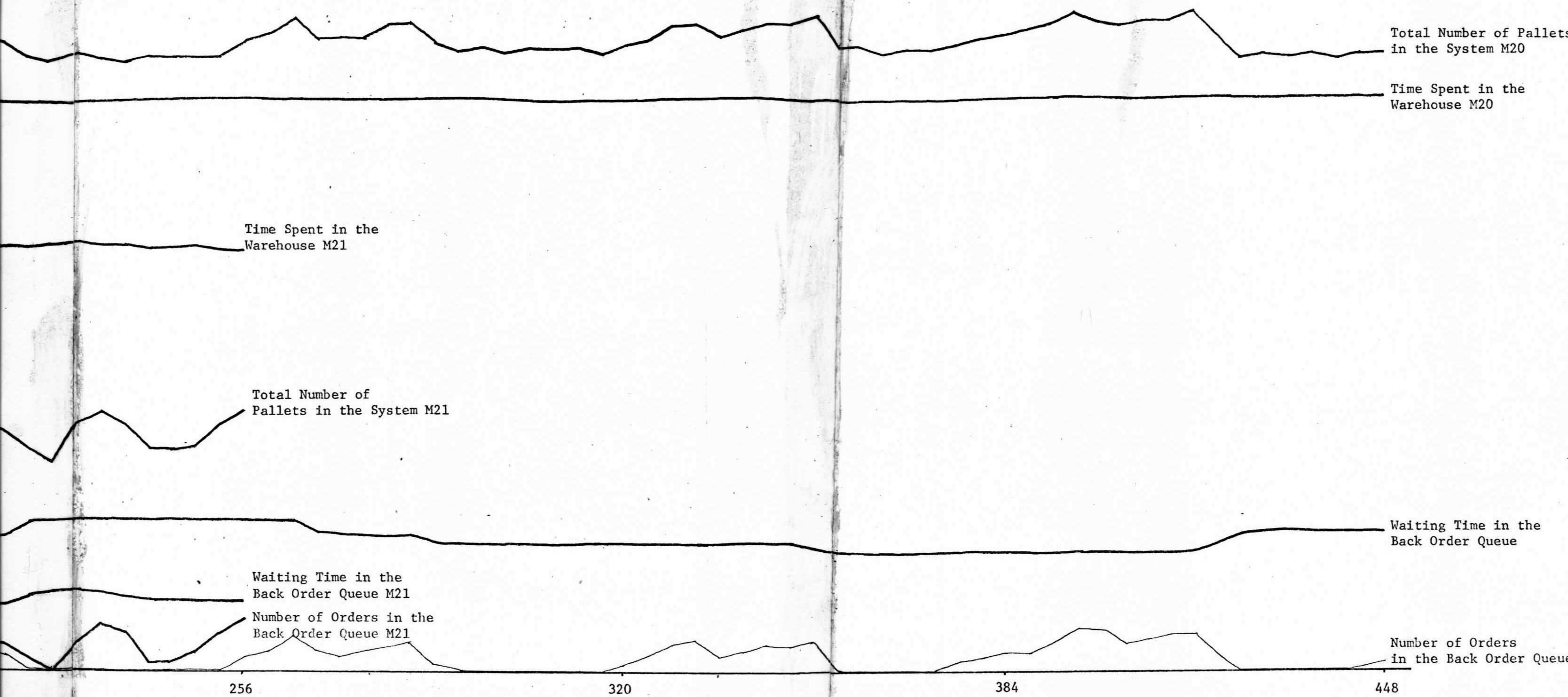


Figure [20]. Model M20(64, 32, 78) and M21(64, 32, 78).

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Though the waiting time in the back order queue is slightly more than that of M15 at 256 hours, on an average the waiting time in the back order queue is smaller in M17 than in M15.

Figure [21] shows the frequency distributions of the waiting time in the back order queue for M14 and M17 that have been compared. The effectiveness of the preload formula is clearly shown by the histograms. Figures [22] and [23] show the histogram of the several models with 32 hour storage. M20 seems to be the most effective of them all. M22 has an histogram which is heavier on the left. Though this histogram looks bigger than the others, the waiting time is on the average less than M15, which has an histogram heavier on the right, i.e. more number of items have greater waiting times.

Figures [24], [25], [26], [27], [28], [29] show the waiting time in the retrieval queue for the various models. The waiting time for models preloaded without the preload formula, M14 and M15, are less than that of M17, M18 or M20. This is because M17, M18 and M20 have more number of items preloaded. (Preload + Safety Stock) M22 has less waiting time in the retrieval queue compared to M18 and M20 because the preload is reduced, since no safety stock is added, in this case. The waiting time in the retrieval queue has to be as small as possible, because just by waiting for retrieval the pallets occupy storage space. In any warehouse the stock should be as small as possible. By reducing the retrieval time this can be achieved.

The main features that are apparent from this discussion on preload are:

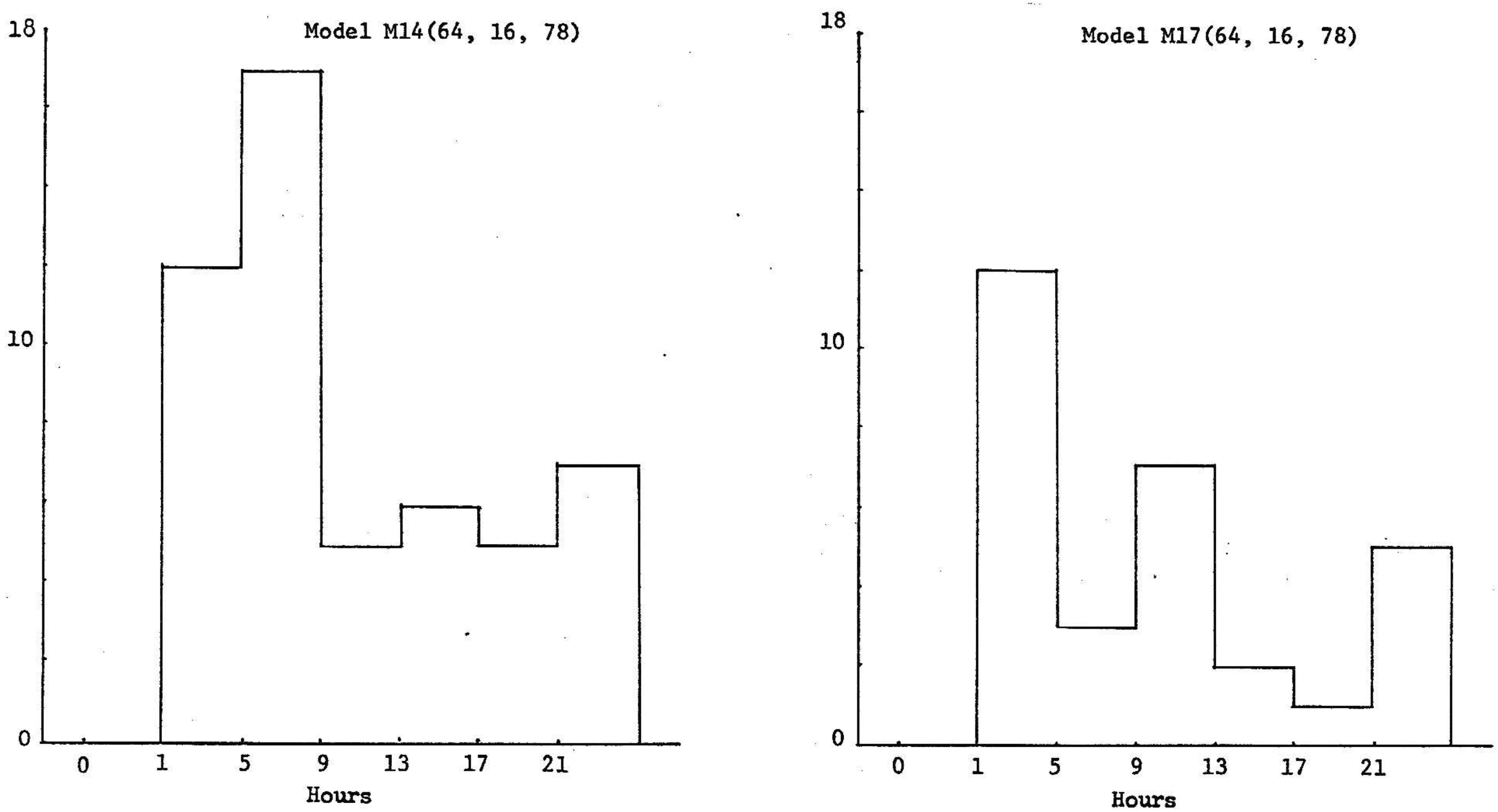

Figure [21]. Frequency distribution of the waiting time in the back order queue of M14(64, 16, 78) and M17(64, 16, 78).

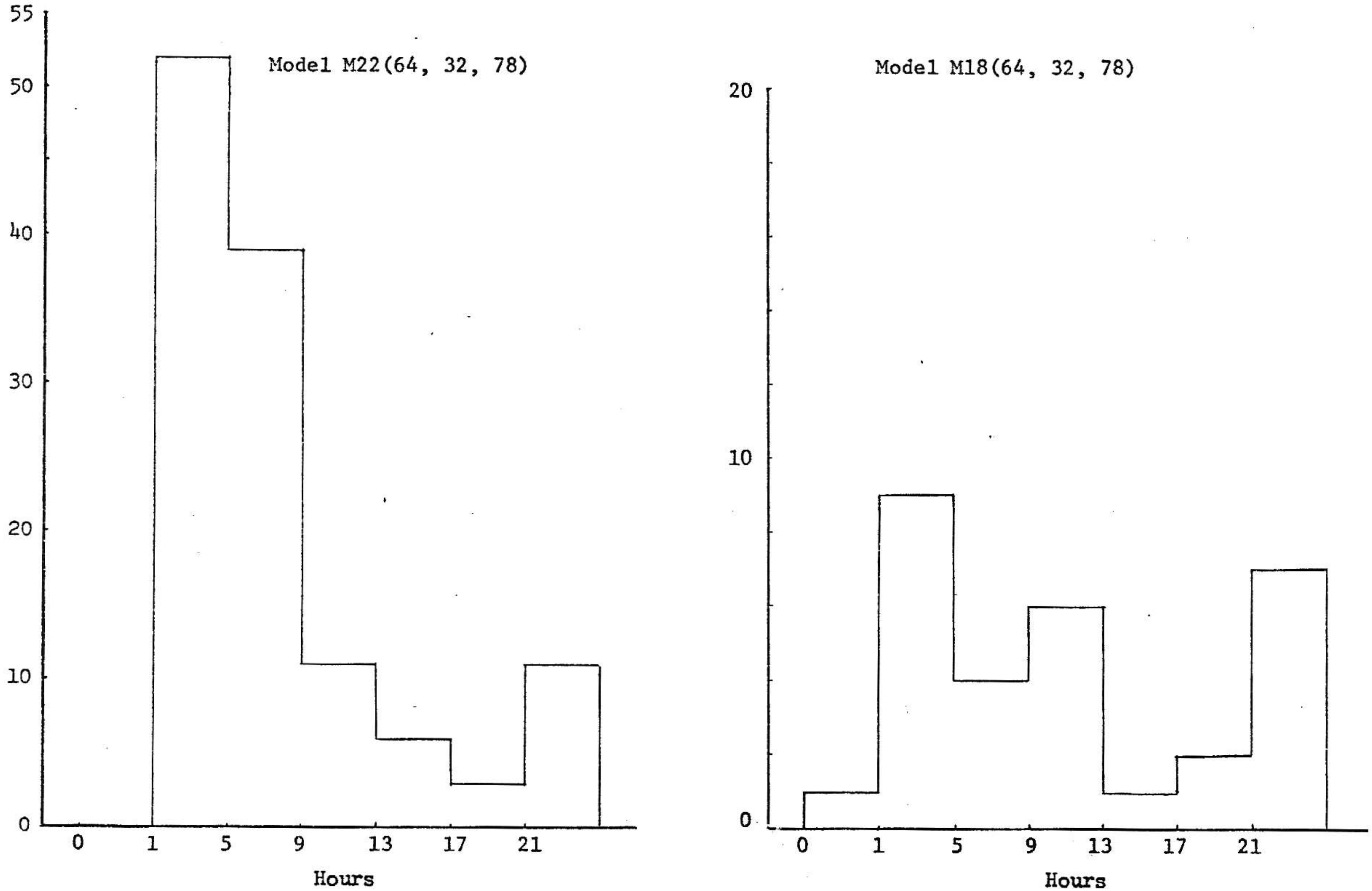

Figure [22]. Frequency distribution of the waiting times in the back order queue of M22(64, 32, 78) and M18(64, 32, 78).

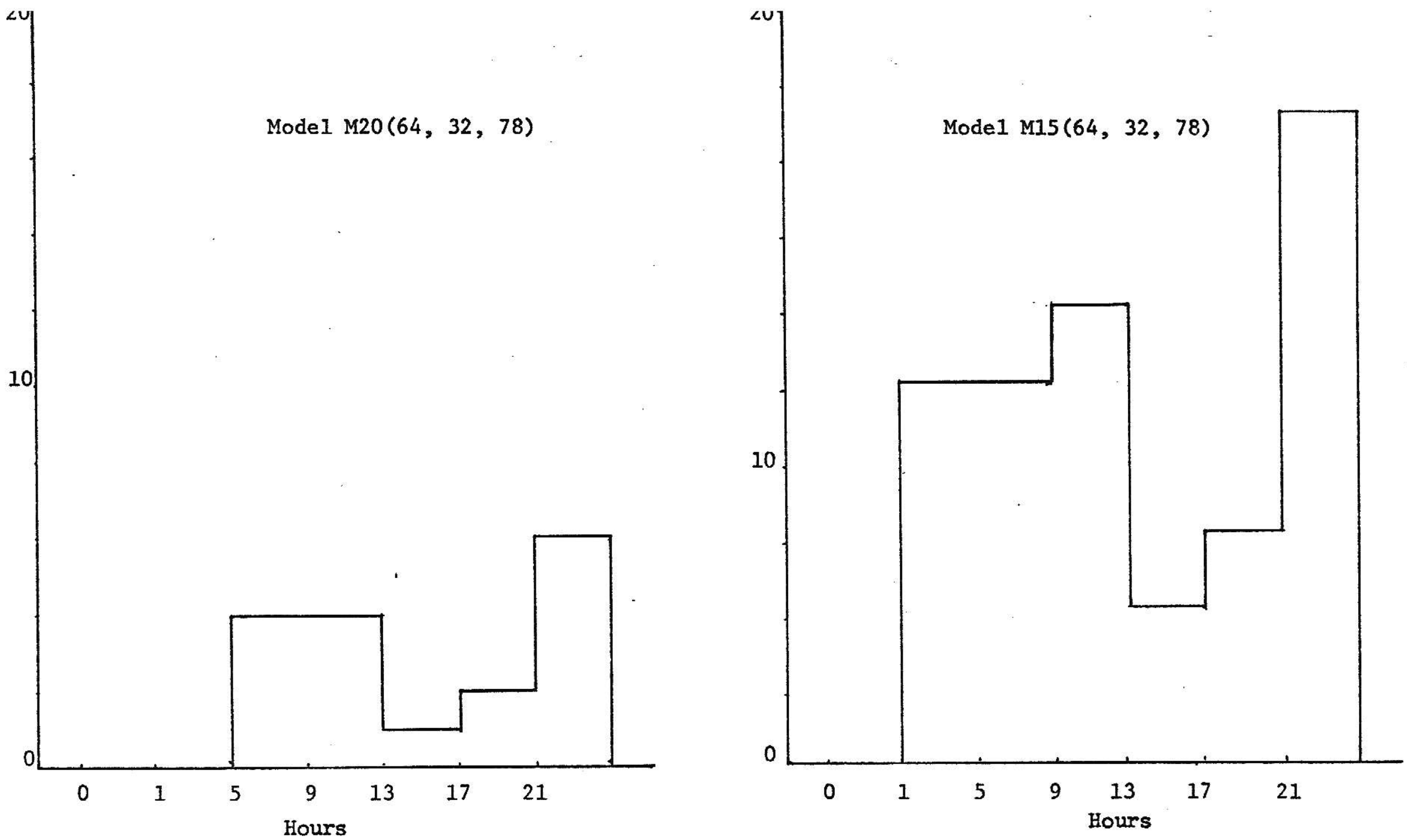

Figure [23]. Frequency distribution of the waiting time in the back order queue of M15(14, 32, 78) and M20(64, 32, 78).

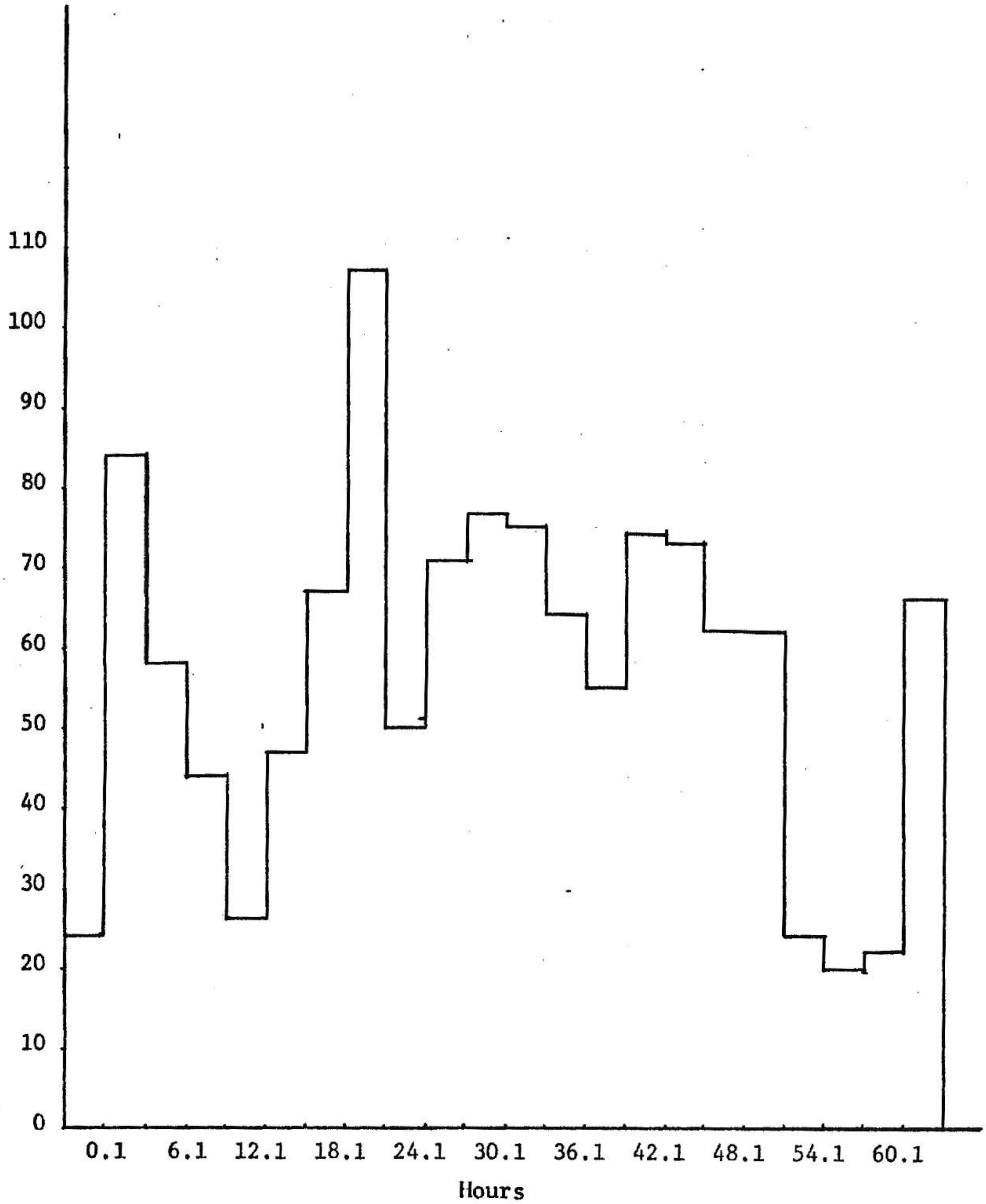

Figure [24]. Frequency distribution of the waiting time in the retrieval queue of M14(64, 16, 78).

