DIGITAL SIMULATION OF AN ORDER PICKING SYSTEM IN AN AUTOMATIC WAREHOUSE

by

RAJ KUMAR DHINGRA

B. TECH (Honours), Indian Institute of Technology, Bombay, India, 1967

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Approved by:

L. E. Grosh

Major Professor

"Every time material is handled, something is added to its cost, nothing to its value", EDA.

"Machines should work. People should think", IBM.

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To my loving and respected parents.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER 1

INTRODUCTION

Business and industry are faced with ever-increasing pressures of becoming more efficient and economical and, at the same time, of improving products and quality of service. Automation has thus far proved to be the nonsubstitutable answer to these problems, thanks to its time, money, and labor-saving capabilities. The last, namely the labor-saving aspect ot it has a far-reaching significance in countries where manual labor is relatively costly. One such area that deserves close attention is the application of automatic control to the handling of materials - in particular, order picking and associated information in an automatic warehouse.

Automatic order picking is a relatively new field compared to the other fields of materials-handling. This is a fascinating part of automatic warehousing which in the last decade has attracted the greatest attention in automation. However, at present there is a very small number of warehouses in the U.S.A. and Europe which is making use of completely automatic order picking systems. But order picking has a very great potential of use in existing and new warehouses. It is one of the most rapidly developing sectors of automation, because of increasing labor costs and related labor problems. Use of electronic data processing equipment overcomes the limitations of human memory and this enhances his decision-making capacity.

One of the purposes of this thesis is to study and make a brief survey of literature on existing order picking systems. Literature in this field is not readily available except from few reports and articles published by some people who have worked on or have some experience of automatic warehousing. It was observed by the author that the application of simulation technique to this field has been more or less neglected. In this thesis, a model for automatic order picking has been designed and simulated on a digital computer.

The proposed automatic order picking system has been simulated on an IBM 360/50 computer at Kansas State University, using GASP IIA, a new version of GASP II [56]. The effects of different rates of orders, of stock replenishment and number of restocking clerks needed, and of other system parameters have been studied. The behaviour of product profile, the relative throughput of the volume item by item, over the whole range of items, is also investigated.

A literal definition of order picking is "filling of orders from a warehouse or a store." It simply means retrieving from a large quantity of goods those required for dispatch against a particular order. Order picking is the most heavy consumer of manhours among general warehousing operations and is an important area for possible savings in stores and warehouses.

The conventional method of picking items for an order would require the picker to move throughout the warehouse and pick the items for one order at a time. Many times the lists of items for an order may not be in an optimal sequence, i.e., they may be listed in a random fashion, which causes backtracking. It has been found that over half the floor personnel is generally employed as pickers, because of the labor required for picking. Various studies have shown that approximately 90% of the time [66] of the picker may be spent unproductively in walking from one location to another, only a very small amount of time is being employed for the productive work of picking items. A large number of orders may be picked together, but in many cases, this is nearly impossible for a human being because of his speed and memory limitations. If such a variety of items has to be picked for a large number of customers, the task of consolidating and marshaling these orders becomes laborious. Also, it has been observed that there is much labor involved in order picking and the labor required is more fluctuating than that for input stock placing.

ECONOMIES OF ORDER PICKING

At present, there is an intense interest in automatic order picking systems for warehouses. But the missing element in all this interest is an authoritative voice which will say "an automatic order picking system can be economical and profitable." Automatic order picking, controlled and directed by a computer, can provide a reasonably good answer to some of the problems discussed. Mechanized and (or) automatic order picking offers a wide range of advantages to the management. Some of them are:

a. savings in cost,

b. upgrading of labor,

c. accuracy of order filling,

d. first in, first out (FIFO) turnover of stock,

e. improved customer service by shortening the time between receipt of orders and shipment of goods,

f. higher space utilization,

g. efficient use of loading docks,

h. reduced damage to stock and pilferage of goods to a minimum,

i. better inventory control,

j. efficient handling of customer paperwork,

k. accurate scheduling of order pick-ups by trucking companies.

In general, the decision to automate must be based on cost/performance analysis in terms of long-range company plans. The following factors must be considered before a decision on automatic order picking can be made:

a. very high volume,

b. relatively small number of different items-a few product lines,

c. regular sizes with few variations in size or weight,

d. large number of orders to be procured with relatively a few units per order per item,

e. high wage rate.

Any particular system not conforming to the above conditions may call for a combination of an automatic picking and manual picking, in other words, a semi-automatic order picking system. In actual practice, the author observed that semi-automatic order picking systems are the ones which are most commonly employed. A major purpose of all warehousing operations is to increase the speed of order picking and reduce the cost of distribution. For this, efficient planning and the highest degree of financially justifiable mechanization and automation must be used.

The actual picking of the items depends on the product variety and the sorting and consolidation operations depend on the customer variety. The labor content of the store is directly related to the number of times the picker 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 labor content of the store. With a greater variety of goods, it becomes infeasible to have completely automatic order picking. If there are 2000 product lines, then for true order picking, 2000 sets of machines are needed. Some of the product lines may be slow moving and so the particular sets of machines may be underloaded and hence uneconomical, apart from the huge capital investment that is needed initially. For a larger number of product lines, computer-assisted manual order picking can be employed.

The National Joint Council of Materials Handling [50] has published a report on automatic warehousing. The council studied the existing automatic/semi-automatic warehouses and came up with the following suggestions:

> Automatic order picking is economical up to 100 or even 200 varieties of products. There have been some examples where automatic picking has been applied to 2,000 varieties of cartoned goods, although the weight of expert opinion would generally be against it. It appeared to be universally agreed that when one is considering order picking of 5,000 varieties or more, human hands are the best methods for the foreseeable future.

In looking at the economies [69], one should look first at the cost accounting. In warehousing, these break into building depreciation and operation; equipment depreciation, operation and maintenance, labor and supervision, and control systems. Systems capabilities, after it has been designed, are often not checked. One must see whether it is running as it was designed. Another objective should be to design in enough flexibility so that changes in ranges or sizes of product can be absorbed.

Most people [53] think that the investment in an automatic warehouse ought to be paid off in between three and five years after commissioning; but it is not easy to define terms of reference here, and all persons in a company often cannot agree on the complicated factors involved in such a concept. In making these types of preliminary calculations, it is important to bear in mind that it can take at least two to three years to get an automatic warehouse of any size and complexity into commission, including the time required for a feasibility study linked to the adjustment of a company's distribution strategy.

SIMULATION IN ORDER PICKING

Any materials-handling system should be designed and tested; in other words, it should be simulated, before it leaves the drafting board. simulation allows one to "see" the interactive effects of a system's various elements. With proper programming, the problems and bottlenecks can be projected before they occur. Discovered solutions save time and money. Most materials-handling systems, such as order picking, which have a repetitive definable nature, involve a sequence of process events. These same characters are desirable for constructing any discrete event simulation model.

Simulation can be defined [51] as a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behaviour of a business or an operating system over extended periods of real time. By the use of digital computers, management can simulate the behaviour of entire business and operating system in order to evaluate the overall performance under the influence of interacting factors. Employed in this way, simulation can be an important factor in the managerial decision process, since it can provide a method for testing and evaluating alternative plans long before management must commit itself to action.

Simulation represents the real world in terms of a mathematical model which can be manipulated by a digital computer. The model would represent the actual situation and would take into account structural relationships that would be affected by any proposed change. The accuracy of the model would determine the accuracy of the results of the simulation.

COMPUTERS IN ORDER PICKING

There are two sides to order picking which can be computerized - documents and hardware. One can have a totally manual order pick, but have all documents prepared by computer in the location sequence. Conversely, one can have a mechanized order selection system which either uses punched cards or manually prepared documents. In sorting out advantages and evaluating new systems, one should separate order picking hardware from order picking documents system.

By computerization of documents, it is meant that all the paper work and accounting related to order picking may be done by the computer. Examples of this type of duties carried out by the computer are: inventory control, printing replenishing information, billing, shipping invoices, customers' paper work and preparation of picking lists arranged in the store sequence. Computerized documentation can also help to separate the items which are picked as individual cartons, less than pallet loads or full pallet loads. The full pallet loads need not go through the picking machines and can travel directly to shipping stations to save unnecessary handling.

Most order picking systems [37] are basically the same but they must take into account the environment in which they are to work. Orders may be picked on to carts or pallets, or it may be a fluid type of operation, a marshalling and consolidating system with a manual or mechanized sorting. All these situations can be handled on a computer. One can have a real-time on line system in which the computer decides and directly interacts with the system environment. The computer can simultaneously monitor [46] many hundreds of limit switches and material control relays. Also, at the same time, it takes care of documents required for materials flow and control. Sensors on the handling equipment monitor its operation and feed back to the computer the status of items in storage and the movement of goods which takes place. So a real-time on line computer can control all facets of order picking, right from the receipt of an order till it is shipped out to the customer, including order picking preplanning.

When an order [63] enters the computer system, it can be simultaneously entered into inventory and posted to receivable accounts. This automatically includes credit clearance procedures and inventory preposting action which prevents warehouse refusals - the attempt to pick items that are not in stock. Elimination of warehouse refusals significantly reduces warehouse labor.

There are drawbacks to switching to computers, too. One needs back-up to its system. Say, a warehouse is committed to five or six days of shipment each week at eight hours a day. If the computer goes down, there must be a back-up system that can be relied on to produce documents and to control physical materials-handling. One cannot maintain a manual and a computer control system at the same time or a standby computer. Once the decision to go on computer is taken, one is committed to working only that way.

The decision to use computers should not be held sacred. The computer will not perform miracles. For a system to work well on a computer, it must also work well without one. The computer does only one thing - it speeds up the process that one would ordinarily do by hand, and it does it infallibly. Another point, it is always best to have the company's own computer personnel write the programs because they must understand the whole system to do so. Later on, if changes are to be made, they are in a good position to see how the changes will affect the total system and understand what is possible or impossible.

CHAPTER 2

LITERATURE SURVEY

This chapter reviews some of the literature available on automatic and semi-automatic order picking systems. Unfortunately, consideration of space and time permits only a brief sketch. However, references have been cited wherever a more detailed explanation was felt warranted.

Not very many reports or articles have been published on simulation of semi-automatic or automatic order picking systems. Sundstrom [65] has developed a computer model of a conveyor simulation. The model has been treated in detail along with a step-by-step analysis. The simulation language used was IBM's General Purpose Systems Simulator, a language specifically written for discrete event simulation. Both new and current conveyor designs were evaluated.

COLGATE PALMOLIVE'S LATEST PLANT AT JERSEY CITY:

Lefer [30] has described Colgate Palmolive's latest toilet articles warehouse at Jersey City, N. J., equipped with a design capacity of 18,000 cases a shift. They have already installed two such plants, though not as sophisticated as the latest one, one each at Jeffersonville [34] and Kansas City [59]. They were all designed to pay off in less than five years. Each new system was an improvement over the old one in design and controls, as well as in terms of capacity.

The plant handles a product mix of approximately 350 items, in a wide variety of case sizes and weights. Ninety fast movers which constitute from 75 to 90% of the case movement are dispensed from automatic lanes with the help of punched cards, whereas the remaining 260 items which account for 10 to 20% of the activity are picked manually from live storage racks. Sales quantities of these items are not high enough to justify the cost of automatic lanes for these items.

The order data first goes to a manual picker who handpicks items which make up a train behind the lead tote box. Then the order data travels to a console operator, who checks the truck dock activity and places the cards in a console reader. This sends the lead tote box of the selected order and its train, into the system. As the train passes the front of automatic racks, cartons drop from the three-lane levels on three high speed belts, building the train into a complete order. The order then merges into a single line before it reaches the address-stenciling station and then continues, automatically routed by photo-electric cell controls to one of the five pairs of assigned truck docks. Pallet load quantities normally bypass the conveyor system and go directly to the dock. Color coding is used to identify orders.

The Monorobot XI controls the whole order picking operation on IBM 024, IBM 403 and IBM 519 are used to read, print and punch cards respectively for each item. Versatility of the system is shown by the fact that the automatic lanes are designed to be flexible enough to handle packages ranging from 8 to 60 pounds, with various combinations of lengths, widths and heights. A set of error routines is also built into the system.

WOOLWORTH CHICAGO - WAREHOUSE AND DISTRIBUTION CENTER

Schwind [61] has given details for a Chicago warehouse and distribution center. Wright supervised the design and installation of an up-to-date, first class automated full case order selection system, which he claims to be a very reliable mechanical system with electric and electronic control. Basically, the warehouse buys the merchandise and resells to the stores. The distribution is completely customer-oriented. Stores reorder from the warehouse either by sending a hand-written order which is converted to punched cards and fed into the computer or by sending in "seed" tickets and punched cards from items they have sold.

Woolworth has IBM 360's at each of their warehouses to handle all programs for order paperwork and inventory control. In addition, the computer at the Chicago distribution center prepares the punched tape which directs the entire order selection system. The computer keeps track of each item sold every day by size and quantity. The complete interface between the computer and order selection system is a single sheet invoice, labels, and punched tape. The punched tape with as many single sheets of invoice as it takes to list all the ordered items, and a shipping label for each item, is all the paperwork needed to get the order through order selection into shipping.

The entire product line is divided into two categories - automatic selected items and manually selected items. Both of them are picked from different areas of the warehouse. The invoice sheet with hand select items indicated by a code, plus the correct number of labels for these items, is given to a stock-picker a day ahead of the machine selected order. "Ordermatic," the automatic order selection machine, picks the bulk of the order and both sections of the order travel to a merge belt. The cartons are checked against the invoice as they pass through the control area. The computer is programmed to print out a nine-digit message at the control console if there was a stock shortage in a lane or hang-up which prevented a carton from dropping. The computer knows if it is available so a short order stock chaser would be sent to determine the trouble and bring a carton out of the order selection system.

The computer is also programmed to keep inventory records and print out a list of the lanes or chutes that the stockmen must replenish. This list also gives the order in which the lanes are to be replenished so that there won't be any mistakes in the order filling sequence. The beauty of the system lies in the fact that almost any degree of automatic control is available at any stage of storage. The computer even does preplanning for the next day and the inventory status of any item can be obtained on command. Schwind [61] described the system in detail, but no mention was made whether simulation techniques were used or not.

S & H GREEN STAMP COMPUTER CONTROLLED DISTRIBUTION CENTER

Cellucci [7] has written about a highly-mechanized S & H Green Stamp distribution center (9,000,000 cu. ft.) located in Hillside, Illinois. The system, with the help of a computer and highly sophisticated controls, picks items with wide variation in sizes and shapes. The warehouse handles in a single system more than 2,000 items from 700 suppliers ranging from small transistor radios to sporting goods to household furniture. Operations research techniques, such as queuing theory and computer simulation, were used to design the system which is semi-automatic in nature. Special computer simulation of the entire system enabled them to test and project through-puts and determine the best patterns for running the orders through the system much before the actual system was constructed.

The results of the simulation also recommended patterns which program both workers and equipment for maximum speed, productivity and efficiency.

The basic scheme of the system consists of four order picking conveyor lines merging into an interchange that automatically redistributes to three pairs of truck-dock lines. The computer divides each order into quadrants or sections to program order pickers activities on each of the four lines. Large and small orders (large and small quadrants) are fed into the system in proper sequence to balance order picking time equally among the four lines. Processing of an order calls upon the system to perform four basic functions: order picking, accummulation, interchange, and truck dock accummulation. The accumulation of quadrants into queues or trains on conveyors provides a buffer between supply and demand that helps average out variables in the system and its throughput. Computer/ controls release trains with precise timing to avoid collisions, blocking of other lines or trains too long for available trackage. Segments of individual orders, with the help of various positions of retro-reflective tape on the side of the tote boxes, travel to their assigned truck docks together, without mixing in segments of another order. Only four order pickers, with the help of this system, are able to ship over 16,000 cartons in each 7.5 hour work shift through six loading docks. The use of sophisticated computer programming and control devices permits this clean configuration and system.

The highlight of this system is a great amount of expandability which has been built in. It is essential in such a system, because it requires a fantastic amount of initial investment. In this system, there will be no problem in handling three times the merchandise they handle presently, without any physical alteration.

COMPUTER CONTROLLED WAREHOUSE FOR BOOTS PURE DRUG CO., U.K.

This firm has constructed a semi-automatic warehouse which has full potentialities of automatic data processing for order picking and marshalling and a satisfactory compromise between space economy and systems flexibility [49]. The most interesting part of this system uses a "gather-dispense" principle throughout the warehouse. According to this principle, the stock can be gathered in accordance with order summaries and subsequently sorted into individual branch orders. This system makes use of an IBM 260/40 computer to process warehouse documents. A Philips PR 8000 computer provides the real-time function for automatic control in the system. Boots developed some new techniques for order picking, such as computer controlled "gathering towers" and picking machines named "penelveyors". These help them to pick items from 3,000 lines of merchandise for a wide range of order sizes to 1300 Boots branches dispersed throughout the U. K. The use of computers to process warehouse documents has made a significant contribution to the speed, efficiency and economy of effort in all sections of the warehouse, and at all stages of order picking and marshalling.

A few other examples of sophisticated computer controlled systems are Sara Lee, Johnson & Johnson, and Union Carbide complexes. Kitchens of Sara Lee, Deerfield, Illinois [9] which combine process control and warehousing functions into one system. This is one of the biggest computerized food manufacturers today. Johnson & Johnson's shipping center in New Brunswick, N. J. [58] is a major manufacturer of medical and surgical supplies storing about 400 different product lines. A well-planned and designed computer controlled distribution warehouse at Union Carbide's plant is located at S. Charleston, W. Va. [9].

It has been observed in many cases, that either a large number of product lines and/or a wide variation in product sizes and shapes do not warrant the use of automatic order selection systems. In such cases, it is advantageous to use semi-automatic order picking systems - such as a computer assisted order picking system, use of a computer controlled vehicle and many other kinds of mechanized systems. Some good examples of semi-automatic systems are Dennison Manufacturing Company, Stop & Shop, Consolidated Sales, Penguin Books, and West Bend Company warehouses. Dennison Manufacturing Company's quarter million square foot warehouse at Holliston, Mass. [14] which fills orders in full case quantities and broken case quantities out of a stock of fast moving and slow moving items. Stop & Shop's grocery warehouse, in North Haven, Connecticut [12] which with the help of a conveyor system fills orders in New York-New Jersey region. Consolidated Sales' warehouse at Indianapolis, Indiana [18] making use of order picking trucks, selects orders out of 4,800 item lines. Penguin Book's distribution center at Harmondsworth, Middlesex, England [15] is picking and shipping small and large orders of about 100,000 books a day. West Bend Company's warehouse in Wisconsin [29] is serving a multi-channel market requirements.

CHAPTER 3

ORDER PICKING TECHNIQUES

One of the main functions of an automatic warehouse is order picking. The central group warehouses are focal points in the distribution network. Geared to high turnover and small profit margins of multiple shops and supermarkets, the grocery or mixed goods warehouse is a regrouping center. In the warehouse the bulk is broken, goods are priced and picked for particular orders and sent quickly on their way. In many warehouses, especially those dealing with retail sales and having a large product mix, order picking takes a high percentage of the total warehouse operations. The outbound shipments are in much smaller lots and with a greater variety of items in each order than the incoming shipments. Also, stock input can easily be spread evenly to suit the labor available, whereas order picking must often be quick to meet customer demand and to meet the transportation schedule.

Over the past few years there have been many order picking systems devised to help ship the orders with minimum delay. This chapter describes principles behind these systems. A few innovations in order picking are also discussed. An order picking method linked with a conveyor technique in one piece of equipment is one method to improve customer service. This involves the concept of continuous order picking. Most of the order picking installations follow generally the same principles. The difference is usually in the complex sorting and diverting mechanisms, which are usually tailormade for each installation. A wide range of methods can be employed for manual and automatic order picking, each involving advantages and disadvantages.

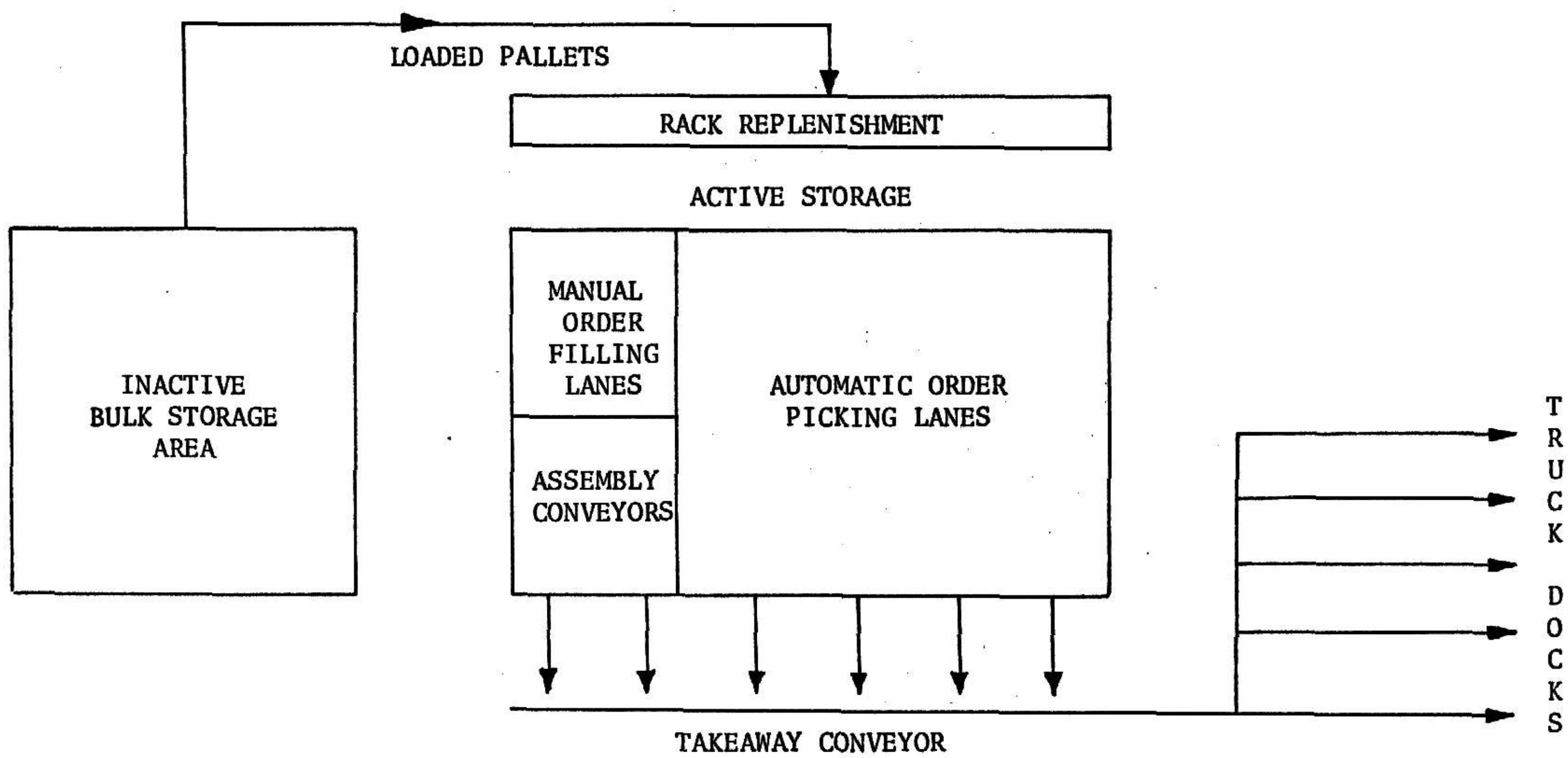

Figure 1. Flow diagram of a typical order picking system.

Quoting Dr. David Foster [24], "The question of order picking of high variety goods raises a fascinating technical and economic problem. In the first place, we can be pretty sure from the evidence that in very high variety warehouses it will be a pair of human hands which extract the goods and we can also be pretty sure that those goods will be sitting passively on shelves since the majority will be slow movers. Thus one has a problem to solve. Do you take the man to the goods or do you take the goods to the man?" The goods can be brought to the man by rotating the stock in front of the man. If the man is provided with a picking list arranged in the stores sequence, one rotation of the goods is sufficient to pick the whole of that batch. Similarly, the man could travel to the goods by means of some mechanical contrivance or by walking. If he is provided with a picking list arranged in the stores route order. Again one scan of the shelves will be sufficient to enable him to complete his picking. Thus either way one cycle of scan is enough. It is seen that in the first case the whole store moved whereas in the second case, only the man moved. On the average, the weight of the stores and the weight of the man should be vastly in favor of moving the man.

A simplified flow diagram [62] of a typical case goods order picking system is shown in Figure 1. This combines a manual and automatic order picking. Fork trucks, stackers or retrievers select pallet loads of cases from inactive bulk storage, place them on the replenishment platforms. Automatic lanes and manual racks are replenished from this platform. Rack replenishment usually is manual, but it can be made automatic with de-palletizers and diverting conveyors to feed the rear of the picking lanes. The completed orders travel automatically from a takeaway conveyor to a delivery conveyor to its loading docks.

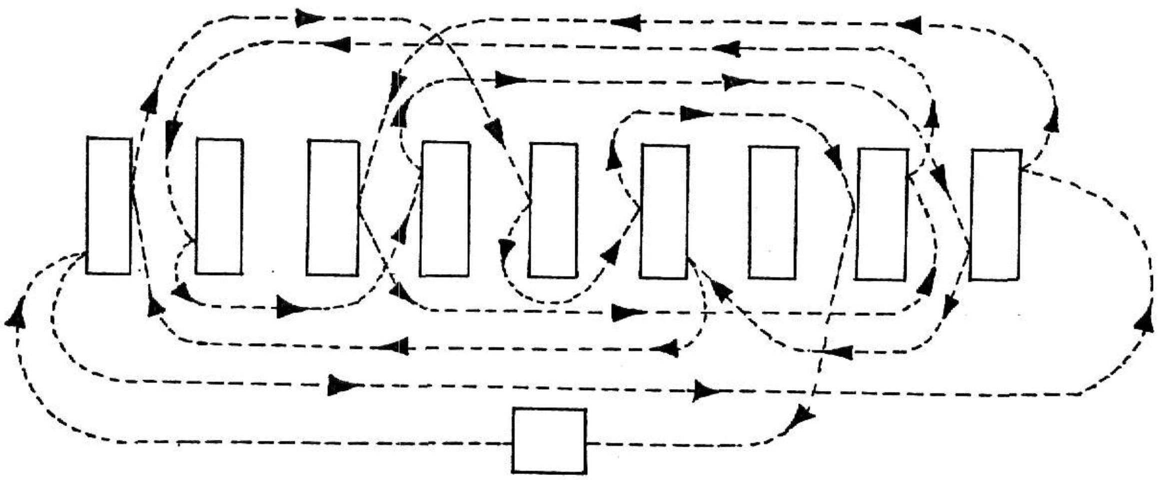

Figure 2a. An example of random picking.

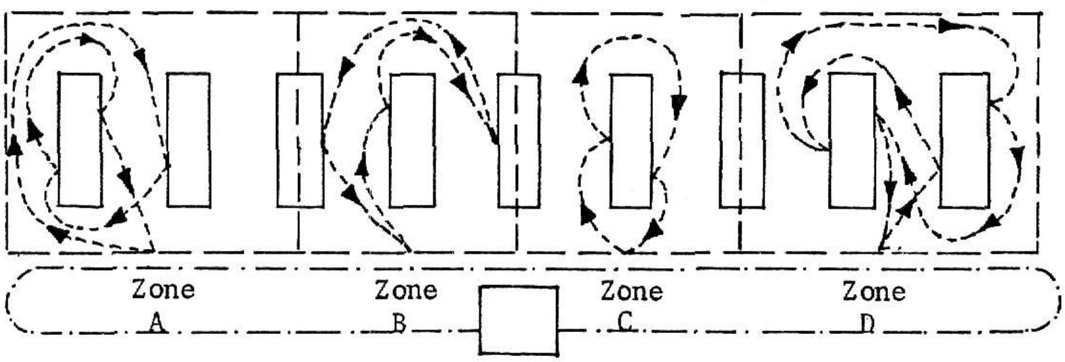

Figure 2b. Order picking by random selection in zones with sequential accumulation.