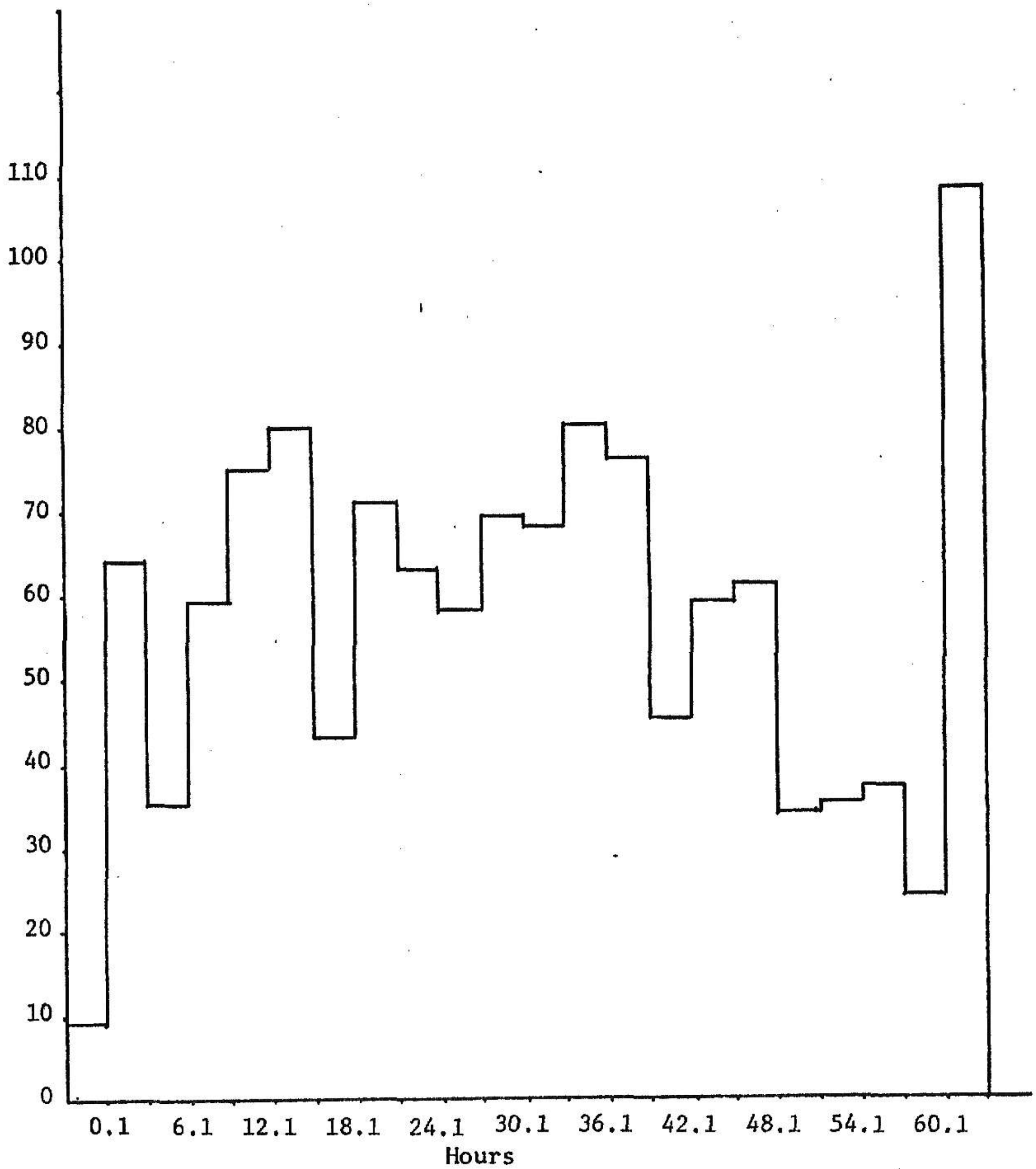

Figure [25]. Frequency distribution of the waiting time in the retrieval queue of M17(64, 16, 78).

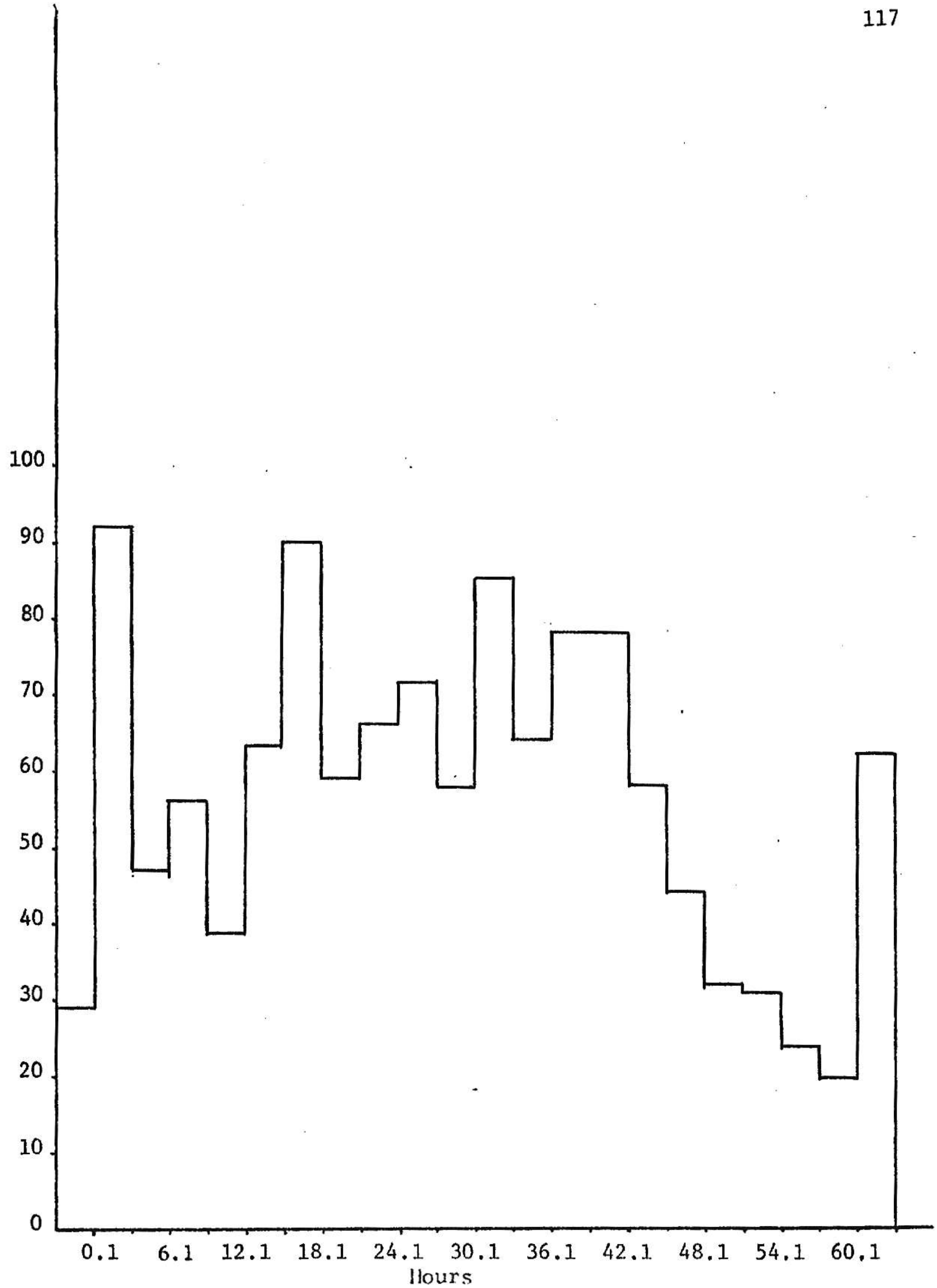

Figure [26]. Frequency distribution of the waiting times in the retrieval queue of M15(64, 32, 78).

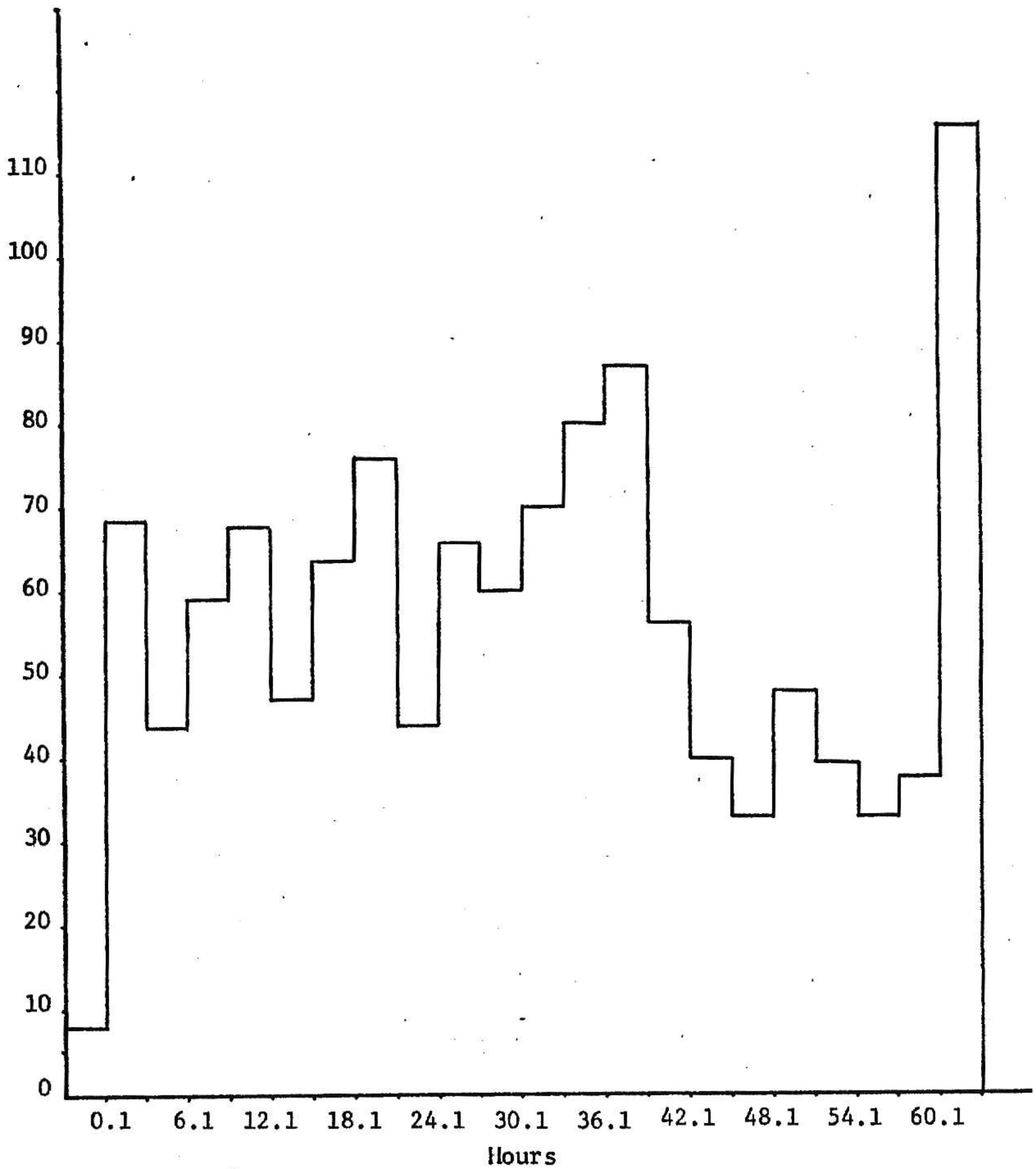

Figure [27]. Frequency distribution of the waiting times in the retrieval queue of M18(64, 32, 78)

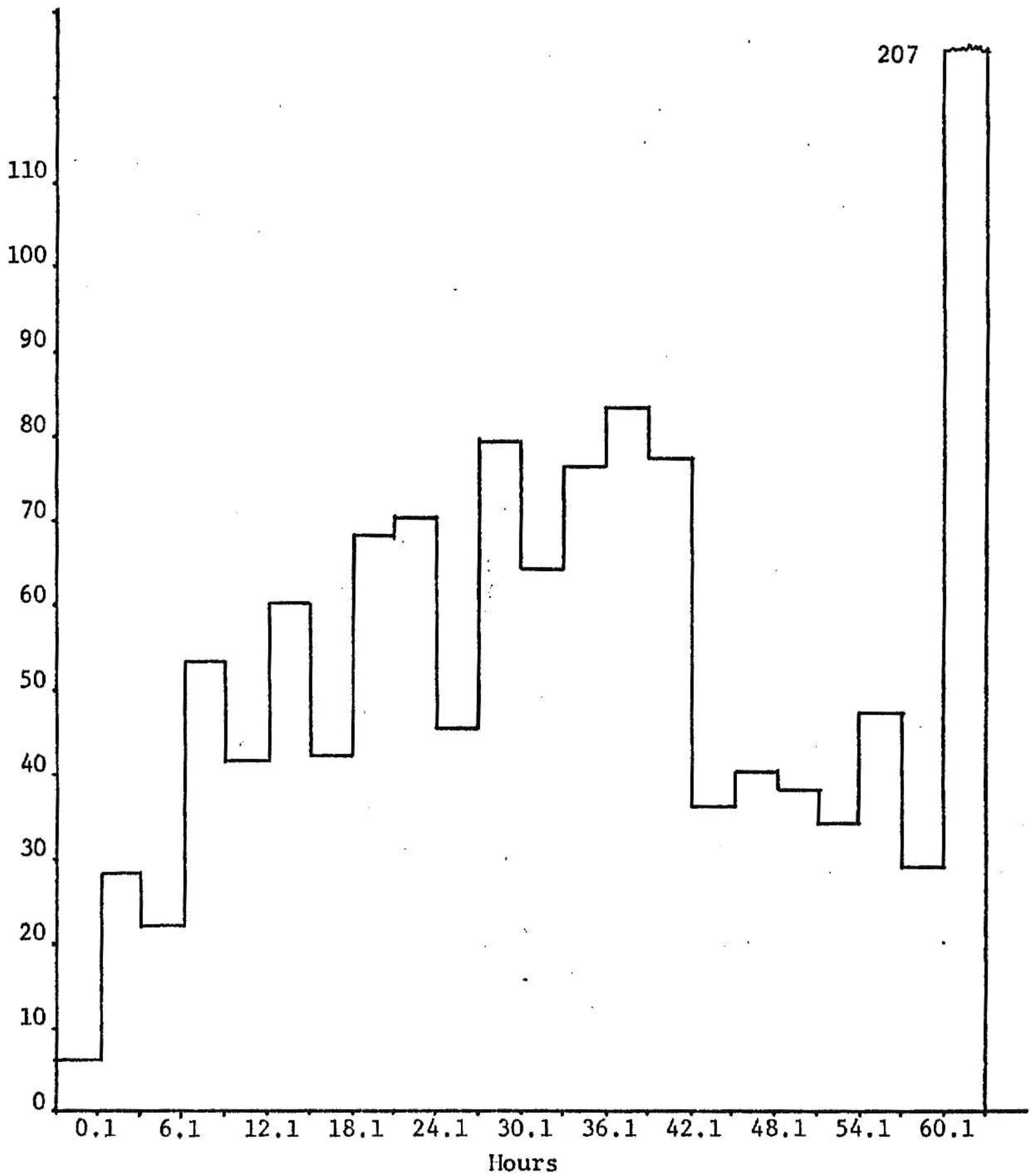

Figure [28]. Frequency distribution of the waiting time in the Retrieval queue of M20(64, 32, 78).

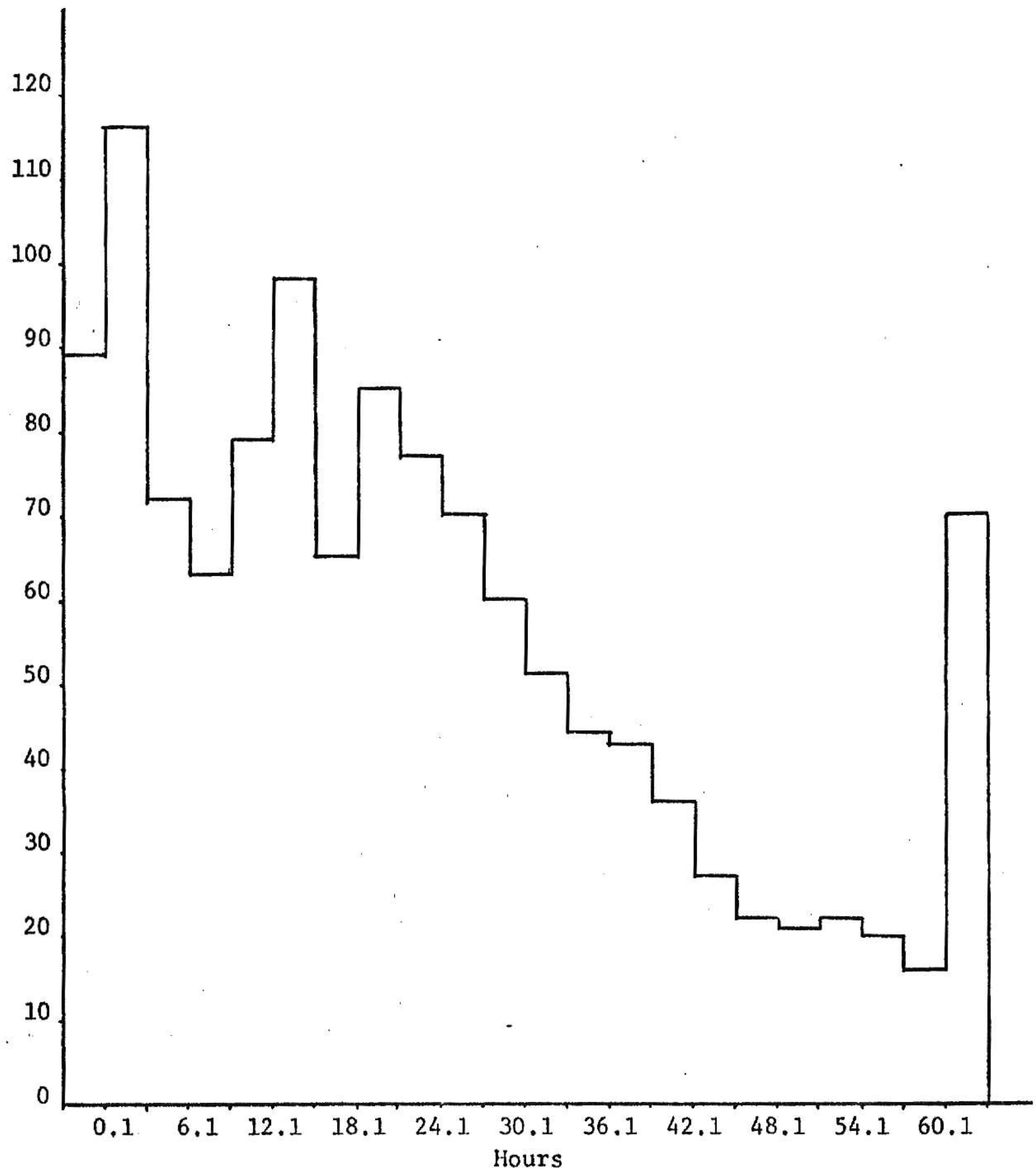

Figure [29]. Frequency distribution of the waiting time in the retrieval queue of M22(64, 32, 78).