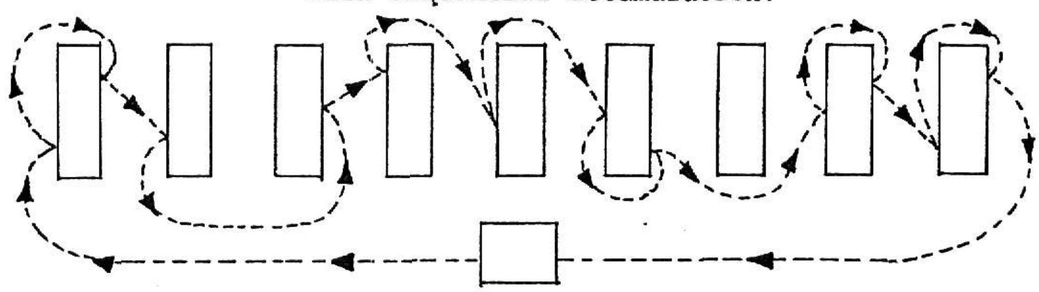

Figure 2c. An example of sequential picking.

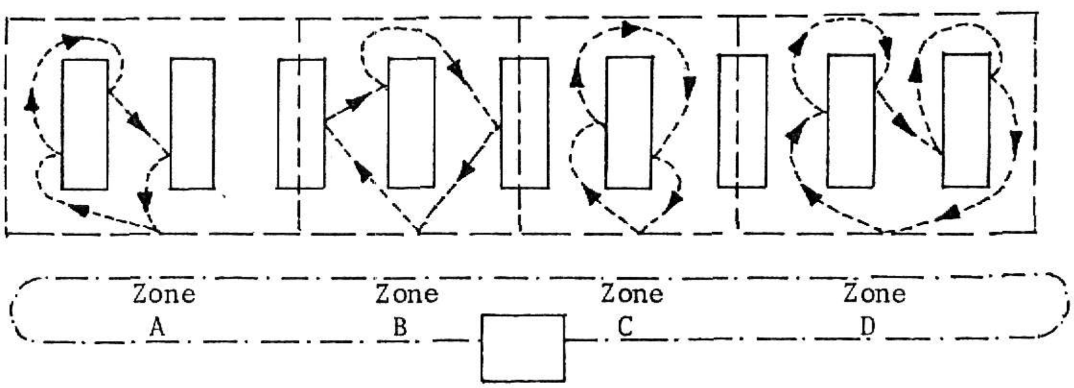

Figure 2d. Sequential accumulation with sequential order picking.

The storage and retrieval of goods can be done in one of the two ways: One is to store the goods in fixed locations and in the second, goods are not placed in fixed locations. On arrival, these goods are placed into the first empty location. This is commonly known as random storage. The warehouses which are semi-automatic in nature and need pickers to locate the stored items can only work with the fixed location system. On the other hand, warehouses using computers to direct and control order picking may have random storage. The use of random storage results in a decrease in the size of the stores building. Because the random nature of arrivals and dispatches leads to an extremely low probability that the stores will be required to hold the maximum quantity of every commodity at the same time.

In general, order picking can be classified into two broad groups, stationary rack warehouses and rotating rack warehouses. In the case of manual picking, from stationary racks there are two possibilities, either the order picker goes around the racks or he uses some kind of mechanical contrivance to carry him.

INDIVIDUAL ORDER PICKING

Stationary rack warehouses are further subdivided into six classes.

1. ORDER PICKING BY RANDOM SELECTION

The items on an order are taken as they come. There can be considerable amount of backtracking as an order is accumulated. Figure 2a is an example of random picking. Because of backtracking, the productivity of the pickers may be low but there are offsetting advantages. There is a clear responsibility for any order. Since one person accumulates it, there are no marshalling problems. A great deal of picking falls into this category. In small stores and where there are few items per order, the productivity loss may not be serious.

2. ORDER PICKING BY RANDOM SELECTION IN ZONES WITH SEQUENTIAL ACCUMULATION

In this technique, the stores are arranged into zones. This reduces the amount of movement involved in each selection. Each zone picks in sequence and adds its contribution to the order [7]. Figure 2b shows an example of such a type of picking.

There are some problems with these systems. The first is that of labor balance. Before using zone picking, orders have to be analyzed very carefully. Also, zones should be designed to ensure that the work loads in each zone are in balance. The balance will seldom be perfect. There may be some idle time or a problem of close day-to-day management involving the constant redeployment of labor. As a consequence of labor balancing problem, an order may have to wait at each zone before it can be handled. The division into zones has to be justified by the economies involved.

3. SEQUENTIAL ORDER PICKING

In this technique of order picking, the picking lists are arranged in the store sequence. This saves a lot of time wasted in backtracking. The use of item reference numbers coded and items placed in ascending or descending order along the picking path can be valuable. In Figure 2c, an example of sequential picking is shown.

With this method, there is a difficulty of sequencing items in a list of an order. This is a documentation problem. One alternative is to carry out an additional clerical operation before issuing the orders for picking. This may lengthen the overall picking cycle time. Another possibility is to use the same input data for items sequencing as used for billing and inventory records. In this way data processing equipment can be employed for sequencing of the items on an order without putting any extra burden on the system.

4. SEQUENTIAL ACCUMULATION WITH SEQUENTIAL ORDER PICKING

This is a logical extension of techniques 2 and 3. In this technique, the warehouse is divided into zones and at the same time picking lists are arranged in the store sequence. This again introduces the problems of labor balance and possible delays of the zones method. This system is shown in Figure 2d. All orders go through the zones in sequence regardless of whether there is any picking to be done in the zone. There are methods which can be employed to reduce the long cycle times caused by delays.

a. Bypassing of Zones

Both congestion and cycle time for an order can be reduced by arranging the system in such a way that any zone can be bypassed. If the picking is finished in zone 1, the order can be sent to dispatch without stopping at the other zones. On the other hand, if the picking of an order does not need any item from the first two zones, the picking can be started from the third zone.

b. Sequential Accumulation and Re-scheduling Picking Sequence

Routine picking through a series of zones may take a long time, particularly if there is a holdup due to an unbalance workload in one zone. A method of obtaining priority in the queues can reduce the cycle time on particular orders and raise efficiency to some special customers. Care should be taken that there are no more than two classes of priority, otherwise the situation may become chaotic and may go out of control.

5. SIMULTANEOUS ACCUMULATION ORDER PICKING

Here picking takes place simultaneously in each zone instead of sequentially. This eliminates likely delays. But an additional problem of marshalling and consolidating of orders is created. This technique is used [29] on large orders where more than one vehicle or container tends to be filled for an order or when the overall cycle time is important.

6. AUTOMATIC ORDER PICKING CONTROLLED AND DIRECTED BY A COMPUTER

Automatic order picking systems are the newest and fastest. Input to these systems is direct entry by a typewriter, punched cards or a tape fed into a reader. Computer controls move the handling equipment from location to location and elevate to the correct picking level for automatic selection and removal of items. In some cases, articles in cartons and packages can be made to fall either by a solenoid operated release mechanism or suction cups onto the conveyor. Belt and roller conveyors move the items from

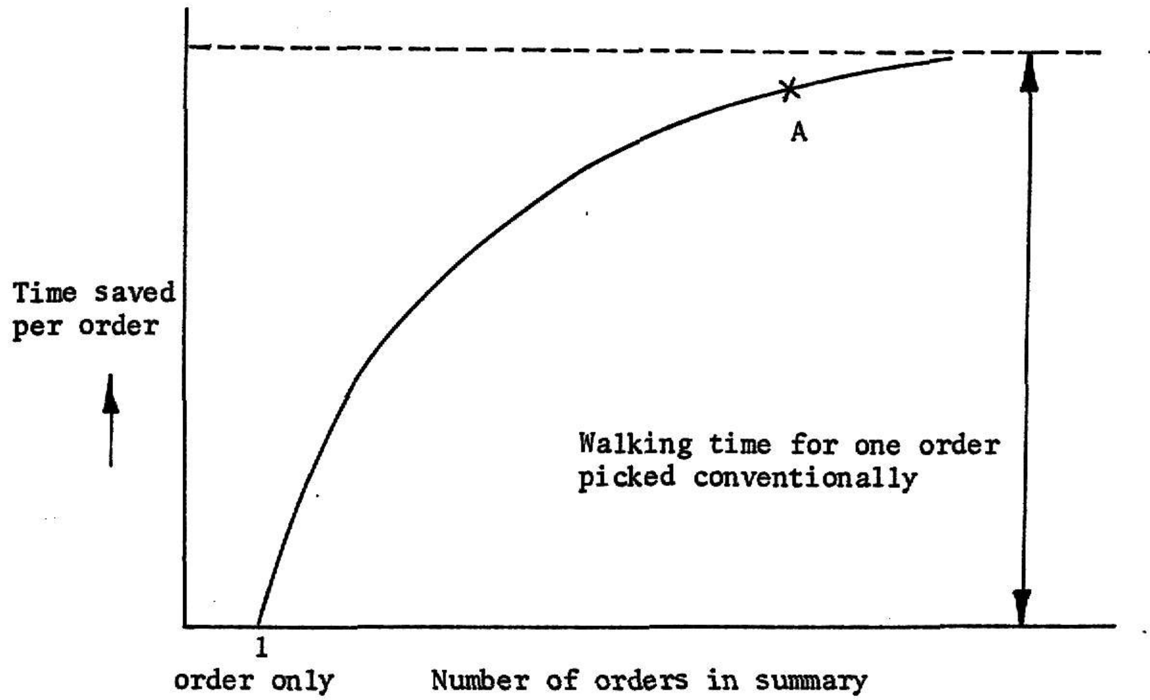

Figure 3a. Time saved per order using automatic sort method.

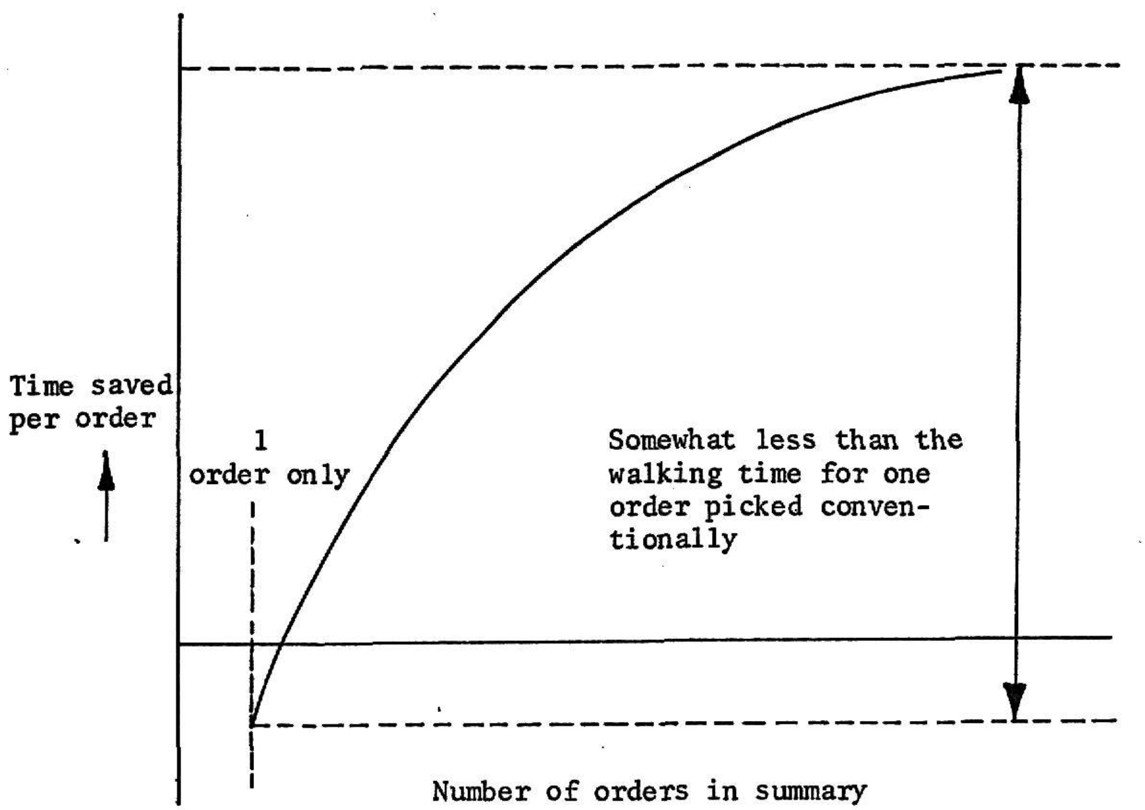

Figure 3b. Time saved per order using mobile rack method.

(These two graphs have been reproduced from "Warehouses brought into line," Trickett and Gale, Mechanical Handling, October, 1965.)

storage machines, racks or bins to the accumulating and shipping points for checking out, labeling and load assembly. If no stock exists at a location, it is possible to introduce an override control in which the computer either backorders it or prints it out as a lost sale. In some cases, a real-time on line computer with proper controls can do the entire picking.

MULTIPLE ORDER PICKING

Apart from the author's own experience, analyses of certain operations [66], [49] have shown that a vast increase in efficiency would be possible if more than one order is picked together. This makes use of the 'gather-dispense' principle and is known as 'block picking.' With this technique, the labor content of each selection is the lowest. But this may be offset by the additional handling necessary to separate the bulk quantities into their individual orders. This technique exploits the facilities of automatic data processing. The paper work is done in such a way that stock can be gathered in accordance with order summaries of a batch of orders. Subsequently, these summary goods are sorted into individual orders. Basically, there are three methods [66] of converting the goods from summary to individual order quantities.

1. AUTOMATIC SORT

The summary goods, once picked, are conveyed to a sorting area. There these are automatically sorted by a mechanical system under the control of a computer. Figure 3a shows a curve of an analysis of possible time savings per order. Time savings vary from zero to an obvious maximum value. This maximum value is the amount of time spent in walking when one order under conventional method is picked. Figure 3a also shows a point (point A) beyond which there is no significant savings to be gained by increasing the number of orders in one summary.

2. MOBILE SUB-RACK

In this method, the summary quantities are placed in a small mobile rack. When the summary has been completed, the picker picks for the individual orders from the sub-rack. This is particularly useful when the volume of goods stored in the racks is much greater than the volume that would be collected for any reasonable summary. Analysis of possible time savings per order using this method results in the curve shown in Figure 3b. This curve is of the same shape as that of the automatic sort. It can be seen that with the automatic sort method, gains may be expected no matter how few orders are summarized. But in this method, there is a minimum summary below which there will be a net loss of time per order.

3. MOBILE TROLLEY

In this method, the picker takes with him a trolley which holds containers for a large number of individual orders. After he has picked the summary quantity for each items of the goods, he immediately sorts it into the individual order containers according to the information given as an extension of the summary sheet. This method is most suitable where both the goods to be picked and the total summary quantities are physically small. The curve of the time saved for this method is of similar shape to that shown for the automatic sort method.

STATIONARY RACKS--THE PICKER USES SOME KIND OF MECHANICAL CONTRIVANCE

This technique has been operating for some time in John Drexel Group Grocery Warehouse in Austria [48]. This uses a computer controlled order picking vehicle. Two-way communication between the vehicle and the computer allows full computer control of the vehicle. The vehicle goes to the proper sequence of locations in the warehouse under computer control without any need for action on the part of the picker. This saves the time otherwise required for operator control and increases the positioning accuracy. With both hands free, the picker can wrap, tag or pack items while he is moving.

The quantities to be picked at the location can be shown on a visual display panel. This reduces the picking time by eliminating the need to refer to the order. When the order picker completes one set of instructions satisfactorily, he can signal the computer by pressing a 'task complete' button. The computer then moves the vehicle to a new location. In case an error or discrepency exists, the picker can signal the computer. The vehicle pulls a wheeled rack behind it. This rack has numbered bins or shelves for receiving items for several different orders. The computer program assigns a particular batch of orders to a vehicle, pre-plans the vehicle route through the warehouse and controls the vehicle as it moves. In assigning orders to a vehicle, the orders are sorted into an optimal sequence and grouped together to make a vehicle load.

Whatever the order picking method, the sequence in which items are presented to the picker or machine should be the same as that in which they are located in the warehouse. For a large number of product lines, the computer can be used to help normal manual picking. The main duty of the computer is to make picking lists from different orders. Each picking list is sequenced according to the product lines and their location in the warehouse. This enables easier picking. That is, if the picker starts from one end of the aisle, picking the items according to the list, he will reach the end of both the list and aisle without having to retrace his steps for any item. Used this way, sequencing of picking lists saves about 30 to 50% of the picking labor otherwise needed.

MOVING STORES (ROTATING RACKS) WAREHOUSES

A new approach to manual order picking is to present pallets to order pickers on a device, fed by a stacker crane, under computer control. This new handling device has been patented under the name 'carousels' [53]. Basically, the carousel consists of two horizontal conveyors mounted one above the other with an elevator/lowerator at the ends to form a closed loop [16]. Pallets on one conveyor move in the opposite direction to those on the other, descending from the upper to the lower level at one end and rising from the lower to the upper level at the other. The idea is to present pallets sequentially to the pickers working independently on both sides. This latest approach to order picking tends to balance the cost of space against the cost of movement. Some of the outstanding advantages of this system are: fast picking, flexible picking, high selectivity, high capacity and accurate picking. The first of such a system is under construction for a Co-operative Wholesale Society's Grocery warehouse at Birtley, London. Rotating rack systems employing a rotating rack conveyor of the type used in cleaning establishments to handle laundry bundles can also be used to get items automatically to the picker [27], [17].

In many distribution warehouses, various types of stocks must be accommodated. The movement of stock may range from very slow to very fast. For optimum efficiency, each type of stock must be considered separately and treated on its own merits. These different types are to be integrated into the flow of the whole warehousing system. One kind of handling equipment may be suitable for fast moving items. Some other kind of handling equipment may be employed to move the slow moving items. Conveyors, release mechanisms, special picking machines, etc. may be used to handle fast moving items. On the other hand, slow moving items may be picked manually.

CHAPTER 4

PROPOSED AUTOMATIC ORDER PICKING SYSTEM

The main purpose of this thesis is to design and simulate an automatic order picking system. A local distribution center, which was contemplating the construction of an automatic order picking system for individually packed items of uniform size, was approached. The author had the opportunity of visiting its warehouse on several occasions. Its present manual order picking system was thoroughly studied. Many details were not available which had to be assumed. Some other assumptions were also made to simpify the simulation model. The skeleton of the problem is given below.

PRESENT SYSTEM

Presently, a girl receives an order from her supervisor. She fills it by walking around the entire picking area. The various items in the orders received are obviously not in the sequence of the warehouse. The girl has to retrace her steps several times to fill one order. The items are recognized by a set of code numbers. She has to read each set of code numbers from the order form, then walk to the picking racks and find the same number on the bin containing the item. This is a very tiring, boring and time-consuming job. She has to do it continuously eight hours a day. If a particular item is not found in its bin, she reports to her supervisor. At this rate, the output per girl is as low 8 to 10 orders per hour. There is every chance of committing an error, so they need to verify each item on the order before shipping it.

DISTRIBUTION CENTER'S WAREHOUSE

This distribution center is a big organization distributing its products throughout the nation and to some places abroad. The distribution center maintains its catalogues at department stores and supermarkets. All ordering and shipping is done by mail. Basically, its warehouse performs the following four functions:

1. Branch supply including the local Manhattan branch warehouse,
2. New issues every month,
3. New customers,
4. Reorder by the customers.

To reduce the load of distribution to the various branch warehouses, it is decided to construct only three central distribution centers. The proposed order picking system is designed for the local distribution center.

Problems like labor productivity, rising labor costs, competition with other similar companies, reduction of handling and distribution costs, and reduction of storage area forced the management to think of some better means of order picking. It is also desired to raise the efficiency of the help, to improve customer service, and to have better inventory control. Automation of the order picking operation is one step in this direction. The distribution center can look forward to the higher savings and increased profits with the help of better material handling methods and reduced lost sales. The proposed system should be capable of giving inventory status and sales reports of any item in the warehouse on command.

PROBLEM STATEMENT

The system is designed for the following uniform sized items:

Length:	8.5 inch
Breadth:	6.25 inch
Thickness:	Varying from 0.25 inch to 0.75 inch

ASSUMPTIONS ABOUT THE SYSTEM

1. The warehouse stores 5,000 different items at a time
2. The warehouse is required to fill 3,000 orders per day.
3. The designed capacity of the order picking machine is 1200 orders per hour.
4. An order may call from 1 item to 30 items. The demand is assumed to be distributed according to the Poisson distribution with a mean of 15 units.
5. Any order does not call for more than one item of one particular kind.
6. Based on activity rates and throughputs, the entire range of products mix is classified into three categories:
    a. Fast moving items
    b. Slow moving items
    c. Occasional demand items.

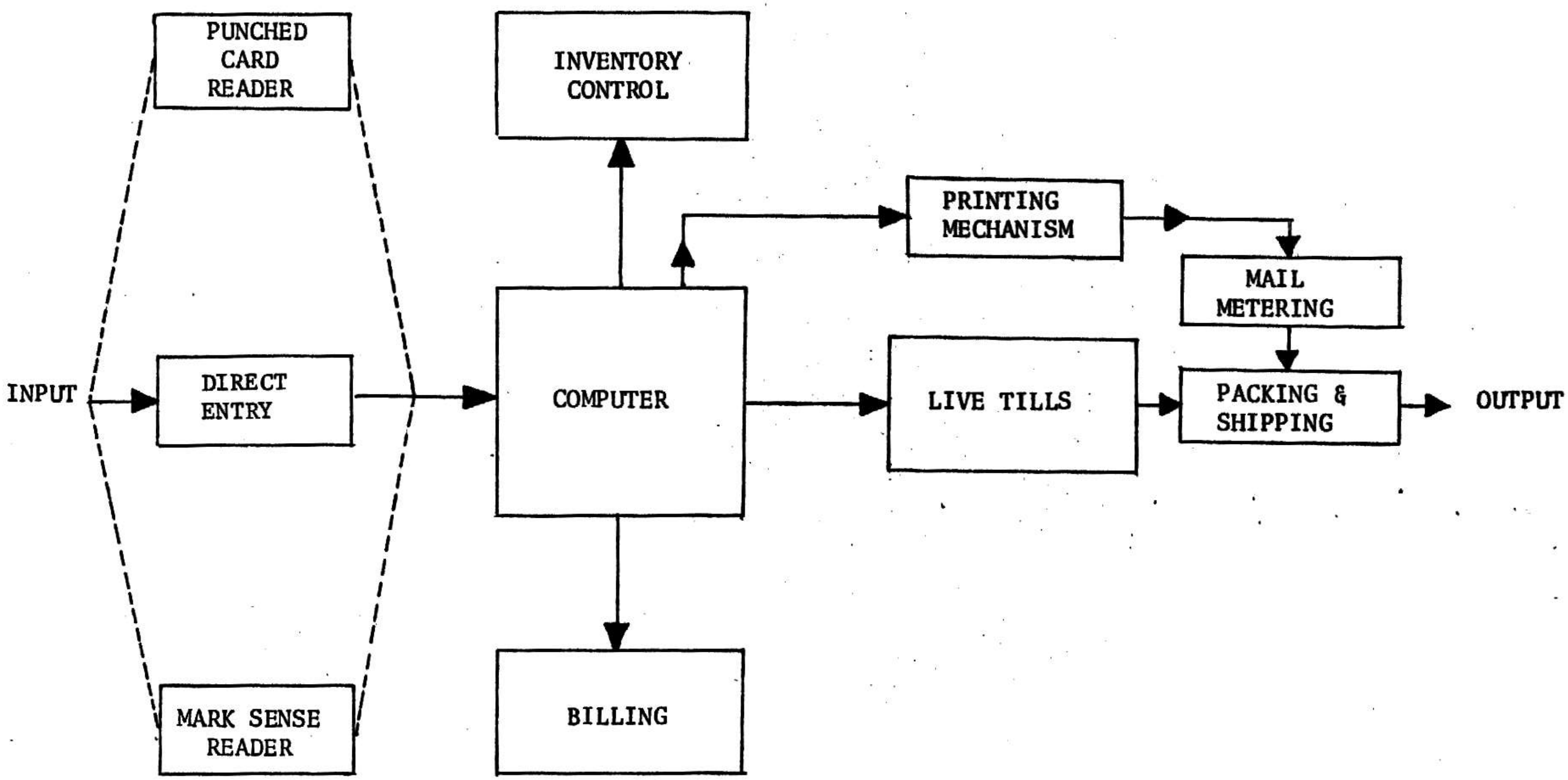

Figure 4. A block diagram showing various duties performed by the computerized distribution center.

The distribution of these three categories is assumed to be eighty percent, sixteen percent, and four percent, respectively. In addition, the slow moving items are supposed to have a sales frequency of 8 times that of occasional demand items and the same ratio holds good between fast moving and slow moving items.

7. The thickness of items is assumed to have only three values. This is done to simplify the simulation model and to reduce computer time. But the model can be easily extended to include all other sizes as well. Eighty-five percent of the items are assumed to be 0.25 inch thick, ten percent 0.50 thick, and five percent 0.75 inch thick.

This computerized warehouse may be asked to do many duties. The following five are important:

1. Control an automatic order picking machine,
2. Automatic inventory control,
3. Automatic billing,
4. Automatic stamping of packages,
5. Automatic packaging and shipping.

In this thesis, only the first duty, namely the design and simulation of an order picking machine, is considered in detail. However, others may have some passing references. Figure 4 shows a block diagram containing all these functions.

INPUT TO THE SYSTEM

Dealer's orders are considered as input to this system. They may reorder in one of the following three ways:

1. In the first method, the dealers are required to send back pre-punched cards accompanying each item to the warehouse. These pre-punched cards are known as "seed tickets." Each of these tickets contains an item's code number represented by various punched holes. These tickets form the basis of automatic re-ordering by the dealers. When a sale is made, the dealer removes the seed ticket from the item's envelope, adding it to his collections. When reordering, he simply mails these tickets to the distribution center. There these tickets are fed into a card reader. This converts them into order information, showing individual items. The same information signals the release mechanisms which releases this item from the live racks.

2. In the second system, the dealers write items for an order on an order form and mail it to the distribution center. The operator at the distribution center enters these items on the order form into the central computer via a direct entry terminal.

3. In the last system, the dealers use a special kind of pencil and mark the items they need to reorder on a specially prepared order form as given to them by the distribution center. On receiving these forms from the dealers, the warehouse operator loads them on a mark sense reader or an optical reader. Thus the information is conveyed to the system.