1. The ratio of the items in the preload, the "preload ratio", is very important. With the right amounts of each item in the preload, the total preload amount can be reduced, thus saving storage space and time.

2. It is seen that with proper preloads, due to the smaller number of both orders, the rechecking events are reduced. In Table [11] there is a column showing the maximum number of entries in the back order queue. It should be noted that this is not the number of orders. Due to rechecking of the same order repeatedly, the same number of orders would have been counted more than once. This number of entries in the back order queue can be considered as a counter. It is seen that with the proper preload the rechecking operations have been reduced considerably.

It is seen that even with the improved method of preloading, the back order queue has not reduced as hypothesized. Small back orders are formed at regular periods, each increasing in small steps. From the present trend it can be assumed that the back order queue will become stable at a future time and for the present method of production and storage, there will be a definite but constant number of orders in the back order queue.

5.9. DETERMINATION OF WAREHOUSE STORAGE CAPACITY:

For a balanced warehouse operation, it has been seen that the total number of pallets in the system tend to be more or less constant. Even in a non-steady operation as in model M7 with the cyclic effects and greater range of fluctuation in the total number of pallets in the system, it is seen that there is a constant average.

The number of pallets in the system for any model depends on the preload. If for example the preload is 200 pallets, then the total number in the system is steady around 200, for the entire simulation run. From these observations a rule can be made to determine the storage capacity of the warehouse or the number of pigeonholes required.

For a particular rate of throughput the number of pigeonholes required will be equal to

The Preload + Safety Stock + Number of locations for emergency storage.

The number of locations required for emergency storage is a management option. If the warehouse has to hold a two days supply in an emergency, then for a throughput of 100 pallets/day, then the buffer storage will be 200. Then the number of pigeonholes required will be

The Preload + Safety Stock + 200.

The storage capacity of this warehouse is adequate for the present rate and type of production and output. It is seen that the capacity is just sufficient for a throughput of 78 pallets per day, a 64 hours production cycle and a storage time of 2 days. For higher throughputs, longer production cycles, and longer periods of storage the warehouse has to be expanded considerably for efficient operation.

5.10. EFFECT OF DUAL AND SINGLE COMMAND STACKER CONTROLS:

Two models one with the single command stacker and the other with the dual command stacker were compared. The single command stacker either retrieves the load or stores it into the pigeonholes according to the instructions - that is it only one operation at a time. The dual command stacker can do both the stacking and retrieving operations at the same time.

Both the models had an average of about 240 pallets in the system and the rate of throughput was 78 pallets per day. The stacker statistics are given below:

	Stacker Cycle Time Minutes	Stacker Utilization
Single Command	1.934	31.9
Dual Command	1.872	29.4

The stacker cycle time and the utilization depend on the number of pigeonholes occupied and the throughput respectively. Due to the low values of both the throughput and the total number of pigeonholes used, there is not a very appreciable difference between the two models.

Still the dual command has slightly lower cycle time of 1.872 minutes as compared to the single stacker cycle which has 1.934 minutes.

For the same throughput, since the cycle time is lower, the stacker utilization when using a dual command stacker is 29.4%, which is less than when using the single command stacker when the utilization is 31.9%.

The dual command stacker is faster and economical to use. It saves time and the number of operations is reduced.

It has been seen throughout the simulation study that the stacker does not increase more than 58%. Generally the average utilization is around 30 to 40%. It can be inferred that the stacker capacity is more than adequate to satisfy the needs of the complete system. In fact more than

50% of the stacker capacity is wasted. The stacker capacity is too large for the present warehouse. It will be adequate even for a 100% expansion in the storage capacity of the warehouse.

Length of the Simulation Run:

It was decided to run the simulation for a length of at least 4 production cycles, to enable the system to stabilize. Statistics like the total time in the system and the waiting time in the retrieval queue (only in M20) have been initialized at 64.0 hours. This is to overcome the effects of the transient phase at the start of the simulation. The preloaded pallet loads stay in the system for a considerably shorter time than the pallets that are a part of the regular throughput. Due to this the total time in the system does not stabilize until about 64.0 hours. So these statistics have been initialized at 64.0 hours. Since one production cycle is lost in initializing, at least 3 more cycles have to be studied to get any confident conclusions on the simulation. Hence the length of the simulation run was 4 cycles.

In some cases the simulation length was 448 hours or 28 days of the warehouse operation. The runs have been lengthened in this case just to study the back order queue - to study whether the waiting time in the back order queue and the number of orders in the queue stabilize.

5.11. COMPUTER TIMES:

A great amount of care and caution was taken to reduce the computing time. Apart from the initial debugging of the program which was done using a 500K WATFOR compiler, most of the simulation runs were made using a FORTRAN IV "H" level compiler. The program was optimized by using OPT = 2, a very efficient optimizing fascility available only in "H" level FORTRAN.

Table [13]. Computer times.

Model	Length of Simulation (Hours)	Compiler	Compilation Time (Hours)	Execution Time (Hours)	Remarks
M1(32,16,78)	48.0	FORT-G	.097	.090	
M2(32,16,78)	16.0	FORT-G	.102	.332	II method
M3(32,16,78)	40.0	FH-OPT*2	.084	.071	
M4(128,32,78)	112.0	FH-OPT1	OBJ.DK	.496	
M5(64,16,78)	256.0	FH-OPT1	OBJ.DK	.516	
M6(32,16,78)	256.0	FH-OPT2	.092	.223	
M7(32,16,150)	104.0	FH-OPT2		.360	Compilation
M8(32,16,100)	256.0	FH-OPT2		.460	Time Was Not
M9(32,16,125)	224.0	FH-OPT2		.506	Available
M10(32,16,78)	256.0	FH-OPT2	OBJ.DK	.420	
M11(32,32,78)	156.0	FH-OPT2	OBJ.DK	.436	
M12(32,32,150)	64.0	FH-OPT2	OBJ.DK	1.694	System Error Unusable
M13(32,24,100)	256.0	FH-OPT2	.089	.338	
M14(64,16,78)	256.0	FH-OPT2	.1	.237	
M15(64,32,78)	256.0	FH-OPT2	OBJ.DK	.288	
M16(128,32,78)	352.0	FH-OPT2	OBJ.DK	.557	
M17(64,16,78)	448.0	FH-OPT2	.092	.367	
M18(64,32,78)	448.0	FH-OPT2	OBJ.DK	.466	
M19(64,32,78)	448.0	FH-OPT2	.094	.373	
M20(64,32,78)	448.0	FH-OPT2	OBJ.DK	.411	
M21(64,32,78)	256.0	FH-OPT2	.085	.187	
M22(64,32,78)	256.0	FH-OPT2	OBJ.DK	.291	

*FH-OPT2 means FORTRAN IV H level, compiler optimised with option OPT = 2. Compile time in core 500K WATFOR is .027 hours.

Moreover for repeated runs, with just small changes in the variables, object decks were used. In these cases, due to the compilation time having been eliminated, the total execution time has been reduced considerably. In addition all the programmes have been run using the fast core. Though the cost for using the fast core is double that of the slow core, the speed of computing using the fast core, more than adequately compensates for the extra cost.

Table [13] gives the compilation and execution time of all the simulation runs. 500K WATFOR was found to be at least three times faster than FORTRAN IV "H" level complier. Hence it was useful in debugging the program initially, though the GASP errors were removed using FORTRAN IV.

FORTRAN IV, "H" level compiler, with OPT = 2 optimizing fascility was found to be the most effecient in Execution and easy to work with.

CHAPTER 6

CONCLUSIONS

The automated warehouse operation has been simulated for a period of 16 to 28 days on an IBM 360/50 computer. The most important feature that has come to light is the quantity that has to be stored in the warehouse before the start of any output operation. Without the right amount of material stored in the warehouse, the operation fluctuates and becomes unsteady. The fluctuations tend to become cyclic and the imbalance is magnified as the rate of throughput increases.

The important variables of the warehouse operation - storage time, production cycle and the rate of throughput, all have various effects on the characteristics of the operation. Since the output distribution of the various types are always the same, each variable has its own effect in the size of the back order queue. As the magnitude of each variable increases, more and more orders are left unsatisfied. The back order queue, it is noted, is formed at particular periods of time, depending on thetype of materials not available for output. The number in the back-order queue has to be limited, because each order not satisfied means that a customer order has not been filled, which results in the loss of customer goodwill.

With the rightamount of material of each type already loaded into the warehouse before the start of the operation, the back orders can be reduced considerably. This preload depends, of course, on the magnitude of the main variables. It is also seen that, the ratio of each item in the preload is important and not the total amount of preload. Using the preload formula that has been developed, it is seen that due to the exact number of pallets preloaded is reduced as compared to the other methods. The preload formula is found to be quite effective, with a small amount of safety stock. This safety stock is necessary to allow for the randomness in the system.

Some of the other features that are apparent are: In a balanced system the number of pigeonholes occupied in a function of the preload and the safety stock. The time spent in the warehouse by a pallet load depends on the number of pallets in the system which in turn depends on the number of pallets in the preload. With more pallets in the system, more time is spent by the pallets in the retrieval queue. This waiting time in the retrieval queue has to be reduced as much as possible because it means that the pallets have completed the minimum time in the warehouse and they are just occupying warehouse space waiting for retrieval.

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APPENDIX A

PROGRAM VARIABLES

(Basic GASP IIA variables are discussed in "Simulation with GASP II", by A. Alan B. Pritsker and Philip J. Kiviat [94]).

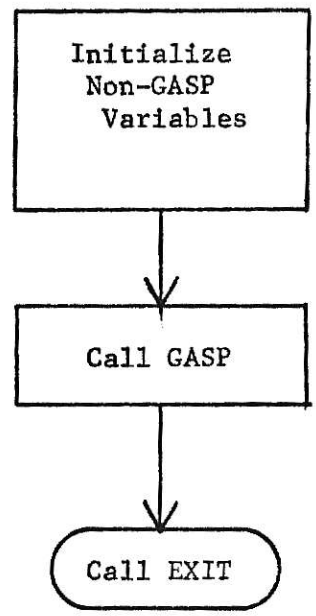
PROGRAM VARIABLES

KDELTA	Report interval.
KTYPE	Type of material considered at the moment.
LST	0 if stacker is idle; 1 if stacker is busy.
TONE	Production time for type 1 and 2 materials.
TTWO	Production time for type 3 and 4 materials.
TTHRE	Production time for type 5, 6, 7 and 8.
TCH	Change over time from the production of one type of item to the next. For example from type 1 to type 3, type 2 to type 4 etc. It is the average of the interarrival times of the two types produced together in a batch.
XTIME	Time taken by the stacker in the "X" direction, to travel to and from the pigeonhole(s).
YTIME	Time taken by the stacker in the "Y" direction, to travel to and from the pigeonhole(s).
STIME	The greater of the two - XTIME, YTIME, used in calculating stacker cycle time.
WTAT	Time at which an <u>order</u> entered the back order queue.
LOAD	The amount of safety stock to be included in the preload.
LEXPL	Amount of extra preload necessary.
KRLDI	Number of pallets of type 1 to be preloaded.
.	.
.	.
.	.
KRLD8	Number of pallets of type 8 to be preloaded.
KRLD	Total preload.

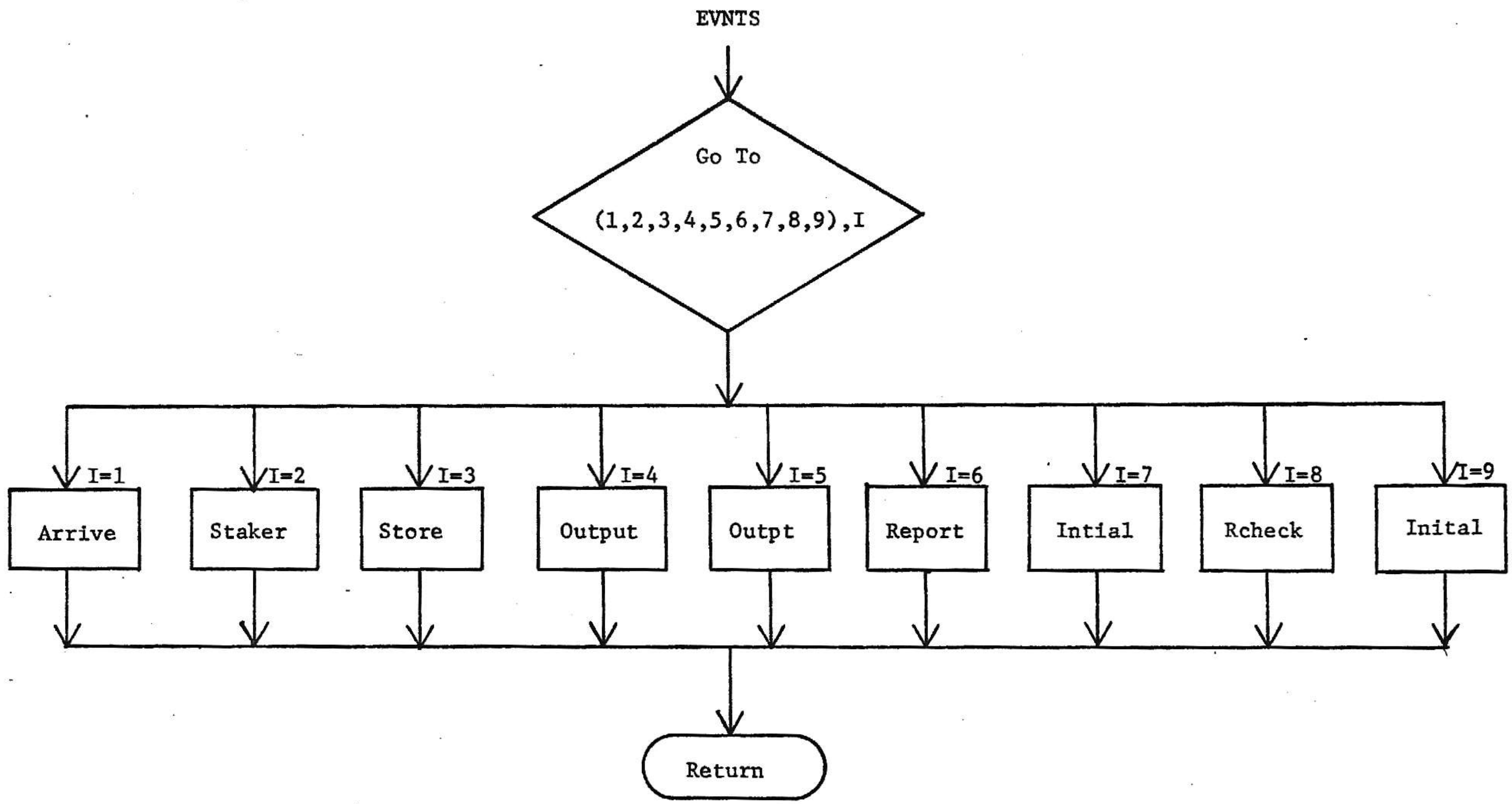
TNPH	Total number of pigeonholes in the warehouse.
CYTI	Stacker cycle time.
XSP	Stacker carriage speed. (speed in the "X" direction)
YSP	Stacker hoist speed. (speed in the "Y" direction)
NXP	Number of pigeonholes in the X direction, in one row of the rack.
NPHI	Number of pigeonholes columnwise.
NPSYS	Number of pallets in the system.
PHU	Pigeonhole utilization.
SU	Stacker utilization.
RATE	Rate of throughput per day.
MT,IT	Indexes used in the calculation of the production times.
LSN	A zero-one variable used in the output subroutine to distinguish between rechecking and Output events.
TSTOR	The minimum storage time for any item in the warehouse.
TRCK	Rechecking interval.
NUM	Number for each entry in the back order file. NUM is incremented by 1 whenever an entry is added to the file. The ranking of the entries in the back order queue is based on JTRIB(3) = NUM.
WTO	Waiting time in the output queue.
WTIS	Total time spent in the system by the particular pallet.
WTA	Waiting time in the arrival queue.
WTBO	Waiting time in the back order queue.
WTR	Waiting time in the Retrieval queue.
NOFIL	A zero-one variable which has been added to the GASP subroutine SUMRY 0 if files are not to be printed 1 if files are to be printed

APPENDIX B

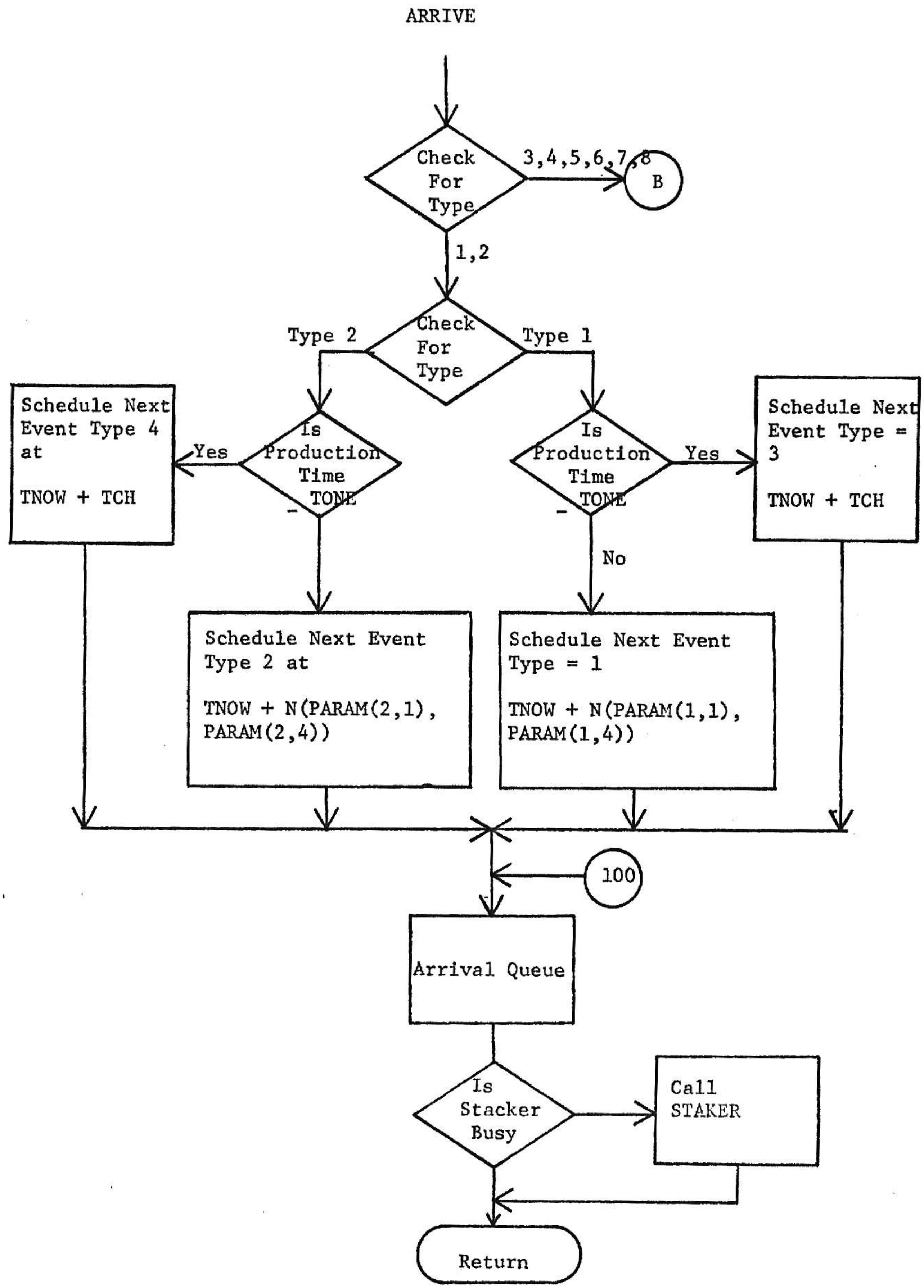
FLOW CHARTS

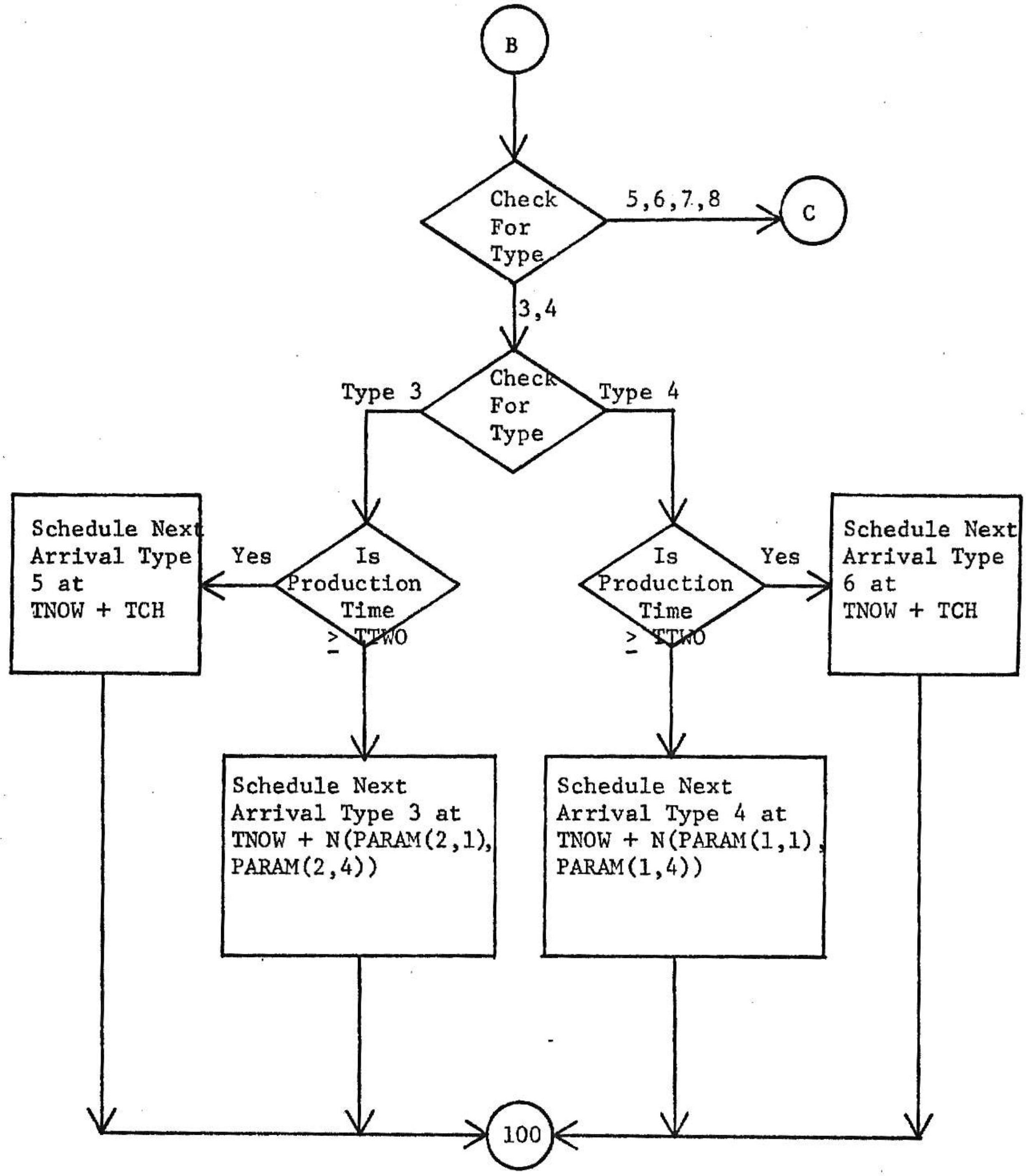


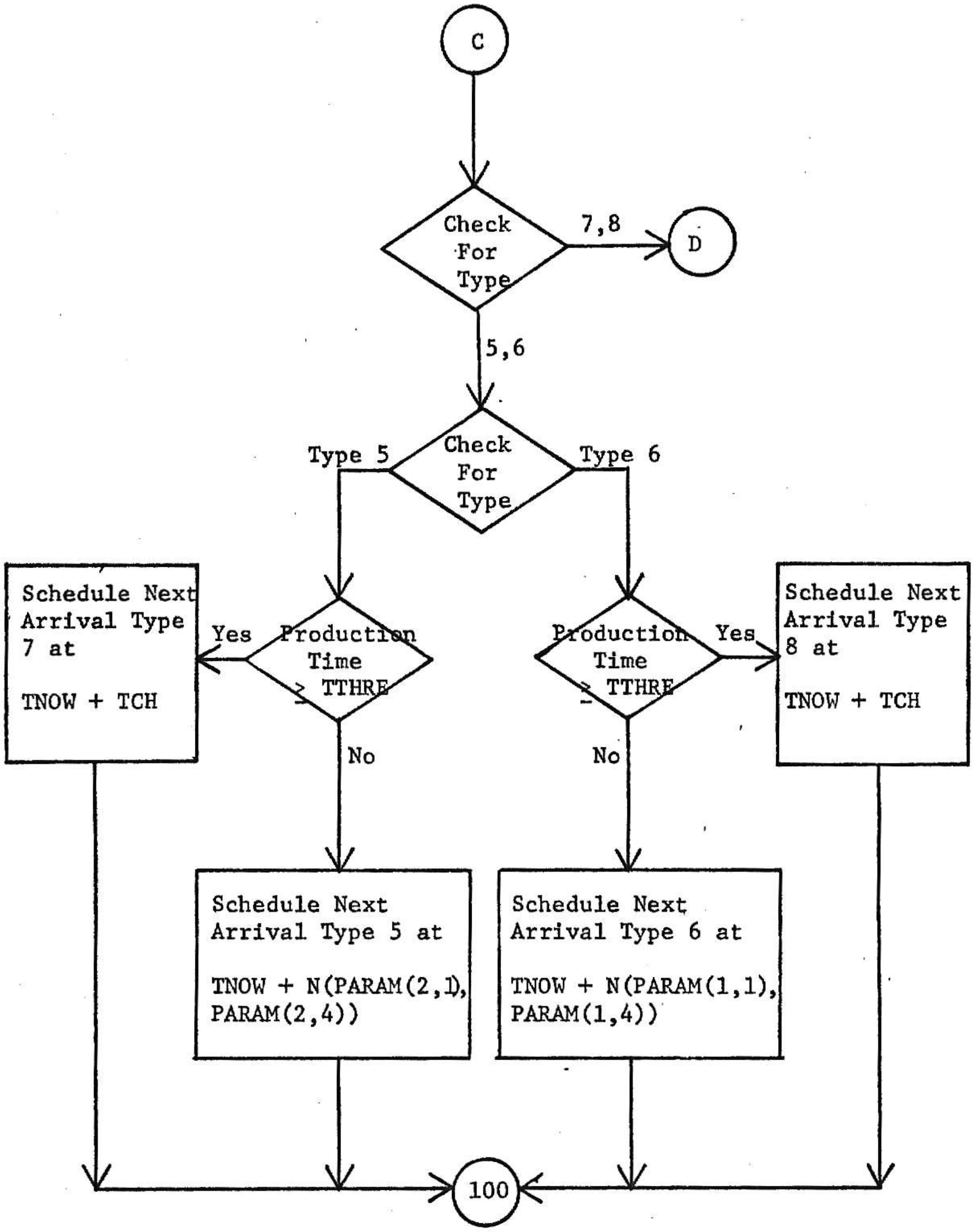
The Main Programme

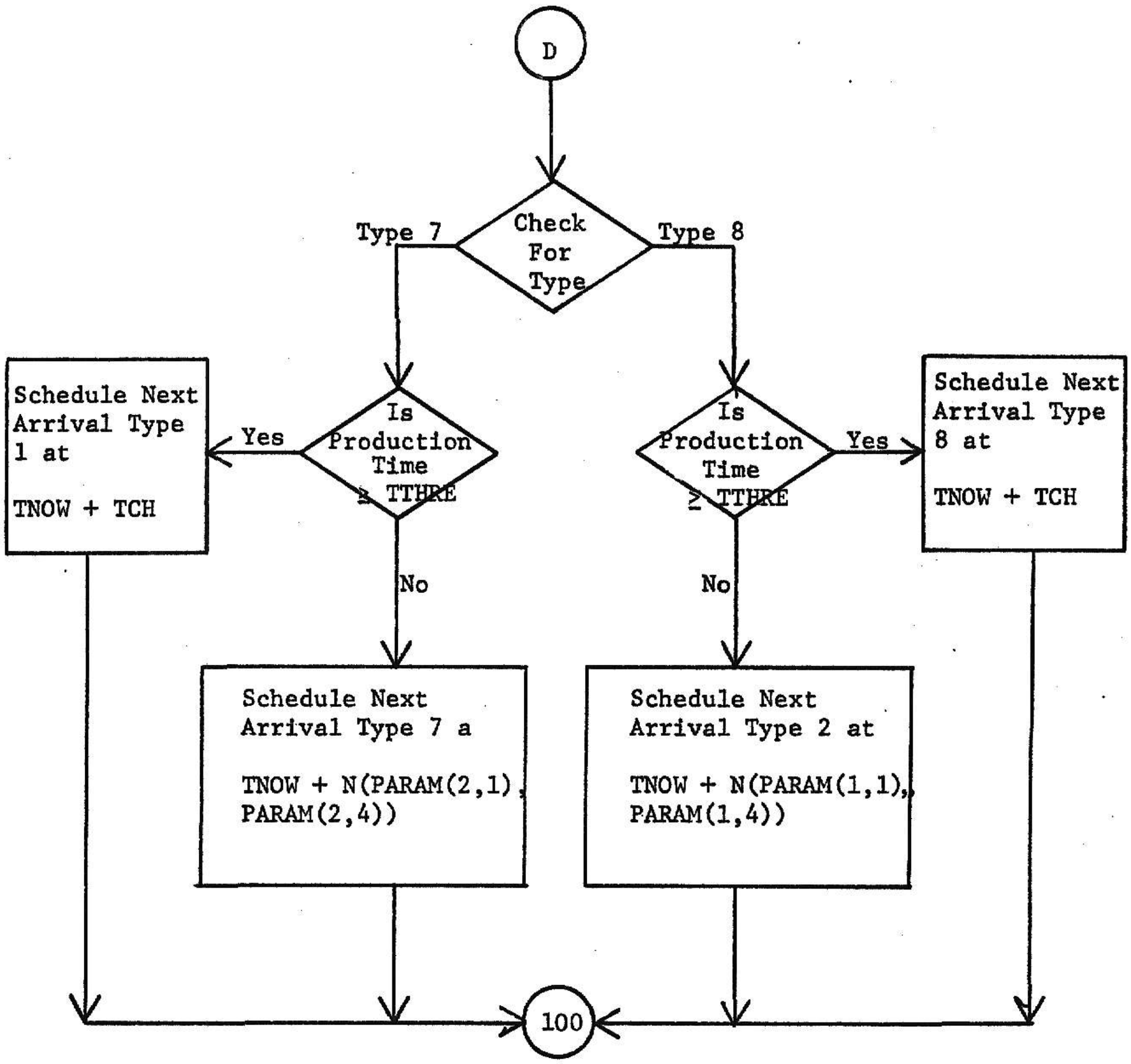


EVNTS Subroutine


ARRIVE
Check For Type
3,4,5,6,7,8
B
1,2
Check For Type
Type 2
Type 1
Is Production Time TONE
Is Production Time TONE
Yes
Yes
No
Schedule Next Event Type 4 at
TNOW + TCH
Schedule Next Event Type = 3
TNOW + TCH
Schedule Next Event Type 2 at
TNOW + N(PARAM(2,1), PARAM(2,4))
Schedule Next Event Type = 1
TNOW + N(PARAM(1,1), PARAM(1,4))
100
Arrival Queue
Is Stacker Busy
Call STAKER
Return

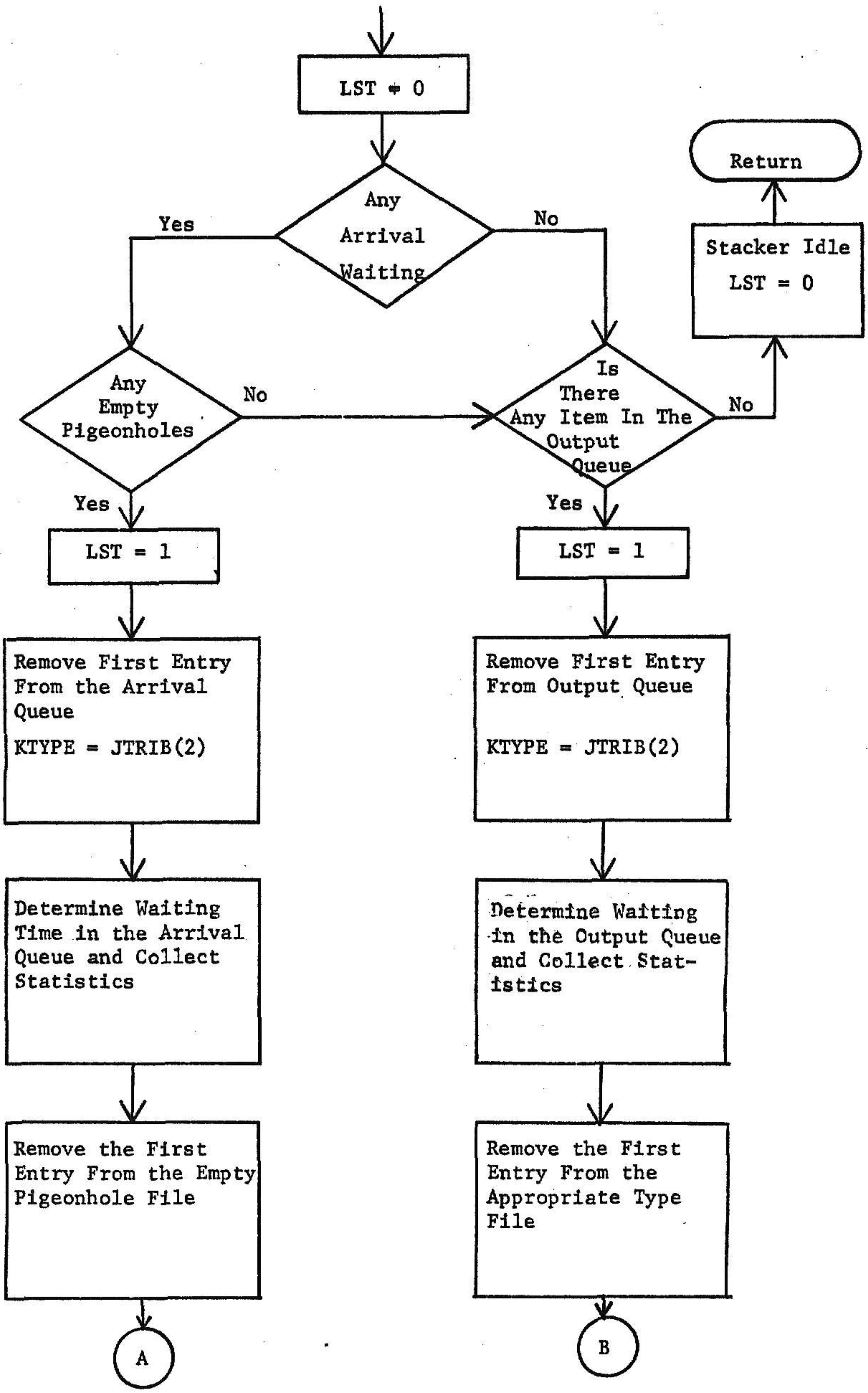

B
Check For Type
5,6,7,8
C
3,4
Check For Type
Type 3
Type 4
Is Production Time ≥ TTWO
Is Production Time ≥ TTWO
Yes
Yes
Schedule Next Arrival Type 5 at TNOW + TCH
Schedule Next Arrival Type 6 at TNOW + TCH
Schedule Next Arrival Type 3 at TNOW + N(PARAM(2,1), PARAM(2,4))
Schedule Next Arrival Type 4 at TNOW + N(PARAM(1,1), PARAM(1,4))
100