Each item in the warehouse is assigned a code number of six digits - four for the item number and two for its size. These six digits are needed

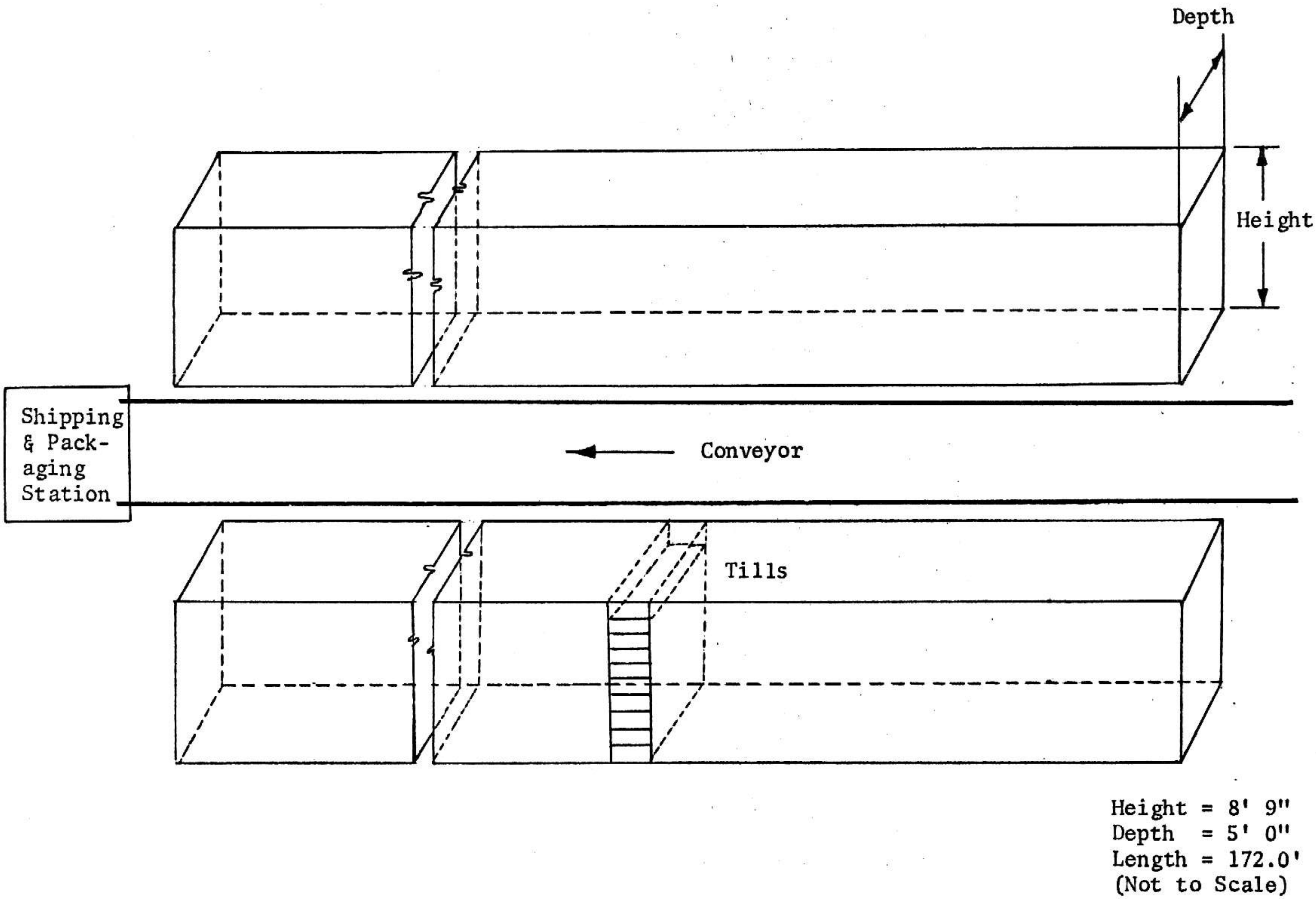

Figure 5. A three dimensional view of the filing racks.

by the dealers to identify each item. However, the picking machine needs only four digits to identify one of the 5,000 items stored in the warehouse. Whichever input system may be employed, each of them sends information to the computer that a given order requires a particular set of items. In the computer memory, the location, price and weight of each item has been stored. The orders read by the computer are also stored in its memory. The various items in an order are rearranged in the sequence of the warehouse by a computer program. At the appropriate time, the computer signals the release mechanisms fixed on each till to drop the items on the take-away conveyor. As the order is being processed by the computer, it can trigger the release mechanism, and at the same time, can be programmed to do inventory control, billing, and sending information to the automatic stamping and packaging machines.

DESIGN OF PICKING MACHINE

The stock in the picking machine takes care of the differences between input to the machine and output from it. To decide the capacity of the machine, there are two opposing factors - if the filing racks are too big, the initial cost of the racks and warehouse space used would go up. On the other hand, if the filing racks are too small, the number of replenishments of the racks would increase. A compromise between these two opposing factors is to be reached.

Items are stored in bins, commonly known as tills, on their smaller dimension, that is 6.25 inch, in ten rows and 250 columns in two racks, as diagrammed in Figure 5. A takeaway conveyor runs in the aisle in

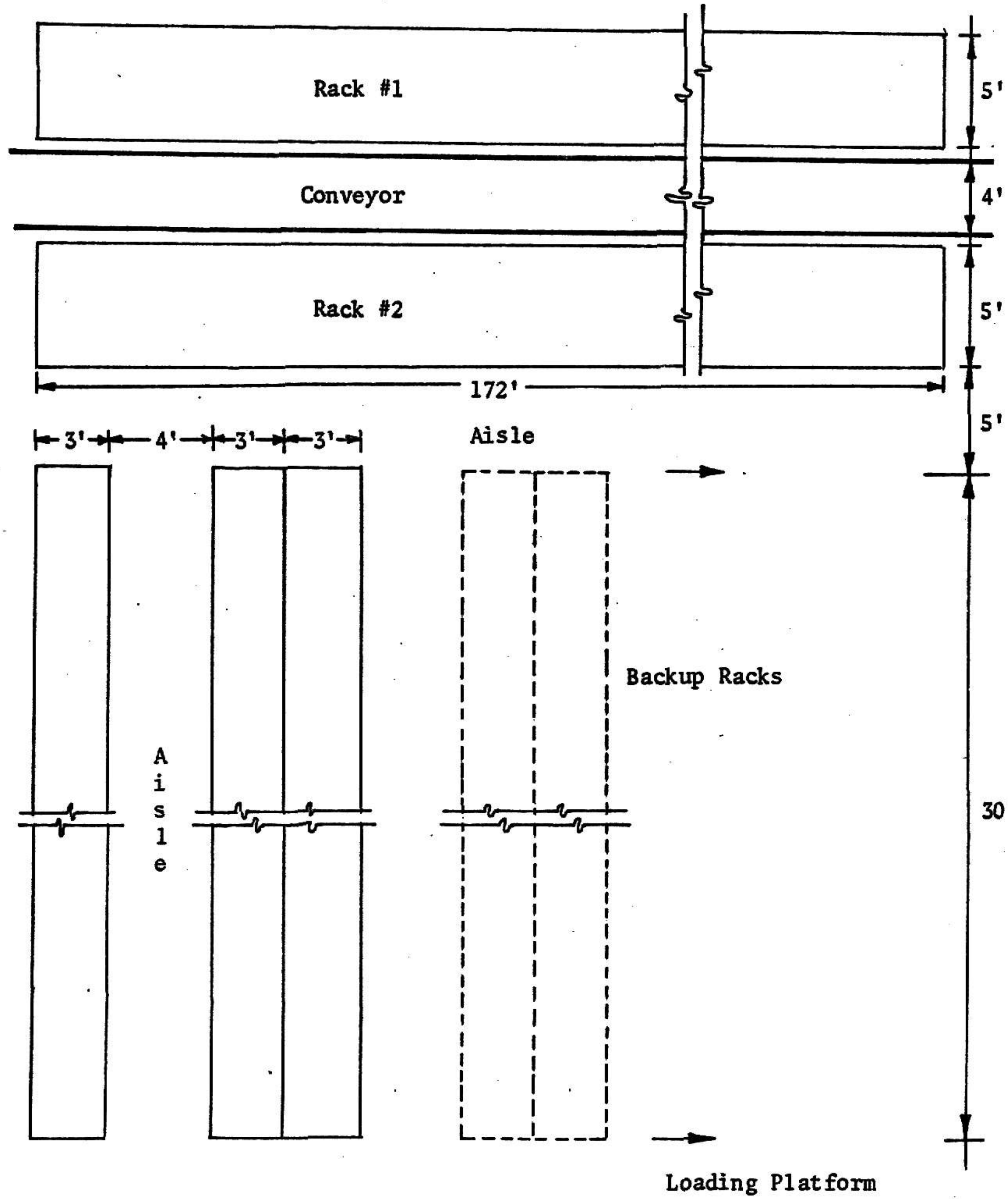

Figure 6. A plan view of the arrangement of the filing racks and the backup racks.

between these two racks. An order is fed into the computer, the computer checks the inventory status of the items called for in the order. If these items are available in the warehouse, it signals the release mechanisms fixed on each of the tills. This results in dropping the needed items for that order onto the takeaway conveyor. Immediately after the item has dropped on to the takeaway conveyor, the inventory of that item is updated in the computer. The items dropped for an order, move up to a shipping station, where they are automatically sacked. The packing sack is stamped and addressed simultaneously by a computer controlled stamping and address printing machine. To eliminate the bottleneck at the shipping station, an automatic item packaging machine is incorporated in the system. As soon as one item drops onto the takeaway conveyor, a spring mechanism pushes the next item to the front. This type of arrangement is known as live storage of items.

CAPACITY OF THE SYSTEM

The depth of the filing racks has been fixed as 5 feet. Complete dimensions and arrangement of these filing racks is shown in Figure 5. From these dimensions, it is estimated that the different number of items of different thickness are accommodated in the same size of a till as shown in Tables I, II and III. Figure 6 shows a plan view of the arrangement of the filing racks and the backup racks. According to the assumptions, the number of three different categories of the product mix are given below.

Number of fast moving items	=	4000
Number of slow moving items	=	800
Number of occasional demand items	=	200

TABLE I Fast Moving Variety

Thickness of the items in inches	Number of product lines	Number of items in one till	Total number of items
0.25	3400	240	816,000
0.50	400	120	48,000
0.75	200	80	16,000
			880,000

TABLE II Slow Moving Variety

0.25	680	240	163,200
0.50	80	120	9,600
0.75	40	80	3,200
			176,000

TABLE III Occasional Demand Variety

0.25	170	240	40,800
0.50	20	120	2,400
0.75	10	80	800
			44,000

Based on these calculations, the total capacity of the picking machine can be estimated as 1,100,000 items. The system as shown in Figure 6 contains only one set of back up racks. In the back up racks, the items are stored in cartons containing bundles of twenty.

CALCULATION OF NUMBER OF ORDERS PER HOUR

The time required to fill one order can be estimated based on the following assumptions.

1. Only one order is processed at a time.
2. All the items for an order get signals simultaneously.
3. No order requires more than one unit of an item. This has no implication on the computer program.
4. The speed of the take away conveyor is 450 feet per minute. This speed has been selected by employing the experience of picking packaged items in existing automatic plants [30], [58].
5. The release mechanism has 3 seconds operation cycle.

Based on the above assumptions, the service time for one order consists of the following three components.

a. Time required for the release mechanism to operate. This is equal to 3 seconds.

b. Time required for an item to fall on the takeaway conveyor. This can be estimated by assuming that the items fall from rest and they fall under gravity.

The following equation is used to estimate the time required for the item to fall 10 feet:

$$S = 1/2\ g\ t^2$$

S = distance travelled in feet

t = time to fall in seconds

g = gravitational constant = 32 feet/sec./sec.

S = 10 feet (maximum)

$$10 = 1/2 \times 32 \times t^2$$

or $t = 0.8$

c. The time required for all items of an order to move to the packaging and shipping station. This depends on length and speed of the takeaway conveyor.

Length = 172 feet

Speed = 450 feet per minute

$$\text{Required time} = \frac{172 \times 60}{450} = 22.8 \text{ seconds}$$

The time required to fill one order can be estimated by adding these three components:

Time required for release mechanism	= 3.0 secs.
Time required for items to fall	= 0.8 secs.
Time required for items to move to the checking and shipping station	= <u>22.8</u> secs.
	26.6

In this case, there is a possibility of some overlap between the release time of items for the next order and the movement of the items of the current order to the packing and shipping station. This would result in saving 3.0 seconds in the overall cycle time of an order and the effective cycle time can be considered as 23.6 seconds.

Therefore, the number of orders picked per hour = 3600/23.6

= 150.

As the picking machine is required to handle 1200 orders per hour, the machine discussed so far is not capable of doing the desired job. Its rate of order picking is very low. There are several ways to increase this rate.

1. To decrease the length of racks and increase the number of conveyors so that each item travels a short distance.
2. To increase the speed of the conveyor. But there are practical limits beyond which the speed of the conveyor can no longer be increased.
3. A better way is to use a pulsating system. In this system, small equal segments of the takeaway conveyor, each with an associated memory stage, are assigned to individual orders. In the proposed picking system, each order is picked onto independent 10 foot segments of the conveyor. As the conveyor segment moves from one end of the racks to the other end, a pulse generator driven along with the conveyor, pulses every time an item is needed for the assigned order comes within the range of the conveyor segment. This results in signalling the release device and dropping the item onto the conveyor. As the conveyor segment reaches the other end of the rack, it would have scanned the whole stock and items needed for that order have dropped onto it.

   The length of each rack is 172 feet. Ten foot conveyor segments are assigned to individual orders. Alternate conveyor segments are used to space two orders. This would result in eight 10-feet segments used for picking orders and eight 11.5

feet spacing segments. With this system, eight orders can be picked simultaneously. The pulsating mechanism increases the number of orders picked from 150 per hour to 1200 per hour, the desired output.

INTERFACE BETWEEN THE COMPUTER AND AUTOMATIC ORDER PICKING SYSTEM

The most important aspect of this automatic order picking system is the interface between the computer and the materials handling equipment. The interface bridges the gap between the computer and the order picking machine, doing the entire job of picking. The interface may be described by the number of channels requied to transmit proper information about an order from the computer to the picking machine. There are two ways of looking at this interface device.

FIRST APPROACH:

Each item on an order is considered as one piece of information. It is assumed that each piece of information consists of four characters. On the average, an order requires 15 pieces of information for 15 items on the order. Therefore, on the average, the computer is required to transmit the following number of characters per second to the picking machine:

Number of orders picked per hour	=	1200 orders/hr.
Number of pieces of information transmitted per hour	=	1200 x 15
" " " "	=	18,000 inf./hr.

Number of pieces of information transmitted / sec. $= \dfrac{18,000}{60 \times 60}$ inf./sec.

" " " characters $= \dfrac{18,000}{60 \times 60} \times 4$ characters/sec.

" " " $= 20.0$ characters/sec.

As one channel can transmit 37.5 characters per second [72], the order picking system requires one channel of information to connect the computer and order picking machine.

SECOND APPROACH:

The conveyor is divided into eight segments, each picking an individual order. An obvious approach is to assign an independent channel of information for each of these eight conveyor segments. As one conveyor segment moves from one end of the rack to the other end, the channel scans the whole range of patterns stored in live tills on the both sides of the conveyor. Whenever an item needed for that order comes within the range of the segment, the channel signals the release mechanism fixed on each till. This results in the dropping of that item on to the conveyor segment. When the segment reaches the end of the racks, all the items needed in that order would have dropped on to the assigned conveyor segment. Then, these items for an order move to the packing and shipping station. Alternate conveyor segments are assigned to the individual orders. The remaining segments provide spaces between two orders. Thus, there will be no overlapping or mixing of items for two different orders. Under this system, eight independent channels of information are required to connect the computer and the order picking machine.