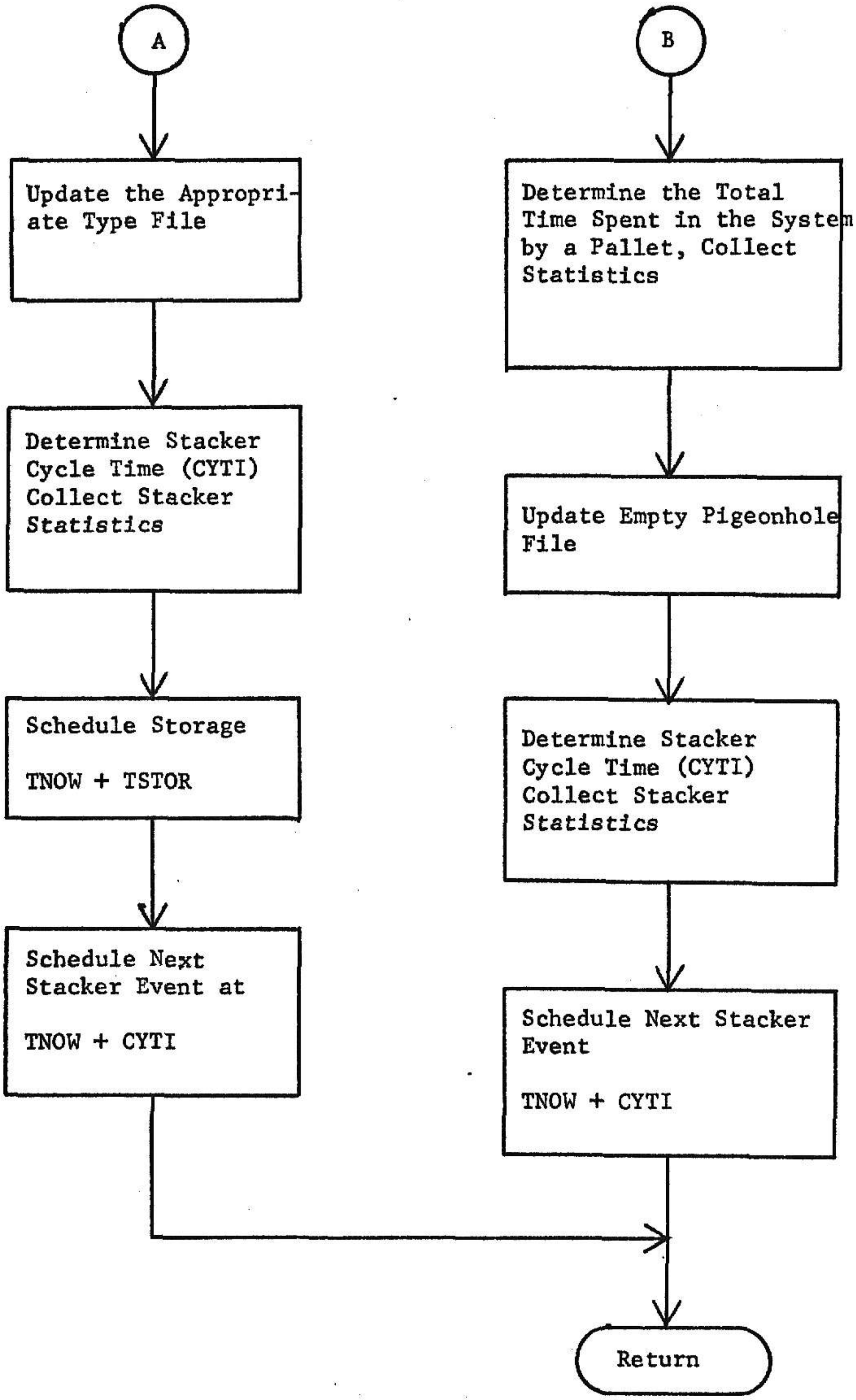

C
Check For Type
7,8
D
5,6
Type 5
Check For Type
Type 6
Schedule Next Arrival Type 7 at
TNOW + TCH
Yes
Production Time ≥ TTHRE
Production Time ≥ TTHRE
Yes
Schedule Next Arrival Type 8 at
TNOW + TCH
No
No
Schedule Next Arrival Type 5 at
TNOW + N(PARAM(2,1), PARAM(2,4))
Schedule Next Arrival Type 6 at
TNOW + N(PARAM(1,1), PARAM(1,4))
100



ARRIVE Subroutine

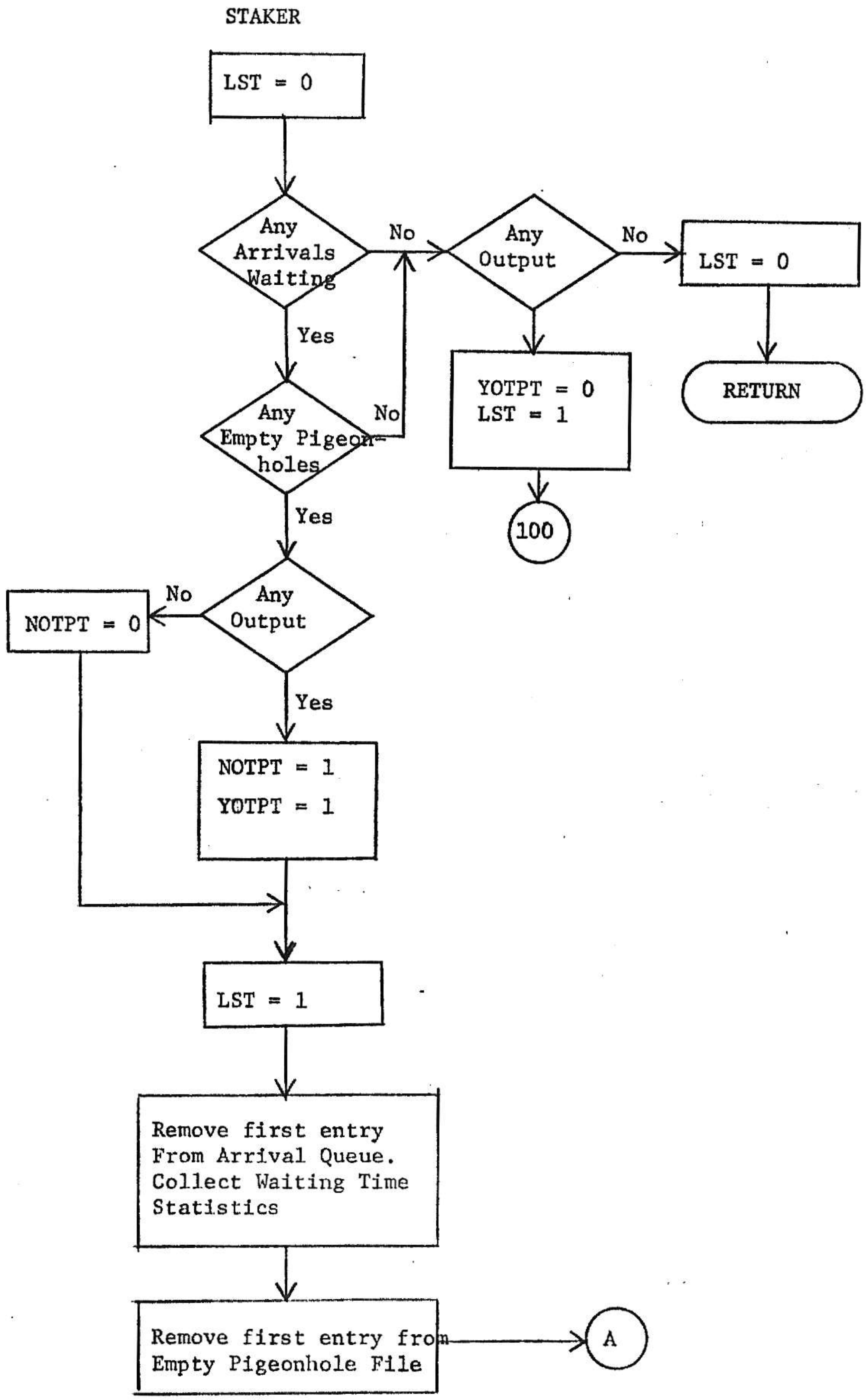
STAKER

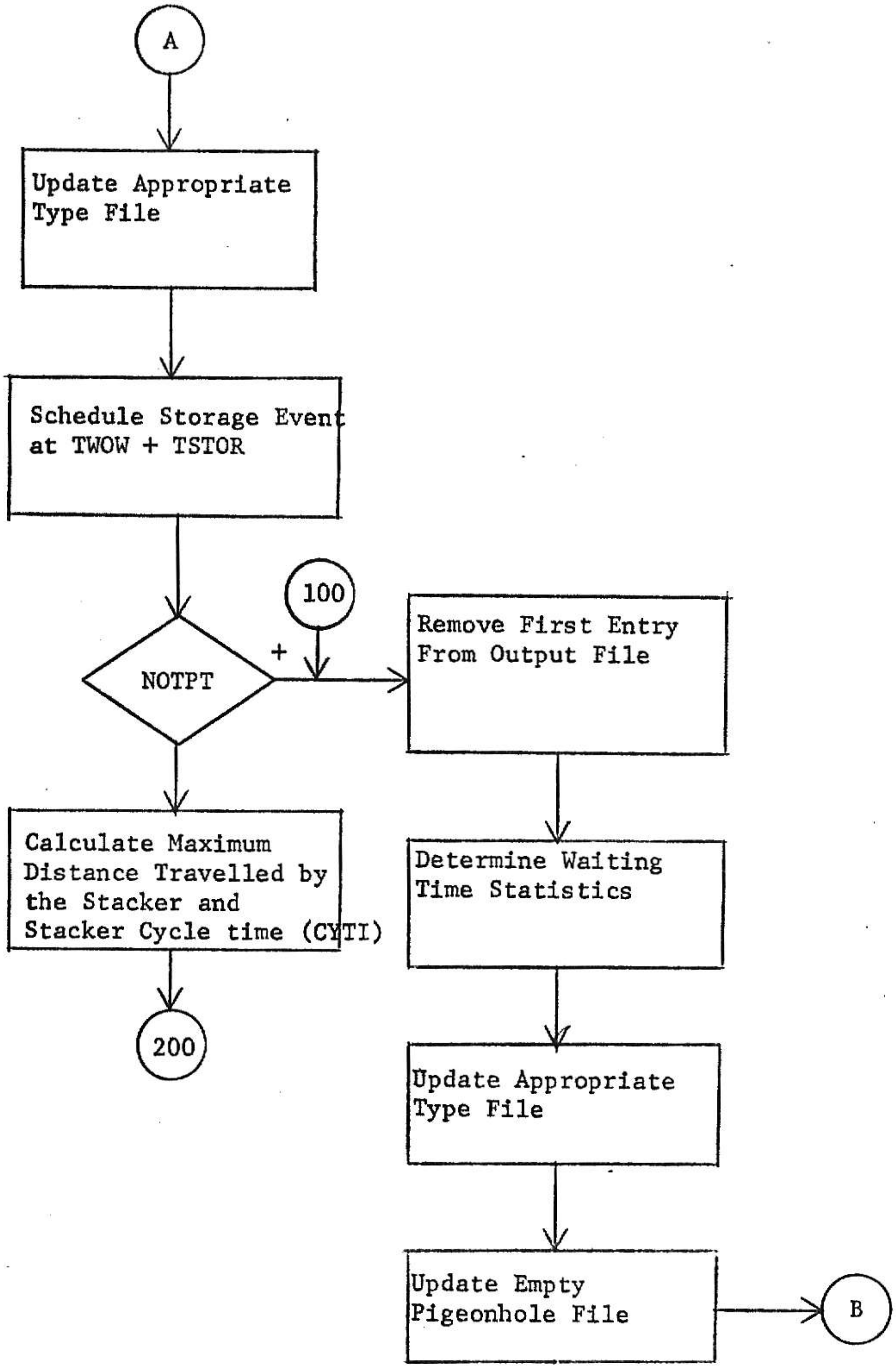

LST ≠ 0
Any Arrival Waiting
Yes
No
Return
Stacker Idle
LST = 0
Any Empty Pigeonholes
No
Is There Any Item In The Output Queue
No
Yes
Yes
LST = 1
LST = 1
Remove First Entry From the Arrival Queue
KTYPE = JTRIB(2)
Remove First Entry From Output Queue
KTYPE = JTRIB(2)
Determine Waiting Time in the Arrival Queue and Collect Statistics
Determine Waiting in the Output Queue and Collect Stat-istics
Remove the First Entry From the Empty Pigeonhole File
Remove the First Entry From the Appropriate Type File
A
B

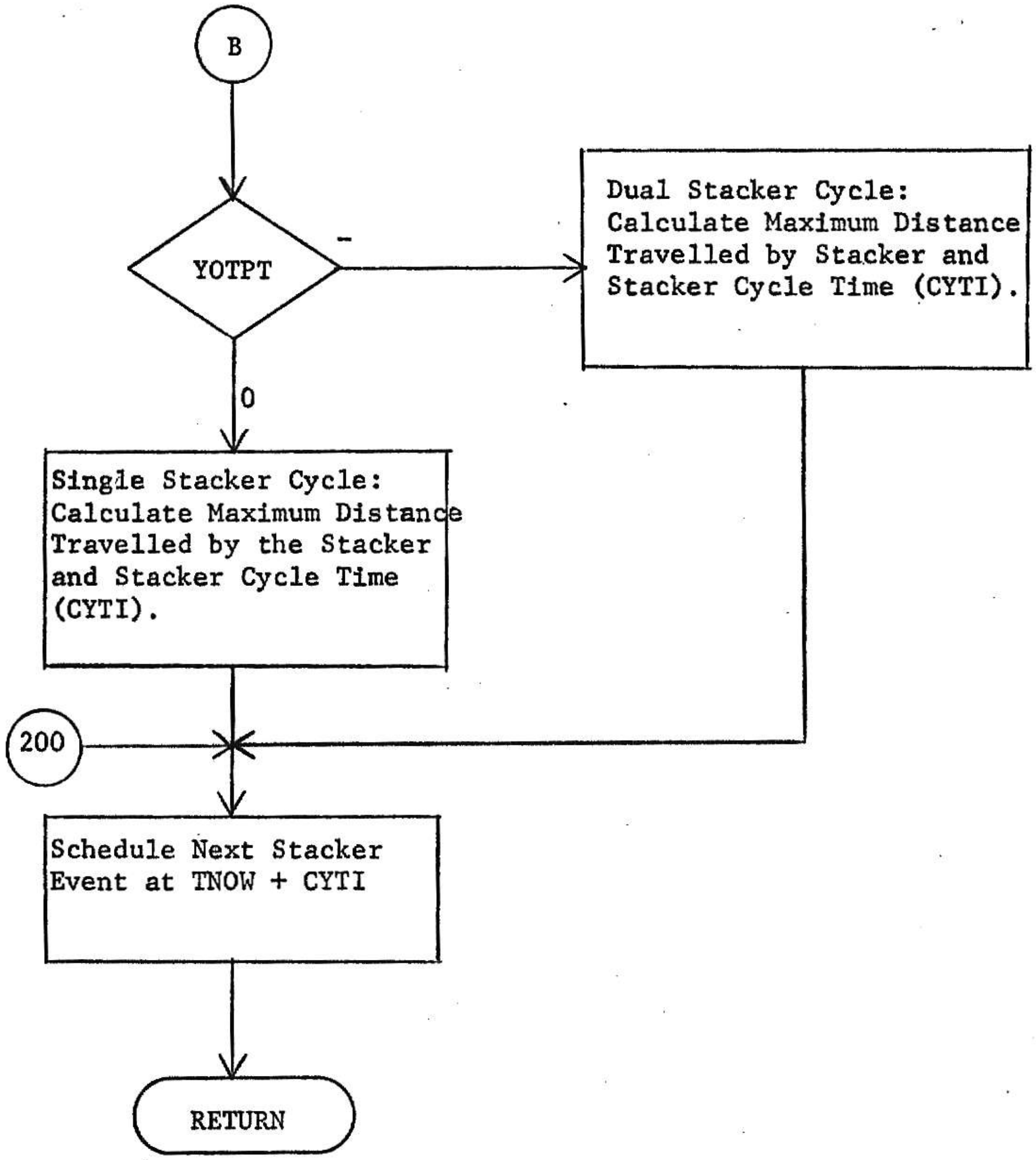


STAKER Subroutine

(Single Command)

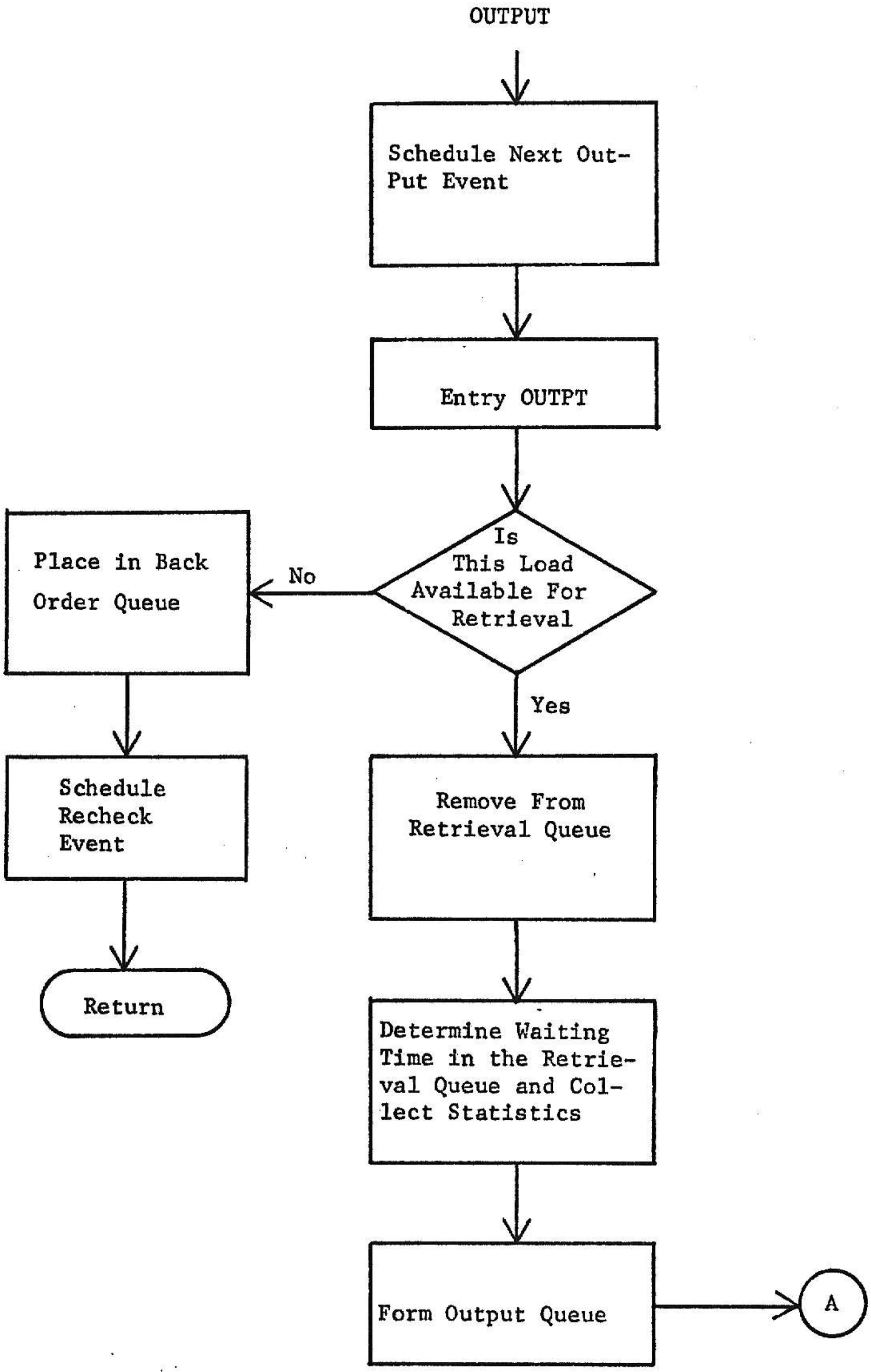

STAKER
LST = 0
Any Arrivals Waiting
No
Yes
Any Empty Pigeon-holes
No
Yes
Any Output
No
Yes
NOTPT = 0
NOTPT = 1
YOTPT = 1
LST = 1
Remove first entry From Arrival Queue. Collect Waiting Time Statistics
Remove first entry from Empty Pigeonhole File
A
Any Output
No
LST = 0
RETURN
YOTPT = 0
LST = 1
100

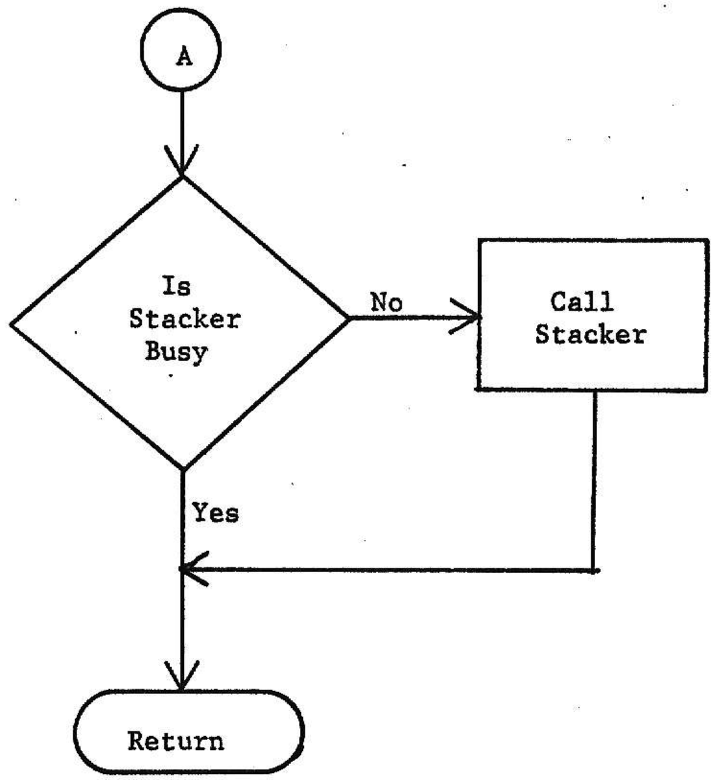

A
Update Appropriate Type File
Schedule Storage Event at TWOW + TSTOR
NOTPT
+
100
Remove First Entry From Output File
Calculate Maximum Distance Travelled by the Stacker and Stacker Cycle time (CYTI)
200
Determine Waiting Time Statistics
Update Appropriate Type File
Update Empty Pigeonhole File
B



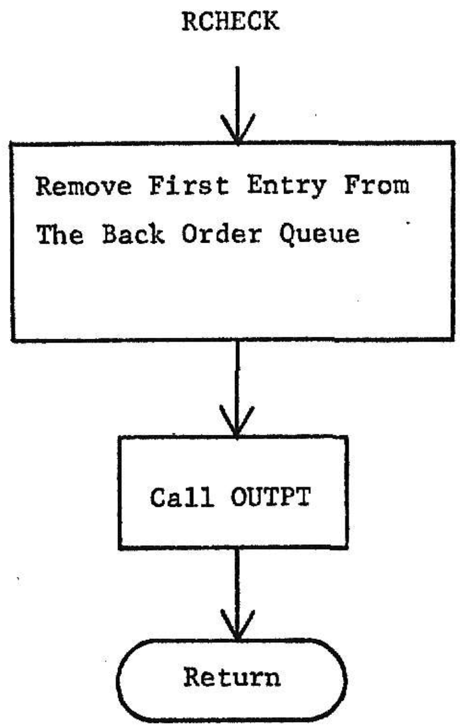
Subroutine STAKER

(Dual Command)

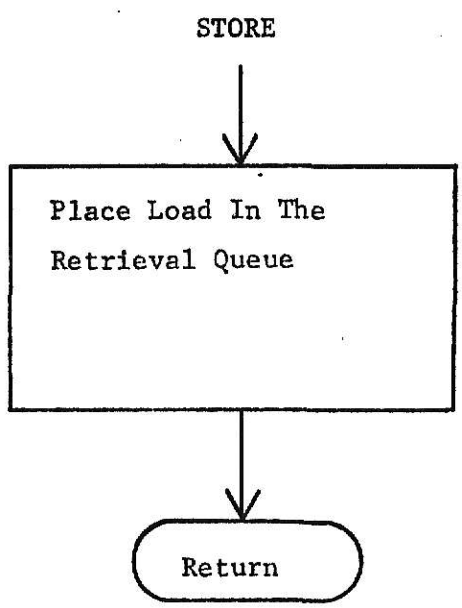

OUTPUT
Schedule Next Out-Put Event
Entry OUTPT
Is This Load Available For Retrieval
No
Place in Back Order Queue
Schedule Recheck Event
Return
Yes
Remove From Retrieval Queue
Determine Waiting Time in the Retrieval Queue and Collect Statistics
Form Output Queue
A



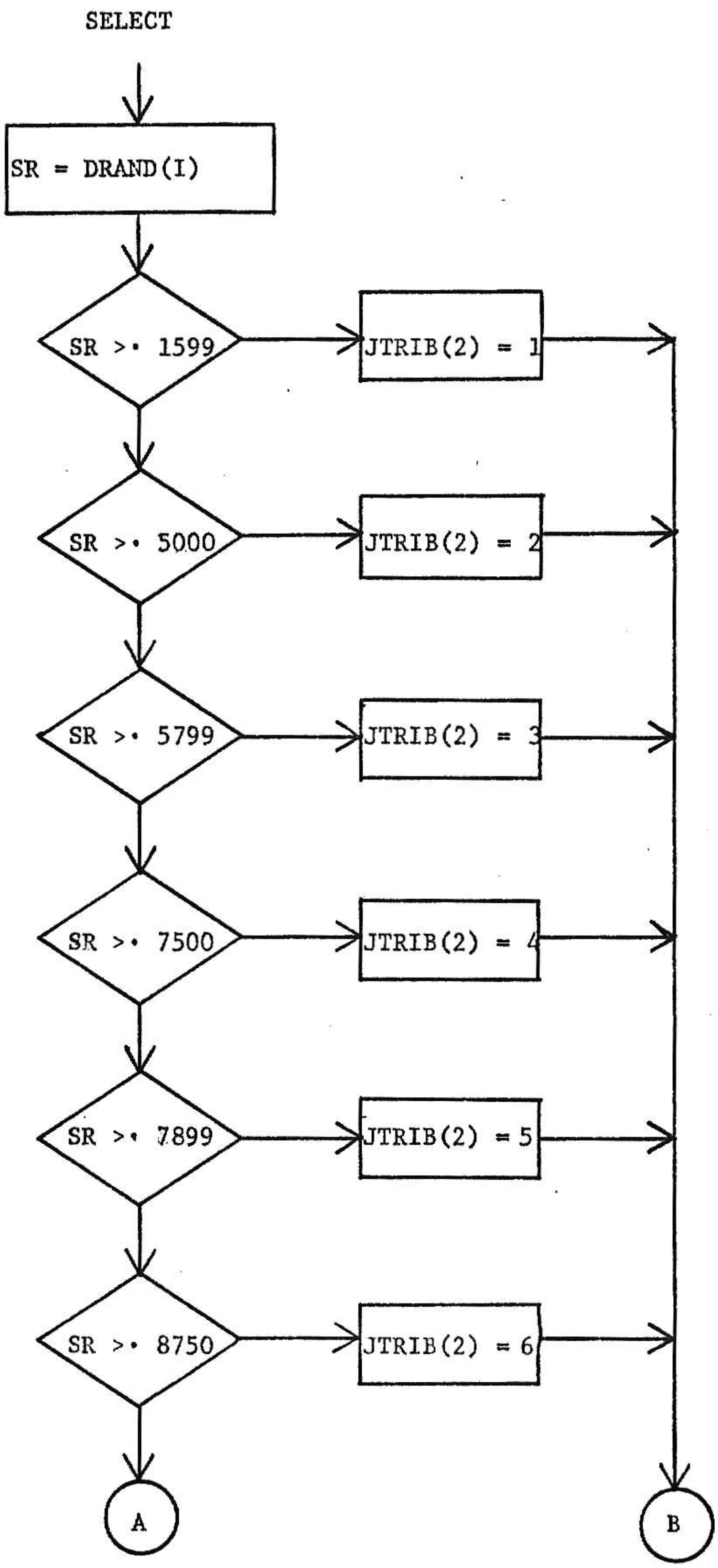
OUTPUT Subroutine

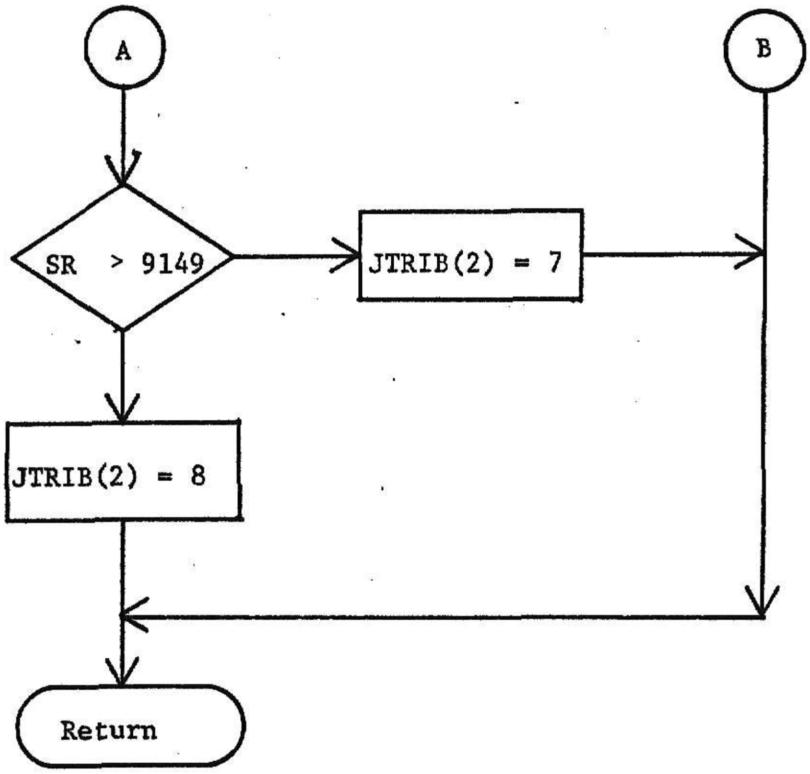


RCHECK Subroutine

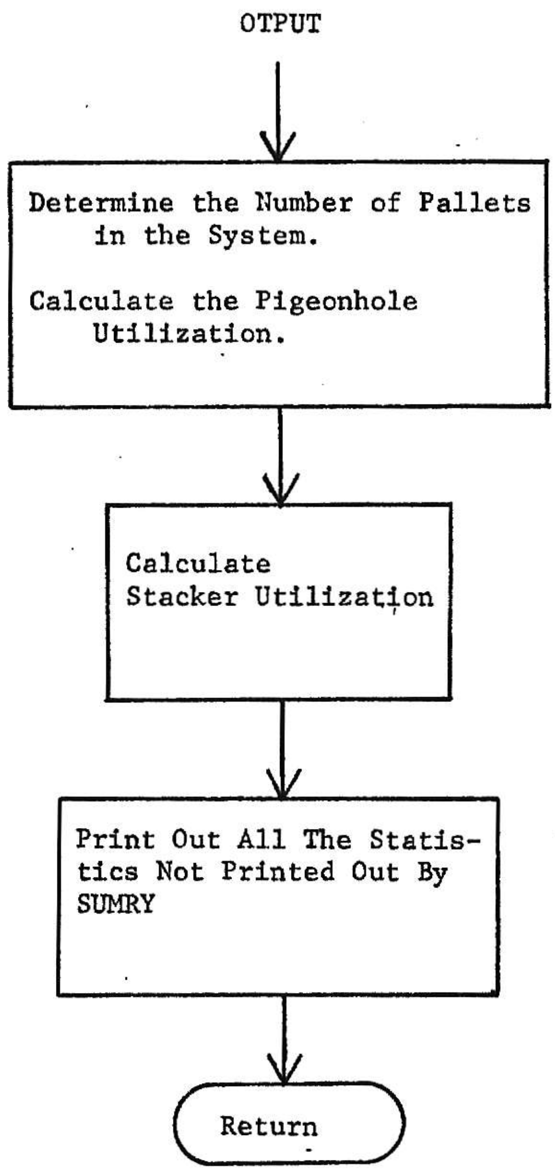


STORE Subroutine

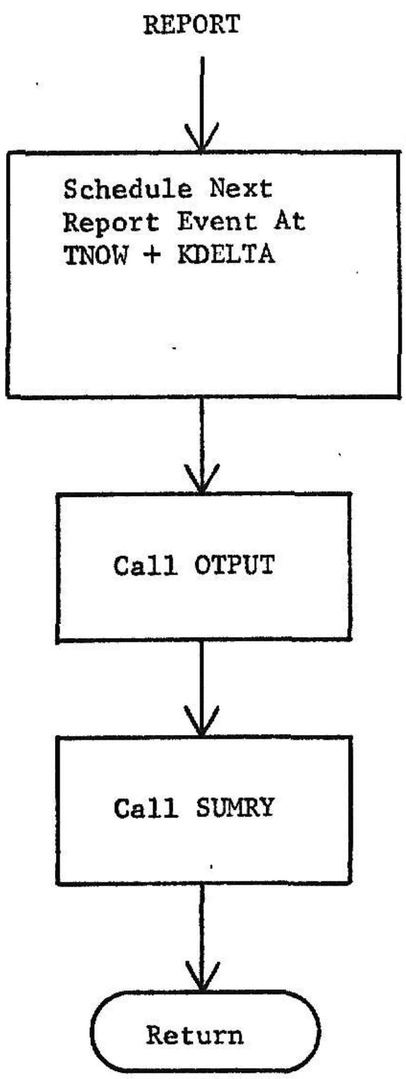

SELECT
SR = DRAND(I)
SR >· 1599
JTRIB(2) = 1
SR >· 5000
JTRIB(2) = 2
SR >· 5799
JTRIB(2) = 3
SR >· 7500
JTRIB(2) = 4
SR >· 7899
JTRIB(2) = 5
SR >· 8750
JTRIB(2) = 6
A
B



SELECT Subroutine

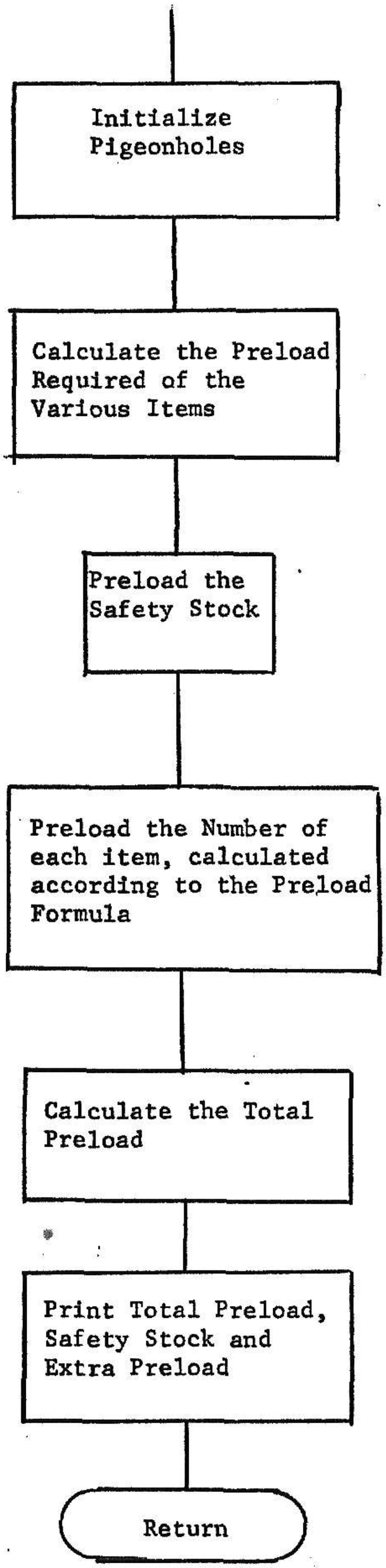


OTPUT Subroutine



REPORT SUBROUTINE

INTIAL



Subroutine INTIAL

APPENDIX C

THE PROGRAM

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,
              DIMENSION NSET(18000),QSET(6000)
              COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
             1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
             2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
              COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
             1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
             2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
              COMMON IT,KDELTA,KTYPE,LST,TONE,TTWC,TTHRE,TCH,XSP,YSP,NPX,NPHI,
             1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
             2PL
      C
      C***** THIS IS THE MAIN PROGRAM FOR THE AUTOMATED WAREHOUSE SIMULATION.
      C*****THE MAIN PROGRAM INITIALIZES THE NON GASP VARIABLES AND CALLS
      C*****SUBROUTINE GASP, THE GASP EXECUTIVE, WHICH THEN CONTROLS THE
      C*****COMPLETE SIMULATION.
      C
      C
      C***** INITIALIZE NON GASP VARIABLES.
      C
            NCRDR=1
            NPRNT=3
            IT=1
            MT=1
            LST=0
            NUM=1
            CALL GASP(NSET,QSET)
            STOP
            END