REPLENISHMENT OF THE PICKING MACHINE

The varying thickness of items poses a problem. The capacity of the tills is directly proportional to the thickness of the items. The restock point and the restock quantity also depend on the thickness of the items. A restocking signal could be given depending upon the number of items left in the till or when some pre-determined depth of the till is emptied. To simplify the simulation model, it has been decided that both the restocking point and quantity are to be calculated on the basis of a pre-determined number of items left in the till. Under these conditions, the following two models have been considered:

TABLE IV RESTOCKING SCHEME FOR MODEL I

Thickness of the items in inches	Capacity of the filing racks	Restocking point	Restock quantity	Number of bundles to be restocked
0.25	240	80	160	8
0.50	120	40	80	4
0.75	80	20	60	3

TABLE V RESTOCKING SCHEME FOR MODEL II

0.25	240	20	220	11
0.50	120	20	100	5
0.75	80	20	60	3

The inventory of the system is being maintained by the computer. As soon as the restock point is reached, the computer generates a restock signal. This is called a "computer signal" for restocking of the items. The computer prints out the code number of the till desiring replenishment, number of bundles required to fill the till and the location of the back up rack at the typewriter terminals. There could be a typewriter terminal located at the rear of each rack. The computer is also interfaced with a mechanical system to give a replenishment signal. These signals could be given to restock clerks by flashing lamps at the tills needing restocking, ringing of the bell and/or with the help of some flags which show up at the tills whenever restocking is desired. After getting the signal to restock, the clerk brings the required number of bundles from the backup racks. He removes a punched card from each bundle before loading it on the live racks. These punched cards are fed into a card reader which signals the computer to update its inventory.

If a till is empty for any reason and that item is called for, an override control is built into the system, which records the item as a lost sale, and lets the computer proceed to the next item. The number of restocking clerks required depends on the time elapse between two restockings, the proximity of the picking machine from the backup racks, and the number of restocking signals occuring at the same time. One of the aims of this simulation study is to estimate the number of restocking clerks required.

CHAPTER 5

SIMULATION MODEL OF THE PROPOSED ORDER PICKING SYSTEM

The proposed order picking system has been simulated on a digital computer. Simulation [44] offers a unique opportunity to observe the dynamic behaviour of complex interactive systems. A model is a representation of the system. A carefully constructed, realistic simulation model provides a laboratory environment in which to make observations under controlled conditions. Simulation provides an experimental environment for testing hyphotheses, decision rules, and alternate systems of operation under a variety of assumed conditions.

Many practical limitations exist on our ability to construct dynamic large scale business and economic models [44]. Gathering appropriate data is a task of great magnitude. Realistic dynamic models using mathematical analysis are difficult to construct, and the capability has been lacking to perform calculations required for analysis of complex systems. Simulation techniques that make use of the capacity of modern digital computers and new concepts in software can be of material assistance in removing some of these barriers to understanding and effectively controlling the behaviour of large business and economic systems. Digital computers help do a vast number of calculations in a very short time. This feature of simulation in which years of history evolving in a few minutes on a computer is termed as time compression [67].

GASP IIA (General Activity Simulation Program) developed by Pritsker and Kiviat [56] has been used for the proposed automatic order picking system. GASP IIA offers the next event type of simulation in which the logic of simulation moves from event to event. Events, cause the status of the system to change at a discrete point in time. The measure of performance are taken at discrete event times. GASP IIA assists the analyst by providing a modeling framework and a set of programming language statements that both expedite and improve this task. GASP IIA, being FORTRAN based, is easy to understand, practical and useful.

GASP IIA is a set of 26 FORTRAN IV subprograms organized to assist in performing simulation studies. Common elements of simulation studies which are independent of particular problems, have been specified and subprograms have been organized to perform these specialized tasks. Among more important functions [51], GASP performs time movement and control, file maintenance, data collection, statistical computing and reporting, standard initialization, monitoring and error reporting.

GASP IIA views the real world [51] as though it consisted of entities that are characterized by attributes. A system moves from state to state as its entities engage in activities that change their status. Events indicate the start and completion of activities. When the event occurs [56], it can change a system state in three ways: by altering the value of one or more attributes of entities, by altering relationship that exist among entities, and/or by changing the number of entities present in a system. Methods are present in GASP IIA for accomplishing each type of change. The behaviour of the system is reproduced by examining the system at the event times. Events, like entities, have attributes.

Subroutine GASP IIA is the master control routine and is referred as the GASP executive. GASP starts the simulation at a specified starting state, initializes the system, selects events, sequences times, controls the monitoring of intermediate simulation results, and initiates the printout of the final output when the simulation has been completed. The GASP executive assumes responsibility of assuring that all events happen in correct time sequence so that the temporal order of the model is retained. Subroutine GASP is only called by the "main" program, written by the programmer. Once control is turned over to the GASP subroutine of a simulation run, it is not returned to the "main" program until the run is completed.

In GASP II, the filing array NSET is used for storing events and their attributes, entities and their attributes. Since NSET is a fixed point array, the scaling of attributes values can cause truncation errors and limit the magnitude of the attribute stored in the filing array. GASP IIA, an extended version of GASP II, circumvents these difficulties by dividing the filing array into a fixed point and a floating point array. The fixed point attributes are stored in one dimensional array NSET and the floating point attributes are stored in another one dimensional array QSET. The array pointers are maintained in the array NSET. In GASP IIA, there are two buffer storage vectors: JTRIB for fixed point attributes and ATRIB for floating point attributes. The number of fixed point and floating point attributes are specified by the GASP IIA variables IM and IMM. 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.

FORMULATION OF THE MODEL USING GASP IIA

Figure 6 gives a general picture of the system to be simulated. To save computer time, only one rack of the system is simulated. Initially, a sub-system of this system involving only 300 items and about 20 feet of the conveyor was debugged. Once the model was in running condition, it was enlarged to include 2500 items. The system was extended to get a better picture of the behaviour of the product mix in the warehouse. Since the size of the order depends on the number of items out of which the selection is to be made, the order size was also increased from the average size of 0.9 items per order to 7.5 items per order. The extended system also facilitated in the study of the requirement of the number of restocking clerks.

All the variables used in this study have been defined in the Appendix A. The flow diagrams and computer program listings of the main program and other subprograms are given in Appendix B and Appendix C, respectively. These programs are discussed below.

MAIN PROGRAM

This program is very general in nature. In most cases, changes can be made right in this program without altering other subprograms. The percentage of items in different categories, total number of items to be simulated, sales frequency of each variety of products, time interval between two reports and many other changes can be easily made by reading in the changed data on input cards to this program.

First the main program initializes the non-GASP variables. Each item is assigned initial stocks on a random basis. A uniform random number between 0 and 1 is called and the initial stock is calculated by the following formula:

Initial stock = (RESTOCK POINT) + (RANDOM NUMBER) * (RESTOCK QUANTITY)

This kind of initialization scheme helps in achieving steady state condition early in the simulation run, thus saving computer time. After all the initialization operation is complete, subroutine GASP is called. This releases control of the simulation run from the main program to subroutine GASP. The first activity performed in subroutine GASP is to call subroutine DATAN. DATAN initializes all GASP variables. In addition, the events necessary to start the simulation, to create the initial conditions specified for the simulation, and to control the simulation run are read as input variables.

SUBROUTINE ORDERS

This subroutine has a significant amount of technological logic built in it. First, the next order is scheduled to occur at the time as given below.

Time for the next order = TNOW + 1/ODPERH,

where ODPERH is the variable used for the number of orders per hour to be filled by the distribution center.

The number of items in the current order is determined by sampling from a POISSON distribution, using the statement NOITEM = NPOSN (1,1), where the parameters are stored in the row 1 of the array PARAM.

Next, a HISTOGRAM is called on the variable FNITEM to gather statistics on the distribution of the number of items in an order. Then each item in the current order is tested whether it belongs to the fast moving variety, slow moving variety, or occasional demand variety. This is facilitated by operating a DO loop from 1 to NOITEM, the number of

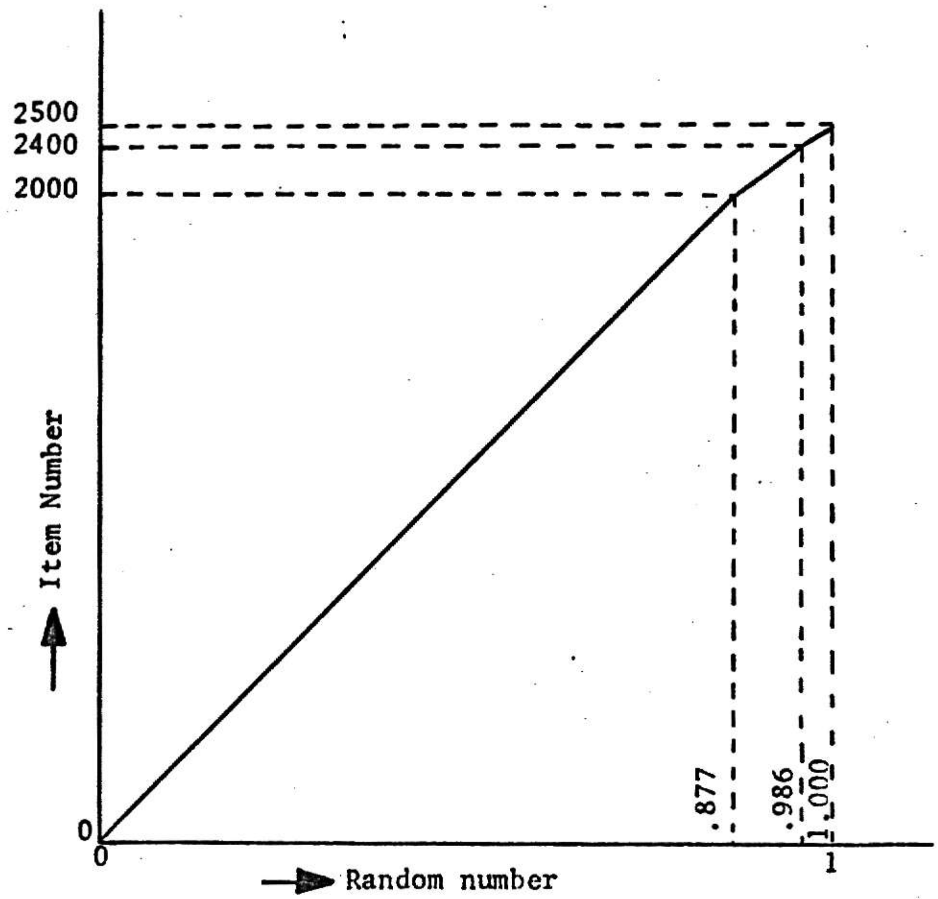

Figure 7. Distribution of product varieties

items in the current order. The percentage of different varieties of items has already been read in the main program by the variables FRACF, FRACS and FRACO for fast, slow, and occasional demand variety respectively. The movement of each variety of items based on its sales frequency has been calculated in the main program by the variables FFAST, FLOW and FOCCD. The test of each item has been simulated by calling a uniformly distributed random number between 0 and 1. This is shown in Figure 7. If the random number is between 0 and FFAST, the item is considered as fast moving; between FFAST and FFAST plus FSLOW, it is considered slow moving, and between FFAST plus FSLOW and 1, it is considered as occasional demand item. Depending upon the value of the random number, the control goes to one of the three similar sets of logical statements for the fast, slow or occasional demand variety. In this study, a sales frequency ratio of 1/8 is used. This resulted in the following values:

FFAST = 0.877

FSLOW = 0.109

FOCCD = 0.014 .

If the random number is between 0 and 0.877, the item is put in the fast variety group; between 0.877 and .986, the item is put in slow variety group, and if it is between 0.986 and 1.000, it is put in the occasional variety group.

Next, the item is assigned a stock number. It is tested to see whether there is any stock of that item on hand. If the answer is negative, a subroutine ERROR is called and a return is made. If it is zero, lost sales of that item are increased by one. On the other hand, if there is stock on hand, sales are increased by one and stock on hand is decreased by one.

Next, the item's thickness is determined. With thickness determined, the restock point and restock quantity is assigned to the variables NRESTP and NRESTQ respectively. Then the inventory position is calculated by adding the stock on hand to the stock on order, if any for that item. The inventory position is then compared with the restock point of that item. If this is greater than the restock point, the control is transferred to the next item on order. If the answer is negative, the file of items waiting to be restocked (File 2) is interrogated. If there is no item waiting and a restocking clerk is available, the restocking of the current item is scheduled. Otherwise, the current item is filed in File 2. The restocking is scheduled by sampling from an Erland distribution employing the statement ATRIB (1) = TNOW + ERLNG (1,2), where the parmeters are stored in the row 2 of the array PARAM. Statistics are collected on FNRSC, the number of restocking clerks available. Next, the availability of restocking clerks is decreased by one and control is transferred to the next item on order.

Similar logic is followed for the slow moving and occasional demand items. When all the items of an order are checked, number of orders is increased by one and return is made to the calling routine.

SUBROUTINE EVNTS

Subroutine GASP calls subroutine EVNTS with the appropriate value of IT. This routine selects events as directed by the variable IT. This is a little more than one computed GO TO statement.

SUBROUTINE RESTOK

Subroutine RESTOK adds the restock quantity to the stock on hand of the item to be restocked. It decreases the quantity on order by the restock quantity. Then it increases the number of restockings of that item by one.

Next, a check is made whether there is any item waiting to be restocked in File 2. If the answer is negative, a subroutine ERROR is called and a return is made. If it is zero, statistics are gathered on the number of the restocking clerks. The availability of the restocking clerks is increased by one and a return is made to the calling routine. On the other hand, if there is an item waiting to be restocked, restocking of that item is scheduled. Lastly, statistics on the number of restocking clerks is collected and a return is made.

SUBROUTINE REPORT

Subroutine REPORT prints out a brief or a detailed simulation report whenever called. The first activity in this routine is the scheduling of the next report at the time as given below.

$$\text{Time for the next report} = \text{TNOW} + \text{TIMREP} ,$$

where TIMREP is the variable used for the time interval between two successive reports.