D OF COMPILATION ******
```

ILLEGIBLE

THE FOLLOWING DOCUMENT (S) IS ILLEGIBLE DUE TO THE PRINTING ON THE ORIGINAL BEING CUT OFF

ILLEGIBLE

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,
            SUBROUTINE EVNTS(I,NSET,QSET)
      C
      C***** THIS SUBROUTINE SELECTS THE APPROPRIATE EVENTS WHEN THEY ARE
      C*****SCHEDULED TO OCCUR.
      C
            DIMENSION NSET(1),QSET(1)
            COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
           1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NCFIL,
           2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
            COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
           1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
           2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
            COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
           1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
           2PL
      C
      C***** SELECT THE EVENTS.
      C
            GO TO (1,2,3,4,5,6,7,8,9),I
          1 CALL ARRIVE(NSET,QSET)
            RETURN
          2 CALL STAKER(NSET,QSET)
            RETURN
          3 CALL STORE(NSET,QSET)
            RETURN
          4 CALL OUTPUT(NSET,QSET)
            RETURN
          5 CALL OUTPT(NSET,QSET)
            RETURN
          6 CALL REPORT(NSET,QSET)
            RETURN
          7 CALL INTIAL(NSET,QSET)
            RETURN
          8 CALL RCHECK(NSET,QSET)
            RETURN
          9 CALL INITAL(NSET,QSET)
            RETURN
            END

D OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
            SUBROUTINE ARRIVE(NSET,QSET)
      C
      C***** THIS SUBROUTINE SIMULATES THE ARRIVAL OF A PALLET LOAD INTO THE
      C***** WAREHOUSE.
      C
            DIMENSION FIN(1000),FZN(1000),NSET(1),QSET(1)
            COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
           1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
           2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
            COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
           1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
           2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
            COMMON IT,KDELTA,KTYPE,LST,TONE,TTWC,TTHRE,TCH,XSP,YSP,NPX,NPHI,
           1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
           2PL
            KTYPE=JTRIB(2)
      C
      C***** CHECK FOR THE TYPE OF PALLET LOAD ARRIVING.
      C
            DO 5 I=1,8
            IF(KTYPE.EQ.I) GO TO(10,11,12,13,14,15,16,17),KTYPE
          5 CONTINUE
         10 FIN(IT)=TNOW
            IT=IT+1
            FI=TNOW-FIN(1)
      C
      C***** IS THE TIME SCHEDULED FOR PRODUCTION OVER.
      C
            IF(FI-TONE)20,23,23
      C
      C***** SCHEDULE THE SAME TYPE OF LOAD TO ARRIVE NEXT.
      C
         20 JTRIB(2)=1
         25 ATRIB(1)=TNOW+RNORM(1,1)
         26 ATRIB(2)=0.0
            JTRIB(1)=1
            JTRIB(3)=0
            JTRIB(4)=0
            CALL FILEM(1,NSET,QSET)
            GO TO 1000
         23 IT=1
      C
      C***** IF THE PRODUCTION TIME IS OVER, SCHEDULE THE NEXT TYPE OF PALLET
      C***** LOAD TO ARRIVE.
      C
         21 ATRIB(1)=TNOW+TCH
            ATRIB(2)=0.0
            JTRIB(1)=1
            JTRIB(3)=0
            JTRIB(4)=0
            MK=KTYPE+2
            IF(MK-8)50,50,51
         50 JTRIB(2)=MK
            GO TO 52
         51 JTRIB(2)=MK-8
```

```
   52 CALL FILEM(1,NSET,QSET)
      GO TO 1000
C
C***** PALLET LOAD TYPE TWO.
C
   11 FZN(MT)=TNOW
      MT=MT+1
      FI=TNOW-FZN(1)
      IF(FI-TONE)27,80,80
   80 MT=1
      GO TO 21
   27 JTRIB(2)=2
      ATRIB(1)=TNOW+RNORM(2,2)
      GO TO 26
C
C***** PALLET LOAD TYPE THREE.
C
   12 FIN(IT)=TNOW
      IT=IT+1
      FI=TNOW-FIN(1)
      IF(FI-TTWO)28,23,23
   28 JTRIB(2)=3
      GO TO 25
C
C***** PALLET LOAD TYPE FOUR.
C
   13 FZN(MT)=TNOW
      MT=MT+1
      FI=TNOW-FZN(1)
      IF(FI-TTWO)29,80,80
   29 ATRIB(1)=TNOW+RNORM(3,2)
      JTRIB(2)=4
      GO TO 26
C
C***** PALLET LOAD TYPE FIVE.
C
   14 FIN(IT)=TNOW
      IT=IT+1
      FI=TNOW-FIN(1)
      IF(FI-TTHRE)30,23,23
   30 JTRIB(2)=5
      GO TO 25
C
C***** PALLET LOAD TYPE SIX.
C
   15 FZN(MT)=TNOW
      MT=MT+1
      FI=TNOW-FZN(1)
      IF(FI-TTHRE)31,80,80
   31 JTRIB(2)=6
      ATRIB(1)=TNOW+RNORM(4,2)
      GO TO 26
C
C***** PALLET LOAD TYPE SEVEN.
C
   16 FIN(IT)=TNOW
      IT=IT+1
```

```
            FI=TNOW-FIN(1)
            IF(FI-TTHRE)32,23,23
         32 JTRIB(2)=7
            GO TO 25
      C
      C***** PALLET LOAD TYPE EIGHT.
      C
         17 FZN(MT)=TNOW
            MT=MT+1
            FI=TNOW-FZN(1)
            IF(FI-TTHRE)33,80,80
         33 JTRIB(2)=8
            ATRIB(1)=TNOW+RNORM(5,2)
            GO TO 26
      C
      C***** ADD TO THE QUEUE OF ARRIVING PALLETS WAITING FOR STACKER.
      C
       1000 JTRIB(2)=KTYPE
            JTRIB(1)=0
            ATRIB(1)=TNOW
            ATRIB(2)=TNOW
            JTRIB(3)=0
            JTRIB(4)=0
            CALL FILEM(11,NSET,QSET)
      C
      C***** CHECK WHETHER THE STACKER IS BUSY.
      C
            IF(LST)40,41,42
         40 CALL ERROR(10,NSET,QSET)
      C
      C***** IF STACKER IS IDLE , SCHEDULE STACKER EVENT AT TNOW.
      C
         41 CALL STAKER(NSET,QSET)
         42 RETURN
            END

D OF COMPILATION ******
```

```
      COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LO
0002           SUBROUTINE STAKER(NSET,QSET)
         C
         C***** THIS SUBROUTINE SIMULATES THE SINGLE COMMAND STACKER OPERATION.
         C
0003           DIMENSION NSET(1),QSET(1)
0004           COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
              1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
              2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
0005           COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
              1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
              2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
0006           COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
              1NPSYS,PHU,SU,RATE,MT,LSN,TSTCR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
              2PL
0007           LST=0
         C
         C***** CHECK WHETHER THERE ARE ANY PALLETS WAITING FOR THE STACKER IN
         C***** THE ARRIVAL QUEUE.
         C
0008           IF(NQ(11))10,11,12
0009        10 CALL ERROR(20,NSET,QSET)
         C
         C***** CHECK WHETHER THERE ARE ANY PALLETS WAITING FOR OUTPUT.
         C
0010        11 IF(NQ(13))20,21,22
0011        20 CALL ERROR(21,NSET,QSET)
0012        21 LST=0
0013           RETURN
         C
         C*****************   RETRIEVAL   *****************
         C
0014        22 LST=1
         C
         C***** REMOVE FIRST ENTRY FROM THE OUTPUT QUEUE.
         C
0015           MFT=MFE(13)
0016           CALL RMOVE(MFT,13,NSET,QSET)
         C
         C***** DETERMINE WAITING TIME IN THE OUTPUT QUEUE AND COLLECT STATISTICS.
         C
0017           WTO=TNOW-ATRIB(2)
0018           CALL COLCT(WTO,3,NSET,QSET)
0019           CALL HISTO(WTO,0.05,0.05,2)
         C
         C***** REMOVE THE FIRST ENTRY FROM THE APPROPRIATE TYPE FILE.
         C
0020           KTYPE=JTRIB(2)
0021           NY=KTYPE+1
0022           MFT=MFE(NY)
0023           CALL RMOVE(MFT,NY,NSET,QSET)
         C
         C***** DETERMINE THE TOTAL TIME SPENT IN THE SYSTEM.
         C
0024           WTIS=TNOW-ATRIB(1)
0025           CALL COLCT(WTIS,6,NSET,QSET)
```

```
C
C***** UPDATE THE EMPTY PIGEON HOLE FILE.
C
      JTRIB(1)=0
      ATRIB(1)=0.0
      ATRIB(2)=TNOW
      CALL FILEM(10,NSET,QSET)
C
C***** DETERMINE THE MAXIMUM DISTANCE TRAVELLED BY THE STACKER.
C
      XDIST=JTRIB(3)
      YDIST=JTRIB(4)
      XTIME=(XDIST+10.)/XSP
      YTIME=(YDIST+3.)/YSP
      STIME=AMAX(XTIME,YTIME)
C
C***** DETERMINE CYCLE TIME AND COLLECT STACKER STATISTICS.
C
      CYTI=(0.982+2*STIME)/60.
      CALL COLCT(CYTI,5,NSET,QSET)
C
C***** SCHEDULE NEXT STACKER EVENT.
C
      ATRIB(1)=TNOW+CYTI
      ATRIB(2)=0.0
      JTRIB(1)=2
      JTRIB(2)=0
      JTRIB(3)=0
      JTRIB(4)=0
      CALL FILEM(1,NSET,QSET)
      RETURN
C
C******************  STACKING  ******************
C
C
C***** CHECK WHETHER THERE ARE ANY EMPTY PIGEON HOLES AVAILABLE.
C
   12 IF(NQ(10))30,31,32
   30 CALL ERROR(22,NSET,QSET)
   31 GO TO 11
   32 LST=1
C
C***** REMOVE FIRST ENTRY FROM THE ARRIVAL QUEUE.
C
      MFT=MFE(11)
      CALL RMOVE(MFT,11,NSET,QSET)
C
C***** DETERMINE WAITING TIME IN THE ARRIVAL QUEUE AND COLLECT STATISTICS.
C
      TTN=ATRIB(1)
      WTA=TNOW-ATRIB(2)
      KTYPE=JTRIB(2)
      CALL COLCT(WTA,2,NSET,QSET)
      CALL HISTO(WTA,0.05,0.05,4)
C
C***** REMOVE THE FIRST ENTRY FROM THE EMPTY PIGEON HOLE FILE.
C
```

```
      MFT=MFE(10)
      CALL RMOVE(MFT,10,NSET,QSET)
C
C***** UPDATE THE PARTICULAR PALLET LOAD TYPE FILE.
C
      NY=KTYPE+1
      ATRIB(1)=TTN
      ATRIB(2)=TNOW
      JTRIB(1)=0
      CALL FILEM(NY,NSET,QSET)
C
C***** DETERMINE THE MAXIMUM DISTANCE TRAVELLED BY THE STACKER.
C
      XDIST=JTRIB(3)
      YDIST=JTRIB(4)
      XTIME=(XDIST+10.)/XSP
      YTIME=(YDIST+3.)/YSP
      STIME=AMAX(XTIME,YTIME)
C
C***** DETERMINE CYCLE TIME AND COLLECT STACKER STATISTICS.
C
      CYTI=(0.982+2*STIME)/60.
      CALL COLCT(CYTI,5,NSET,QSET)
C
C***** SCHEDULE STORAGE EVENT. THE PALLET HAS TO BE STORED IN THE SYSTEM
C***** FOR A REQUIRED LENGTH OF TIME.
C
      ATRIB(1)=TNOW+TSTOR
      ATRIB(2)=0.0
      JTRIB(1)=3
      JTRIB(2)=KTYPE
      JTRIB(3)=0
      JTRIB(4)=0
      CALL FILEM(1,NSET,QSET)
C
C***** SCHEDULE NEXT STACKER EVENT.
C
      ATRIB(1)=TNOW+CYTI
      ATRIB(2)=0.0
      JTRIB(1)=2
      JTRIB(2)=0
      JTRIB(3)=0
      JTRIB(4)=0
      CALL FILEM(1,NSET,QSET)
      RETURN
      END

END OF COMPILATION ******
```

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOA

```
      SUBROUTINE STAKER(NSET,QSET)
C
C***** THIS SUBROUTINE SIMULATES THE DUAL COMMAND STACKER OPERATION.
C
      DIMENSION NSET(1),QSET(1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
      COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
     1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
     2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
      COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
     1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
     2PL
      LST=0
C
C***** CHECK WHETHER THERE ARE ANY PALLETS WAITING IN THE ARRIVAL QUEUE.
C
      IF(NQ(11))10,11,12
   10 CALL ERROR(20,NSET,QSET)
C
C***** ARE THERE ANY EMPTY PIGEON HOLES AVAILABLE.
C
   12 IF(NQ(10))20,11,22
   20 CALL ERROR(22,NSET,QSET)
C
C***** ARE THERE ANY PALLET LOADS IN THE OUTPUT QUEUE.
C
   22 IF(NQ(13))30,31,32
   30 CALL ERROR(21,NSET,QSET)
   31 NOTPT=0
      GO TO 50
   32 NOTPT=1
      YOTPT=1
   50 LST=1
C
C***** REMOVE FIRST ENTRY FROM THE ARRIVAL QUEUE.
C
     MFT=MFE(11)
     CALL RMOVE(MFT,11,NSET,QSET)
     TTN=ATRIB(1)
C
C***** COLLECT WAITING TIME STATISTICS.
C
     WTA=TNOW-ATRIB(2)
     CALL COLCT(WTA,2,NSET,QSET)
     CALL HISTO(WTA,0.05,0.05,4)
     KTYPE=JTRIB(2)
C
C***** REMOVE FIRST ENTRY FROM THE EMPTY PIGEON HOLE FILE.
C
     MFT=MFE(10)
     CALL RMOVE(MFT,10,NSET,QSET)
     X=JTRIB(3)
     Y=JTRIB(4)
```

```
C
C***** UPDATE APPROPRIATE PALLET LOAD TYPE FILE,
C
      NY=KTYPE+1
      ATRIB(1)=TTN
      ATRIB(2)=TNOW
      JTRIB(1)=0
      CALL FILEM(NY,NSET,QSET)
C
C***** SCHEDULE STORAGE EVENT.
C
      ATRIB(1)=TNOW+TSTOR
      ATRIB(2)=0.0
      JTRIB(1)=3
      JTRIB(2)=KTYPE
      JTRIB(3)=0
      JTRIB(4)=0
      CALL FILEM(1,NSET,QSET)
      IF(NOTPT)99,101,100
   99 CALL ERROR(23,NSET,QSET)
C
C***** DETERMINE MAXIMUM DISTANCE TRAVELLED BY STACKER.
C
  101 XTIME=(X+10.)/XSP
      YTIME=(Y+3.)/YSP
      STIME=AMAX(XTIME,YTIME)
C
C***** DETERMINE STACKER CYCLE TIME.
C
      CYTI=(.982+2*STIME)/60.0
      GO TO 200
C
C***** REMOVE FIRST ENTRY FROM THE OUTPUT FILE.
C
  100 MFT=MFE(13)
      CALL RMOVE(MFT,13,NSET,QSET)
C
C***** COLLECT WAITING TIME STATISTICS.
C
      WTO=TNOW-ATRIB(2)
      CALL COLCT(WTO,3,NSET,QSET)
      CALL HISTO(WTO,0.05,0.05,2)
      KTYPE=JTRIB(2)
C
C***** UPDATE APROPRIATE PALLET LOAD TYPE FILES.
C
      NY=KTYPE+1
      MFT=MFE(NY)
      CALL RMOVE(MFT,NY,NSET,QSET)
C
C***** DETERMINE TOTAL TIME SPENT IN THE SYSTEM.
C
      WTIS=TNOW+ATRIB(1)
      CALL COLCT(WTIS,6,NSET,QSET)
C
C***** UPDATE EMPTY PIGEON HOLE FILE.
C
```

```
          ATRIB(1)=0.0
          ATRIB(2)=TNOW
          JTRIB(1)=0
          CALL FILEM(10,NSET,QSET)
C
C***** DETERMINE MAXIMUM DISTANCE TRAVELLED BY STACKER.
C
          XONE=JTRIB(3)
          YONE=JTRIB(4)
          IF(YOTPT)70,71,72
       70 CALL ERROR(24,NSET,QSET)
       71 XTIME=(XONE+10.)/XSP
          YTIME=(YONE+3.)/YSP
          STIME=AMAX(XTIME,YTIME)
          CYTI=(.982+2*STIME)/60.0
          GO TO 200
       72 XDIST=AMAX(X,XONE)
          YDIST=AMAX(Y,YONE)
          XTIME=(XDIST+15.0)/XSP
          YTIME=(YDIST+6.)/YSP
          STIME=AMAX(XTIME,YTIME)
          CYTI=(1.830+2*STIME)/60.0
      200 CALL COLCT(CYTI,5,NSET,QSET)
          ATRIB(1)=TNOW+CYTI
          ATRIB(2)=0.0
          JTRIB(1)=2
          JTRIB(2)=0
          CALL FILEM(1,NSET,QSET)
          RETURN
C
C***** CHECK WHETHER THERE IS ANY OUTPUT TO BE DONE.
C
       11 IF(NQ(13))80,81,82
       80 CALL ERROR(25,NSET,QSET)
       82 YOTPT=0
          LST=1
          GO TO 100
       81 LST=0
          RETURN
          END

D OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
      SUBROUTINE OUTPUT(NSET,QSET)
C
C***** THIS SUBROUTINE DETERMINES THE TYPE OF PALLET LOAD TO BE RETRIEVED
C***** AND IT PERFORMES THE RELATED OPERATIONS LIKE MAKING THE BACK ORDER
C***** FILE, SCHEDULING RECHECK EVENT ETC.
C
      DIMENSION NSET(1),QSET(1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
      COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
     1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
     2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
      COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
     1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
     2PL
      LSN=1
C
C***** SCHEDULE NEXT OUTPUT EVENT.
C
      KTYPE=JTRIB(2)
      ATRIB(1)=TNOW+RNORM(6,3)
      ATRIB(2)=0.0
      JTRIB(1)=4
      JTRIB(3)=0
      JTRIB(4)=0
      CALL SELECT(8,NSET,QSET)
      CALL FILEM(1,NSET,QSET)
      GO TO 30
      ENTRY OUTPT(NSET,QSET)
      KTYPE=JTRIB(2)
C
C***** DETERMINE WHETHER THIS TYPE OF PALLET LOAD IS IN THE RETRIEVAL QUEUE
C***** THAT IS WHETHER THE PALLET LOAD HAS BEEN IN STORAGE FOR A REQUIRED
C***** LENGTH OF TIME.
C
   30 IF(NQ(12))60,60,61
   60 KCOL=0
      GO TO 70
   61 CALL FINDN(KTYPE,5,12,2,KCOL,NSET,QSET)
   70 IF(KCOL)10,11,12
   10 CALL ERROR(30,NSET,QSET)
   11 IF(LSN)40,41,40
C
C***** IF THE PALLET LOAD HAS NOT BEEN IN THE SYSTEM FOR THE REQUIRED
C***** LENGTH OF TIME, FORM A BACK ORDER QUEUE.
C
   40 ATRIB(2)=TNOW
   41 JTRIB(2)=KTYPE
      JTRIB(3)=NUM
      JTRIB(1)=0
      ATRIB(1)=0.0
      JTRIB(4)=0
      CALL FILEM(14,NSET,QSET)
      NUM=NUM+1
```

```
      C
      C***** SCHEDULE RECHECK OPERATION.
      C
            ATRIB(1)=TNOW+TRCHK
            ATRIB(2)=0.0
            JTRIB(1)=8
            JTRIB(2)=0
            JTRIB(3)=0
            JTRIB(4)=0
            CALL FILEM(1,NSET,QSET)
            RETURN
         12 IF(LSN)50,51,50
      C
      C***** FORM OUTPUT QUEUE.(WAITING FOR STACKER).
      C***** COLLECT STATISTICS ON WAITING TIME IN THE BACK ORDER QUEUE,
      C***** AND WAITING TIME IN THE RETRIEVAL QUEUE.
      C
         51 WTBO=TNOW-WTAT
            CALL COLCT(WTBO,4,NSET,QSET)
            CALL HISTO(WTBO,1.0,4.0,3)
         50 CALL RMOVE(KCOL,12,NSET,QSET)
            WTR=TNOW-ATRIB(2)
            CALL COLCT(WTR,1,NSET,QSET)
            CALL HISTO(WTR,0.1,3.0,1)
            JTRIB(1)=0
            ATRIB(1)=0.0
            ATRIB(2)=TNOW
            CALL FILEM(13,NSET,QSET)
      C
      C***** IF STACKER IS FREE, CALL STACKER.
      C
            IF(LST)20,21,22
         20 CALL ERROR(31,NSET,QSET)
         21 CALL STAKER(NSET,QSET)
         22 RETURN
            END

D OF COMPILATION ******
```

```
**COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
02            SUBROUTINE RCHECK(NSET,QSET)
       C
       C***** THIS EVENT SUBROUTINE REMOVES THE FIRST ENTRY FROM THE BACK ORDER
       C***** QUEUE AND CALLS ENTRY POINT OUTPT IN THE OUTPUT SUBROUTINE , FOR
       C***** RECHECKING OPERATIONS.
       C
03            DIMENSION NSET(1),QSET(1)
04            COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
             1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
             2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
05            COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
             1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
             2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
06            COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
             1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
             2PL
07            LSN=0
08            MFT=MFE(14)
09            CALL RMOVE(MFT,14,NSET,QSET)
10            WTAT=ATRIB(2)
11            CALL OUTPT(NSET,QSET)
12            RETURN
13            END

D OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
02            SUBROUTINE STORE(NSET,QSET)
        C
        C***** THIS EVENT SUBROUTINE FILES THE PARTICULAR PALLET LOAD IN TO THE
        C***** RETRIEVAL QUEUE AFTER THE PALLET HAS BEEN STORED IN THE WAREHOUSE
        C***** FOR THE REQUIRED LENGTH OF TIME.
        C
03            DIMENSION NSET(1),QSET(1)
04            COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
             1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
             2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
05            COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
             1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
             2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
06            COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
             1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
             2PL
07            ATRIB(1)=0.0
08            ATRIB(2)=TNOW
09            JTRIB(1)=0
10            JTRIB(3)=0
11            JTRIB(4)=0
12            CALL FILEM(12,NSET,QSET)
13            RETURN
14            END

D OF COMPILATION ******
```

```
COMPILER CPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,
            SUBROUTINE OTPUT(NSET,QSET)
      C
      C***** THIS SUBROUTINE COLLECTS THE NECESSARY INFORMATION ABOUT THE
      C***** OPERATIONS OF THE AUTOMATED WAREHOUSE.
      C
            DIMENSION NSET(1),QSET(1)
            COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
           1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
           2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
            COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
           1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
           2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
            COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
           1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
           2PL
            PRINT 10,TNOW
         10 FORMAT(1H1,//2X' REPORT OF THE AUTOMATED WAREHOUSE AT TIME'F6.1)
            TNPH=2*NPX*NPHI
            NPSYS=TNPH-NQ(10)
            PHU=(NPSYS/TNPH)*100
            SFA=SUMA(5,1)
            SU=(SFA/TNOW)*100
            PRINT 20,NPSYS
         20 FORMAT(//5X' NUMBER OF PALLETS IN THE SYSTEM ='I8)
            DO 30 I=2,9
            MI=I-1
         30 PRINT 40,MI,NQ(I)
         40 FORMAT(/5X' NUMBER OF PALLETS IN THE SYSTEM-TYPE 'I2,3XI5)
            PRINT 50,NQ(10)
         50 FORMAT(/5X' NUMBER OF EMPTY PIGEON HOLES ='I5)
            PRINT 70,NQ(12)
         70 FORMAT(/5X' NUMBER OF ENTRIES IN THE RETRIEVAL FILE ='I5)
            PRINT 60,NQ(14)
         60 FORMAT(/5X' NUMBER OF ENTRIES IN THE BACK ORDER QUEUE ='I5)
            PRINT 80,NQ(11)
         80 FORMAT(/5X' NUMBER OF ENTRIES IN THE ARRIVAL QUEUE ='I5)
            PRINT 90,NQ(13)
         90 FORMAT(/5X' NUMBER OF ENTRIES IN THE OUTPUT QUEUE ='I5)
            PRINT 21,PHU
         21 FORMAT(/5X' PIGEON HOLE UTILIZATION ='F8.3)
            PRINT 22,SU
         22 FORMAT(/5X' STAKER UTILIZATION ='F8.3)
            RETURN
            END

D OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
002          SUBROUTINE REPORT(NSET,QSET)
       C
       C***** THIS SUBROUTINE AT FIXED INTERVALS OF TIME, PRODUCES THE COMPLETE
       C***** INFORMATION ON THE WHOLE SYSTEM.
       C
003          DIMENSION NSET(1),QSET(1)
004          COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
            1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
            2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
005          COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
            1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
            2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
006          COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
            1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
            2PL
007          ATRIB(1)=TNOW+KDELTA
008          ATRIB(2)=0.0
009          JTRIB(1)=6
010          JTRIB(2)=0
011          CALL FILEM(1,NSET,QSET)
012          CALL OTPUT(NSET,QSET)
013          CALL SUMRY(NSET,QSET)
014          RETURN
015          END
ND OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
              SUBROUTINE SELECT(I,NSET,QSET)
        C
        C***** THIS SUBROUTINE DETERMINES THE TYPE OF PALLET LOAD ENTERING OR
        C***** LEAVING THE SYSTEM, FROM A PARTICULAR DISCRETE PROBABILITY DISTRN.
        C
              DIMENSION NSET(1),QSET(1)
              COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
             1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
             2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
              COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
             1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
             2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
              COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
             1NPSYS,PHU,SU,RATE,MT,LSN,TSTCR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
             2PL
              SR=DRAND(I)
              IF(SR.GT..1599) GO TO 10
              JTRIB(2)=1
              GO TO 20
           10 IF(SR.GT..5000) GO TO 11
              JTRIB(2)=2
              GO TO 20
           11 IF(SR.GT..5799) GO TO 12
              JTRIB(2)=3
              GO TO 20
           12 IF(SR.GT..7500) GO TO 13
              JTRIB(2)=4
              GO TO 20
           13 IF(SR.GT..7899) GO TO 14
              JTRIB(2)=5
              GO TO 20
           14 IF(SR.GT..8750) GO TO 15
              JTRIB(2)=6
              GO TO 20
           15 IF(SR.GT..9149) GO TO 16
              JTRIB(2)=7
              GO TO 20
           16 JTRIB(2)=8
           20 RETURN
              END

D OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
              SUBROUTINE INTIAL(NSET,QSET)
      C
      C***** THIS SUBROUTINE DETERMINES THE LOCATIONS OF ALL THE PIGEON HOLES
      C***** IN THE WAREHOUSE AND PRELOADS THE SYSTEM.
      C
             DIMENSION NSET(1),QSET(1)
             COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
            1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
            2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
             COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
            1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
            2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
             COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
            1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
            2PL
      C
      C***** INITIALIZE THE PIGEON HOLES.
      C
             LXT=0
             ITER=0
          20 DO 10 I=1,NPX
             DO 11 KY = 1,NPHI
             ATRIB(1)=0.0
             ATRIB(2)=TNOW
             JTRIB(1)=0
             JTRIB(3)=6*I-6
             JTRIB(4)=5*KY-5
             IF(ITER-1)2,3,3
           2 JTRIB(2)=2*LXT+KY
             GO TO 8
           3 JTRIB(2)=2*LXT+KY-4
           8 CALL FILEM(10,NSET,QSET)
          11 CONTINUE
             LXT=LXT+NPHI
          10 CONTINUE
             LXT=NPHI
             ITER=ITER+1
      C
      C***** IF ONE SIDE OF THE AISLE HAS BEEN INITIALIZED THEN INITIALIZE THE
      C***** OTHER SIDE OF THE AISLE.
      C
             IF(ITER-2)20,13,13
          13 TIX=.0001
      C
      C***** PRELOAD THE SYSTEM.
      C
             RPH=RATE/16.0
             KRLD1=TSTOR*RPH*.1599
             KRLD2=TSTOR*RPH*.3401
             KRLD3=(TONE+TSTOR)*RPH*.0799
             KRLD4=(TONE+TSTOR)*RPH*.1701
             KRLD5=(TONE+TTWO+TSTOR)*RPH*.0399
             KRLD6=(TONE+TTWO+TSTOR)*RPH*.0851
             KRLD7=(TONE+TTWO+TTHRE+TSTOR)*RPH*.0399
             KRLD8=(TONE+TTWO+TTHRE+TSTOR)*RPH*.0851
```

```
      KRLD=LOAD+LEXPL
      KIT=0
   21 DO 14 KN=1,KRLD
      MFT=MFE(10)
      CALL RMOVE(MFT,10,NSET,QSET)
      KXZ=JTRIB(3)
      KYZ=JTRIB(4)
      KPN=JTRIB(2)
      IF(KIT)23,23,24
   23 CALL SELECT(7,NSET,QSET)
      KTYPE=JTRIB(2)
   24 NY=KTYPE+1
      ATRIB(1)=0.0
      ATRIB(2)=TIX
      JTRIB(1)=0
      JTRIB(2)=KPN
      JTRIB(3)=KXZ
      JTRIB(4)=KYZ
      CALL FILEM(NY,NSET,QSET)
C
C***** MAKE ALL THE PRELOADED PALLET LOADS AVAILABLE - FILE THEM IN THE
C***** RETRIEVAL FILE.
C
      ATRIB(1)=0.0
      ATRIB(2)=TNOW+TIX
      JTRIB(1)=0
      JTRIB(2)=KTYPE
      JTRIB(3)=0
      JTRIB(4)=0
      CALL FILEM(12,NSET,QSET)
      TIX=TIX+.0001
   14 CONTINUE
      IF(KIT)25,25,26
   25 KIT=1
      KTYPE=1
      KRLD=KRLD1+1
      GO TO 21
   26 KIT=KIT+1
      IF(KIT-3)30,40,50
   30 KTYPE=2
      KRLD=KRLD2+1
      GO TO 21
   40 KTYPE=3
      KRLD=KRLD3+1
      GO TO 21
   50 IF(KIT-5)60,70,80
   60 KTYPE=4
      KRLD=KRLD4+1
      GO TO 21
   70 KTYPE=5
      KRLD=KRLD5+1
      GO TO 21
   80 IF(KIT-7)90,100,110
   90 KTYPE=6
      KRLD=KRLD6+1
      GO TO 21
  100 KTYPE=7
```

```
      KRLD=KRLD7+1
      GO TO 21
  110 IF(KIT-9)111,112,112
  111 KTYPE=8
      KRLD=KRLD8+1
      GO TO 21
  112 KLOAD=KRLD1+KRLD2+KRLD3+KRLD4+KRLD5+KRLD6+KRLD7+KRLD8
      PRINT 999,KLOAD
  999 FORMAT(1H1,/////5X' NUMBER OF PALLETS PRELOADED IN THE SYSTEM ='I5
     1)
      PRINT 888,LOAD
  888 FORMAT(//5X' SAFETY STOCK IN THE SYSTEM ='I5)
      PRINT 777,LEXPL
  777 FORMAT(//5X' EXTRA PRELOAD ='I5)
      RETURN
      END

OF COMPILATION ******
```

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=59,SOURCE,EBCDIC,NOLIST,NODECK,LOAD
002           SUBROUTINE INITAL(NSET,QSET)
003           DIMENSION NSET(1),QSET(1)
004           COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
             1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,ISEED,TNOW,NOFIL,
             2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS
005           COMMON ATRIB(2),ENQ(14),INN(14),JCELS(4,22),KRANK(14),MAXNQ(14),
             1MFE(14),MLE(14),MLC(14),NCELS(4),NQ(14),PARAM(20,4),QTIME(14),
             2SSUMA(10,5),SUMA(10,5),NAME(6),MON,NDAY,NYR,JCLR,JTRIB(4),IX(8)
006           COMMON IT,KDELTA,KTYPE,LST,TONE,TTWO,TTHRE,TCH,XSP,YSP,NPX,NPHI,
             1NPSYS,PHU,SU,RATE,MT,LSN,TSTOR,TRCHK,NUM,XTIME,YTIME,WTAT,LOAD,LEX
             2PL
007           DO 10 I=1,3
008        10 SUMA(6,I)=0
009           SUMA(6,4)=1.0E20
010           SUMA(6,5)=-1.0E20
011           RETURN
012           END

ND OF COMPILATION ******
```

APPENDIX D

SAMPLE OUTPUT

REPORT OF THE AUTOMATED WAREHOUSE AT TIME 96.0

NUMBER OF PALLETS IN THE SYSTEM = 272

NUMBER OF PALLETS IN THE SYSTEM-TYPE 1 53

NUMBER OF PALLETS IN THE SYSTEM-TYPE 2 100

NUMBER OF PALLETS IN THE SYSTEM-TYPE 3 16

NUMBER OF PALLETS IN THE SYSTEM-TYPE 4 33

NUMBER OF PALLETS IN THE SYSTEM-TYPE 5 1

NUMBER OF PALLETS IN THE SYSTEM-TYPE 6 21

NUMBER OF PALLETS IN THE SYSTEM-TYPE 7 18

NUMBER OF PALLETS IN THE SYSTEM-TYPE 8 30

NUMBER OF EMPTY PIGEON HOLES = 88

NUMBER OF ENTRIES IN THE RETRIEVAL FILE = 114

NUMBER OF ENTRIES IN THE BACK ORDER QUEUE = 6

NUMBER OF ENTRIES IN THE ARRIVAL QUEUE = 0

NUMBER OF ENTRIES IN THE OUTPUT QUEUE = 0

PIGEON HOLE UTILIZATION = 75.556

STAKER UTILIZATION = 31.560

GASP SUMMARY REPORT

SIMULATION PROJECT NO.**** BY RUKMAKAR RAU

DATE 2/ 8/ 1970 RUN NUMBER 1

PARAMETER NO.	1	0.6400	0.5440	0.7360	0.0320
PARAMETER NO.	2	0.3002	0.2552	0.3452	0.0150
PARAMETER NO.	3	0.2030	0.1712	0.2348	0.0106

GENERATED DATA

CODE	MEAN	STD.DEV.	MIN.	MAX.	OBS.
1	24.5816	21.7172	0.0008	95.9709	464
2	0.0050	0.0104	0.0	0.0532	470
3	0.0042	0.0111	0.0	0.0754	464
4	6.6765	4.8035	1.0000	17.0000	34
5	0.0324	0.0059	0.0189	0.0410	934
6	55.4541	14.9435	32.0109	95.9974	153

GENERATED FREQUENCY DISTRIBUTIONS

CODE	HISTOGRAMS													
1	31	38	32	27	29	33	26	28	35	20	31	11	17	6
	9	9	5	8	13	9	39							
2	459	5	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0							
3	0	13	11	5	4	1	0							
4	469	1	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0							

```
REPORT OF THE AUTOMATED WAREHOUSE AT TIME 100.0

   NUMBER OF PALLETS IN THE SYSTEM =      270
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  1       55
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  2      102
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  3       16
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  4       34
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  5        1
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  6       21
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  7       15
   NUMBER OF PALLETS IN THE SYSTEM-TYPE  8       26
   NUMBER OF EMPTY PIGEON HOLES =   90
   NUMBER OF ENTRIES IN THE RETRIEVAL FILE =  113
   NUMBER OF ENTRIES IN THE BACK ORDER QUEUE =     4
   NUMBER OF ENTRIES IN THE ARRIVAL QUEUE =    0
   NUMBER OF ENTRIES IN THE OUTPUT QUEUE =    0
   PIGEON HOLE UTILIZATION =  75.000
   STAKER UTILIZATICN =  31.707
```

GASP SUMMARY REPORT

SIMULATION PROJECT NO.**** BY RUKMAKAR RAU

DATE 2/ 8/ 1970 RUN NUMBER 1

PARAMETER NO.	1	0.6400	0.5440	C.7360	0.0320
PARAMETER NO.	2	0.3002	0.2552	0.3452	0.0150
PARAMETER NO.	3	0.2030	0.1712	0.2348	0.0106

GENERATED DATA

CODE	MEAN	STD.DEV.	MIN.	MAX.	OBS.
1	25.0842	22.7091	0.C008	99.0735	485
2	0.0052	0.0105	0.0	0.0532	489
3	0.0043	0.C111	0.C	0.0754	485
4	6.4000	4.4882	1.0000	17.0000	40
5	0.0326	0.0059	0.0189	0.0410	974
6	56.0731	16.5134	32.0109	99.0964	174

GENERATED FREQUENCY DISTRIBUTIONS

CODE HISTOGRAMS

1	35	40	32	27	31	33	26	28	35	23	32	11	19	8
	9	9	5	8	13	9	44							
2	480	5	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0							
3	0	15	15	5	4	1	0							
4	488	1	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0							

DIGITAL SIMULATION OF AN AUTOMATED WAREHOUSE

by

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University of Madras, India, 1967

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1970

The present trend in warehousing is the completely automated warehousing controlled by a central computer with random access files. With the systems approach becoming very popular, automation of warehouses have more or less become a necessity in several situations. The automated warehouse and it's functions - storage and order picking have been defined. The various aspects of the warehouse, the types, the economics and the need for an automated warehouse have been discussed as a part of the literature survey.

A model of a pigeonhole type, pallet load automated warehouse had been developed using GASP IIA, and simulated on an IBM 360/50 computer. Multiple items are produced two at a time, each set having different production times. The material is stored for a minimum length of time and taken out of the warehouse in accordance with a particular output probability distribution. Both the interarrival time of the pallets into the warehouse and the output demands are approximated by truncated normal distributions. The effects of the multi item production with varying production cycle times and storage times, on the stochastic nature of the storage process have been studied. The effects of varying the rate of throughput have also been determined.

The most important observation from this simulation is the importance of the initial stock to be stored in the warehouse before any output can be done. This preload, or the amount of initial stock to be kept on hand has a tremendous influence on the storage process. Since the warehouse operation is balanced, improper preloading is responsible for back orders, that is material not available at the required time. Fluctuations in the back orders causes the system to become unsteady. This is more prominent for higher rates of throughput, and the process tends to become cyclic as the magnitude of the variables increase.

The right amount of preload is necessary to have a steady system. The ratio of each item in the preload is important, and not the total preload. An equation has been formalized to calculate the amount of each material in the preload and it is found to be effective, judged on the basis of the number of back orders and the system steadiness.