Next, a check is made whether this is an intermediate report or the final report. If it is an intermediate report, utilization of restocking clerks is calculated and printed out, and a return is made to the calling routine. On the other hand, if this is the final report, a detailed report, item by item, of stock on hand, total number of sales made, total number of restockings completed and lost sales, if any, of each item is also printed.

SUBROUTINE OTPUT

Subroutine OTPUT calls the subroutine report to print the final report when the complete simulation run has been made.

RECORD KEEPING IN THE SIMULATION

Two files are used for record keeping in this simulation study. File 1 is the event file and File 2 is the queue of items waiting for restocking. The attributes associated with each of these files are shown below:

File 1 ATRIB (1): Scheduled time of event.

ATRIB (2): Not used.

JTRIB (1): Event code.

JTRIB (2):
1. for the fast moving items,
2. for the slow moving items,
3. for the occasional demand items.

JTRIB (3): Stock number of any item.

JTRIB (4): Restock quantity of any item.

Ranked FIFO on ATRIB (1)

File 2 ATRIB (1): Not used.

ATRIB (2): Time any item entered this file.

JTRIB (1): Not used.

JTRIB (1): 1. for the fast moving items
2. for the slow moving items
3. for the occasional demand items

JTRIB (3): Stock number of any item.

JTRIB (4): Restock quantity of any item.

Ranked FIFO on ATRIB (2)

STATISTICS COLLECTED

The GASP subroutine HISTO, COLCT and TMST have been employed. The definition of the codes and pertinent quantities stored in the statistical storage arrays are given below:

Subroutine	Code	Name of the variable	Statistics collected
HISTO	1	FNITEM	Number of items in an order.
COLCT	1	STOCKN	Stock on hand of fast moving items when restocking is done,
	2	STOCKN	Stock on hand of slow moving items when restocking is done,
	3	STOCKN	Stock on hand of occasional demand items when restocking is done.
TMST	1	FNRSC	Number of restocking clerks before any change in their availability is made.

CHAPTER 6

SIMULATION RESULTS & DISCUSSIONS

An orderpicking system in an automatic warehouse has been simulated using GASP IIA. The main objective of this study was to demonstrate the application of automation and simulation to the orderpicking of a large variety of items in a warehouse or a distribution center. The literature available to date gives no evidence that the computer simulation and automation can be effectively employed to such a system. A distribution center where a large variety of items is to be shipped in small individual orders was selected for the study. Two simulation models of the automatic order picking system have been developed in chapter 4. In Model I, the restocking point is 80, 40, and 20 for thicknesses of 0.25 inch, 0.50 inch, and 0.75 inch. Model II has the same restocking point of 20 for all three thicknesses of items.

VALIDITY OF SIMULATION

The key question is whether the simulation model is behaving the way it was expected to. Another question is how accurately does this model represent the proposed order picking system?

The split of the items in three groups of fast, slow and occasional demand varieties was initially calculated depending on their sales frequency. At the time of deciding the group to which an item belongs, the counters were set to determine the number of items in each group. The relative throughput of the entire range of products was studied item by item. The simulation results indicate that the actual split is very near to the desired split. As expected, the sale of the fast moving items is greater than the slow moving items. A similar argument is valid for the slow moving and occasional demand items.

The number of items in an order was assumed to be distributed according to the POISSON distribution. Only one half of the total number of items was simulated, so a mean value of 7.5 was taken for the number of items in an order, a value of zero for the random variable was interpreted as no items required from this half of the machine. Statistics were collected on the variable representing the number of items in an order. Theoretical values of the probabilities of a POISSON distribution with $\lambda = 7.5$ were taken, from a Bell Telephone Laboratory's book (38). Both the observed and theoretical frequencies of the number of items in an order are plotted in Figure 8. These two curves look similar in nature. However, on applying a chi-square test, a significant difference was found to exist between these two populations. The mean of the observed population was calculated as 7.5037. This is very close to the desired mean. The main difference between these two populations is in the dispersion about the mean. So long as the observed mean is close to the desired mean, this does not affect our study adversely.

The simulation results of the study show no lost sales at all. To justify no out of stock of any item, a statistical analysis of the lost sales is in order.

Number of orders per hour	=	1200 orders/hour
Number of orders per minute	=	20 order/minute
Average number of items per order	=	15 items/order
Average number of items selected in one minute	=	15 x 20

$= 300$ items/minute

Let p be the probability of selection a fast variety item. According to the assumption made about the three varieties of items and their sales frequency, the following equation determines the probability of selection of a fast-moving item.

$$4000\ p + 800 \times p/8 + 200 \times p/64 = 1$$

or $$p = 1/4103 = 0.0002437$$

The probability of selection of a fast moving item is 0.0002437. This can be considered as distributed according to the binomial distribution with parameter p. Since np is small, the binomial can be approximated by a Poisson distribution. The parameter of the Poisson distribution is given by

$$\lambda = np = 300 \times t \times p$$
$$= 300 \times 0.0002437 \times t$$
$$= 0.07311\ t,$$

where t is the time unit in minutes.

Let the probability of an out of stock be taken as 0.01. From the Poisson tables [45], the value of the parameter λ for the probability of 0.01 of selling more than 20 items is given below.

$$Pr(x \geq 20) = 0.01 \text{ for } \lambda = 11.1$$
$$11.1 = 0.07311\ t$$

or $$t = 11.1/0.07311$$
$$= 152 \text{ minutes}$$
$$= 2.50 \text{ hours.}$$

This shows that if the item is restocked within 2.5 hours after passing the restock point, the probability of an out stock and consequently probability of lost sales is only one percent.

In this analysis, equal probability of the sale of each fast moving items was implicitly assumed. However, in actual practice this may not be true. A sensitivity analysis of the probability of sale may be helpful. It is reasonable to assume that an item should be restocked within 30 minutes after the restocking signal is given. The probability of selection of the item in 30 minutes is calculated as shown below.

$$t = 30 \text{ minutes}$$

$$= 11.1 \text{ for } Pr(x \geq 20)$$

$$= 300 \times 30 \times p$$

$$\text{or} \quad p = 11.1 / 300 \times 30 = 0.00123$$

Thus if any item has a probability of selection as great as five times that of the others, the chance of an out of stock for that item is only one in a hundred. All this indicates that the restock point of 20 items is high enough to prevent any lost sale.

The probability of selection of a fast moving item out of 2000 items (1 rack of the system) is 0.0004874. This is considered as distributed according to the binomial distribution with parameter p. The binomial distribution is approximated by a normal distribution with a mean and standard deviation of the binomial distribution as shown below.

Expected sale of fast moving items =

50 hrs x 1200 orders/hr x 7.5 items/order x .877 x 1/2000 fast items

$\mu = 197.325$

$\sigma = (npq)^{1/2}$

$= (197.325 \times 0.9995126)^{1/2}$

$= 14.05$

The final simulation reports also contained the number of sales made of each item in the distribution center. The sales quantities of all the fast moving items were tabulated. The observed mean and standard deviation of the number of sales made is given below.

$\mu = 198.96$

$\sigma = 14.43$

The curve of the observed population was plotted as shown in Figure 9. The observed data was standardized and an approximate normal curve was fitted to the observed curve. It is evident from the Figure 9, these two curves seem to match at the tails, but there is a lot of noise in the middle portion. Although the mean and standard deviation of the observed population are reasonably close to the theoretical population. This odd behaviour of the curve in the middle portion should be studied and investigated.

SIMULATION CHARACTERISTICS

The transient behaviour of the system was studied. The main question is whether the simulation was run long enough to reach steady state or not. Initially, all the tills were assigned full stocks and a simulation run was made. The system took a long time to reach a steady state. Next, a simulation run with random assigning of initial stocks showed that the system tends to attain a steady state after about 25 hours of operation. This is evident from the graphs of average utilization as shown in Figures 10 and 11.

First, only a sub-system containing only 300 items and 20 feet of the conveyor was simulated. To get a good picture of restocking clerks utilization, the system size was increased to 2500 items. In both the models, the number of restocking clerks required for the 2500 items was found to be two. But the average utilization in the Model II was very low and it was felt that only 3 clerks might be able to do the job for the full machine. This can be facilitated by constructing a common restocking station at one end of the aisle.

The model developed can be easily extended to include the full stock on both sides of the conveyor. This may involve maintaining one separate set of files for each rack. It was observed that the increase in computer time is not due to increase in the number of items in the system. However, the size of the orders does have a pronounced effect on computer time. An increase in order size increases sales activity which in turn increases computer time. On the other hand, the increase in the number of items increases only the choice among which a selection can be made. The record keeping time for the increased number of items is quite small.

CONCLUSIONS

One of the objectives of this simulation study was to estimate the number of restocking clerks needed to give an adequate service. In Appendix G, the average restocking time for an item has been estimated by using Methods Time Measurement. The restocking time per item is distributed according to the exponential distribution at a mean of 1.5 minutes. The exponential distribution was used to allow a hig variability in the restocking time. Some items are very close to the picking machine, requiring a very small time. Some other items are far off, needing a much longer restocking time.

Brief simulation reports were printed for each fifteen minute periods. This report contains the average utilization of the restocking clerks in the fifteen minute period. Figures 9 and 10 show that the average utilization keeps on fluctuating till about 25.0 hours of operation of the system. It finally settles down to the steady state values of utilization. With two clerks for 2500 items, the steady state value of the utilization is 85.3% for the Model I and 64.0% for the Model II. These simulation reports also indicate the number of restocking clerks available at the end of these brief intervals. The plots of the number of restockings in these fifteen minute periods is random with their means as graphed in Figures 12 and 13.

The results of the two models with different restocking points show that the restock point has an important bearing on the system. Simulation results show that the total number of restockings goes down by about 22.6% in Model II, as compared to Model I. The number of restockings in fifteen minute periods also drops down as shown in Figures 13 and 12. Consequently, the average utilization of restocking clerks is less in Model II than in Model I. As discussed earlier, a common restocking station may be employed.

TABLE 6 - Comparison of the Model I and Model II

	Average number of items waiting to be restocked	Maximum number in the waiting Q	Average number of restocking in a 15-minute period
Model I	3.8051	25	16.95
Model II	1.0595	15	13.12

This would increase their average utilization. This arrangement may also result in a better labor balance for restocking. Table 6 compares these two models. The maximum number of items waiting to be restocked goes down from 25 in Model I to 15 in Model II. The average number of items waiting to be restocked reduces from 3.8051 in Model I to 1.0595 in Model II.

The restock quantity needed to fill a till depends upon the restock point for a fixed size of the till. The lower the restock point, the higher the restock quantity for a given capacity of the till. It may be difficult for the restock clerks to carry the increased number of bundles of items. However, the use of some kind of mechanical conveyance will ease the manual labor of carrying the bundles. This will also decrease the restock time for an item. It was observed that the lowering of the restock point decreases the number of restocking for the same level of sales. An increase in the rate of sales will increase the number of restockings and the need for backup space.

This study and the results demonstrate the feasibility of the application of computer simulation techniques to the automatic order picking of a large variety of items in a warehouse.

FUTURE WORK

It is obvious that the thicker items need more restockings than thinner items. This is also confirmed by the simulation results. A possible approach would be to store the same item in more than one till. The computer can be programmed to check all the tills of the same item before giving a signal for restocking. This will result in a reduced number of restockings for these thicker items. Consequently, all the items of the same type will have uniform restocking rates.

This system of order picking has been designed and simulated for customer orders which do not call for multiple units of a particular item in one order. However, the system can be extended to include those orders which do require more than one unit of a particular item. This does not affect the computer program in any way, but some modification in the picking mechanism will be required.

The rate of sales may be varied and its effect be studied on the behaviour of multi-variety of items. It is also felt that in the fast variety group, some items may have faster movement than the rest of the items in the same group. This can be easily handled by treating a larger number of groups. The computer program developed for this study can accommodate all these changes with only slight modifications.

The optimum figures for the number of restocking clerks and other parameters of the system can be easily estimated. For this one would need complete information on the various cost figures.

Yet another area for future work would be to simulate the pulsing of the conveyor along with the selection of the items. This will also facilitate the study of the effect of different conveyor speeds on the system.

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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 (56). This appendix defines the non-GASP variables used in the computer program of this study.)

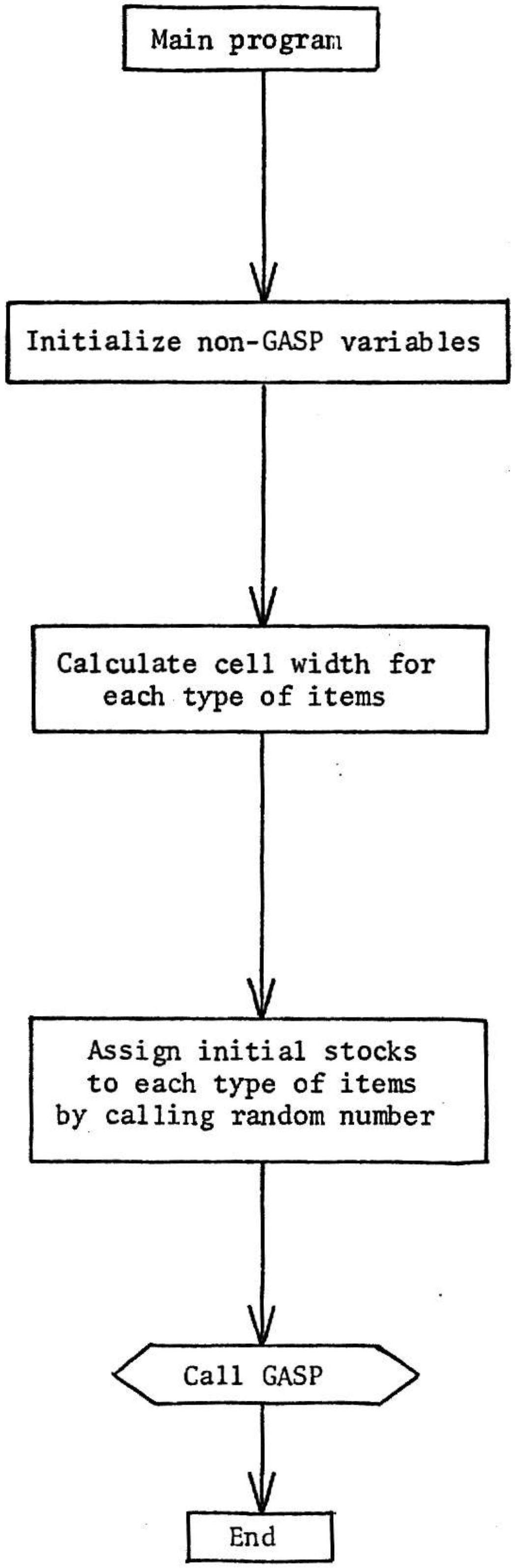
DEFINITION OF THE NON GASP VARIABLES

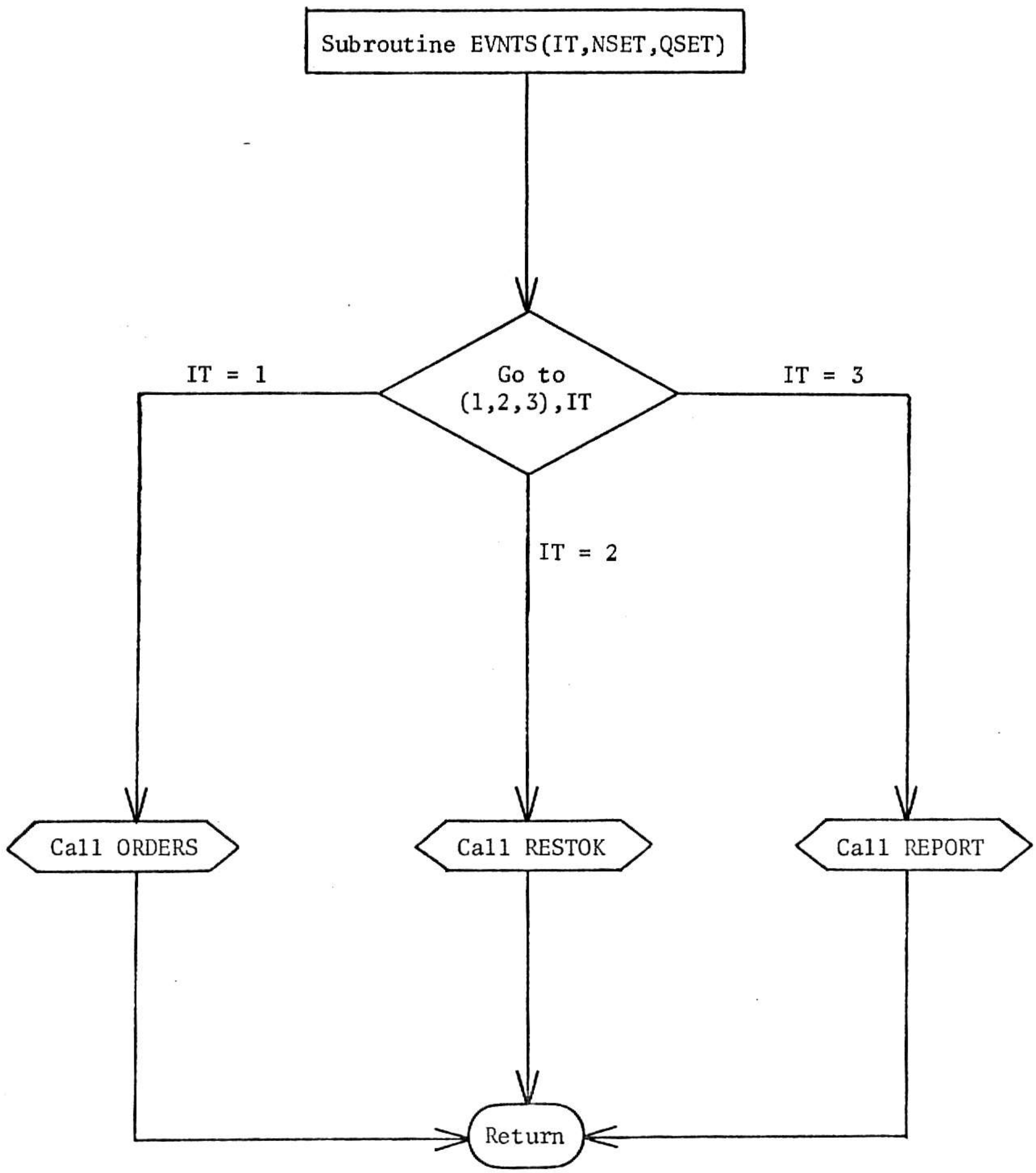
CELLF	Cell width of the fast moving items
CELLS	Cell width of the slow moving items
CELLO	Cell width of the occasional demand items
FNRSCS	Total number of clerks initially employed
FREQS	Sales frequency of the slow moving items
FFAST	Percentage movement of the fast moving items
FSLOW	Percentage movement of the slow moving items
FOCCD	Percentage movement of the occasional demand items
FRACF	Fraction of the fast moving items
FRACS	Fraction of the slow moving items
FRACO	Fraction of the occasional demand items
KOUNT	Serial number of the reports
NRSC	Number of restocking clerks at any time
NUMRST	Total number of restockings made
NTLREP	Serial number of the last detailed report required
NQFAST	Number of fast moving items selected
NQSLOW	Number of slow moving items selected
NQOCCD	Number of occasional demand items
NF1	Number of items of fast moving variety of 0.25 inch thick
NF2	Number of items of fast moving variety of 0.50 inch thick
NF3	Number of items of fast moving variety of 0.75 inch thick
NS1	Number of items of slow moving variety of 0.25 inch thick
NS2	Number of items of slow moving variety of 0.50 inch thick

NS3	Number of items of slow moving variety of 0.75 inch thick
NO1	Number of items of accasional demand variety of 0.25 inch thick
NO2	Number of items of ocasional demand variety of 0.50 inch thick
NO3	Number of items of occasional demand variety of 0.75 inch thick
NORDER	Number of orders
NSTOCK	Stock on hand of any item
NSALE	Sales made of any item
NSLOST	Lost sales of any item
NRSTOK	Number of restocking made of any item
NONORD	Number of units of any item on order but not restocked
NRSPQU	Restock point of 0.25 inch thick items
NRSPHA	Restock point of 0.50 inch thick items
NRSPTQ	Restock point of 0.75 inch thick items
NRSQQU	Restock quantity of 0.25 inch thick items
NRSQHA	Restock quantity of 0.50 inch thick items
NRSQTA	Restock quantity of 0.75 inch thick items
ODPERH	Number of orders per hour
TIMREP	Time between two reports

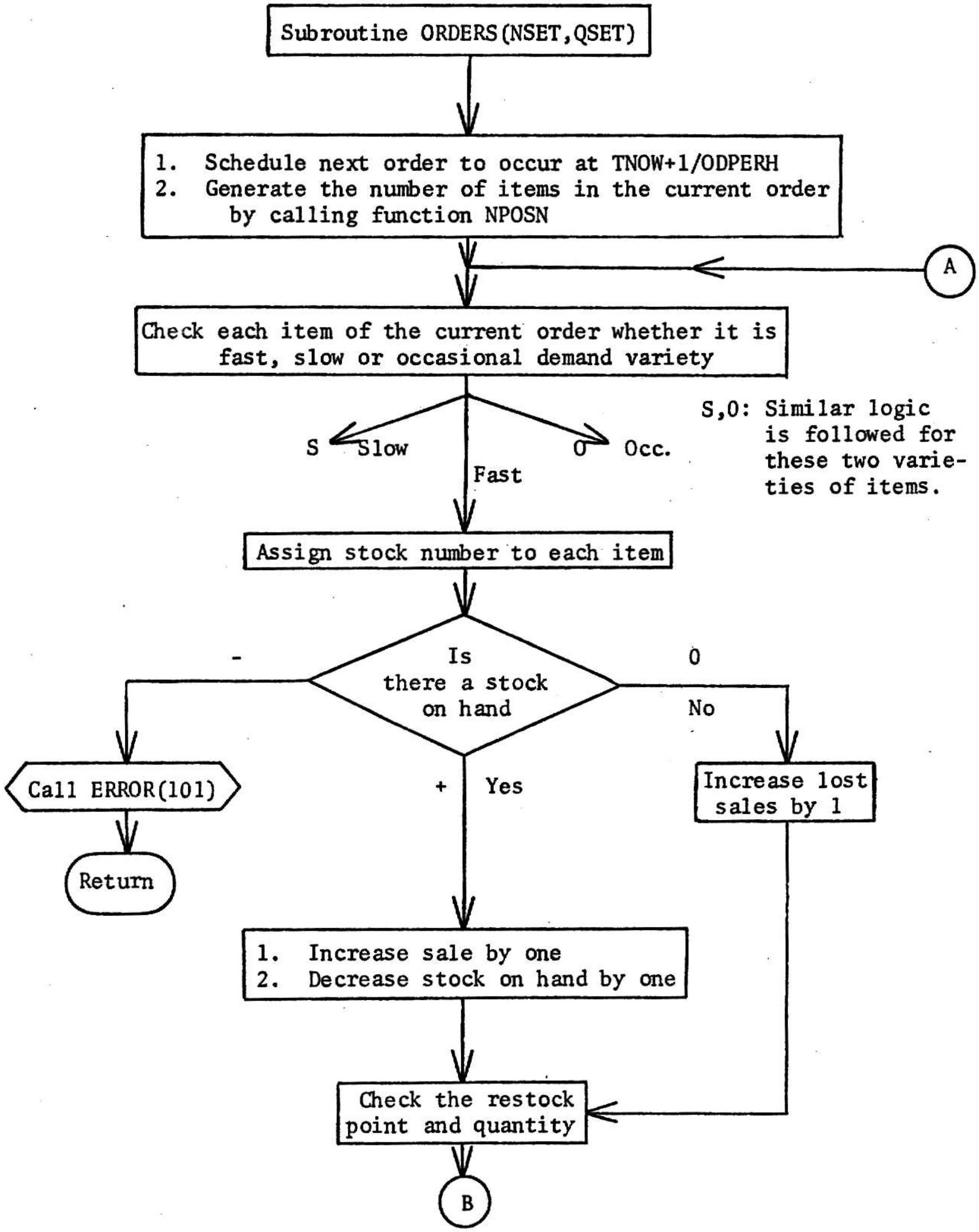
APPENDIX B

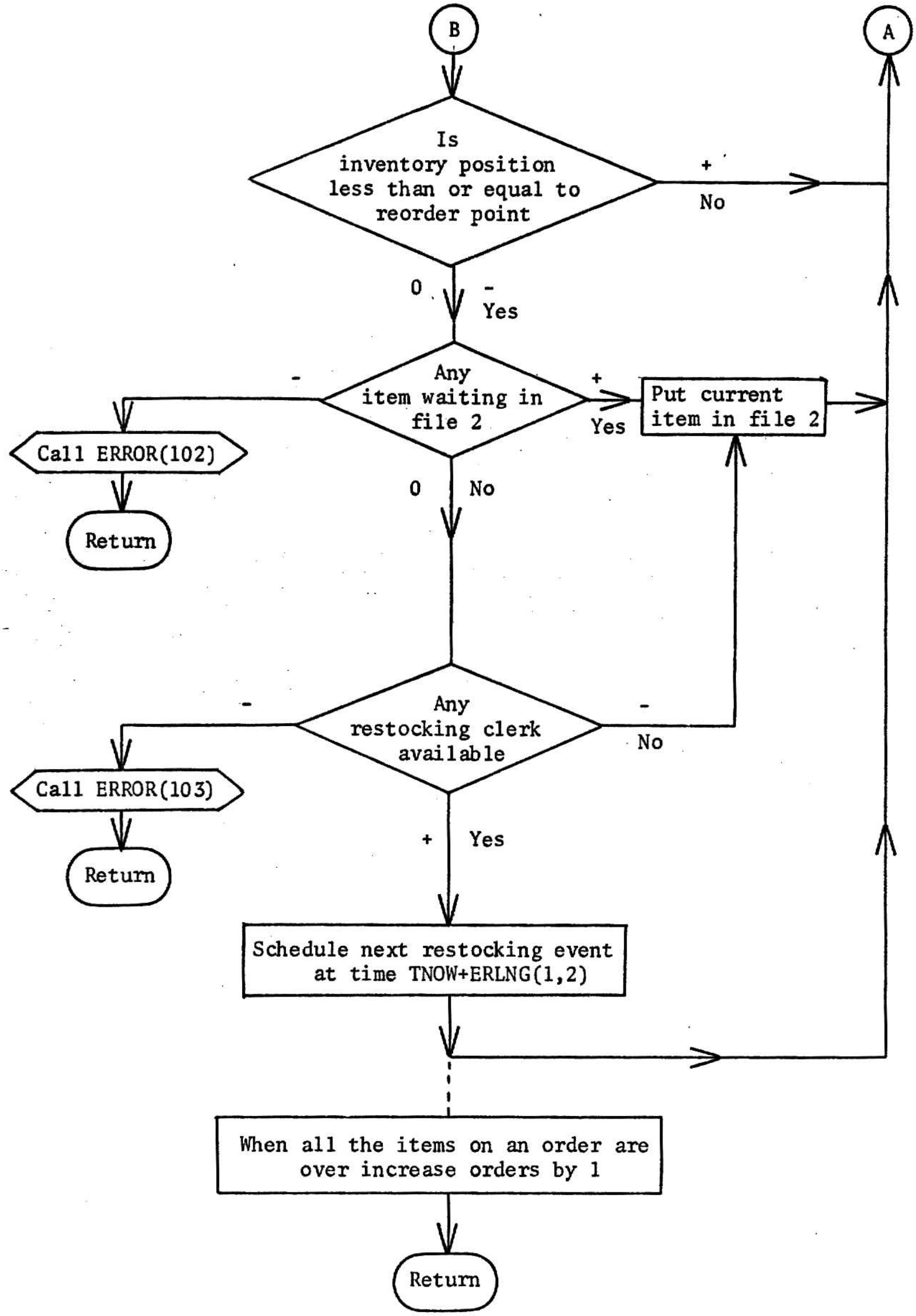
FLOW CHARTS

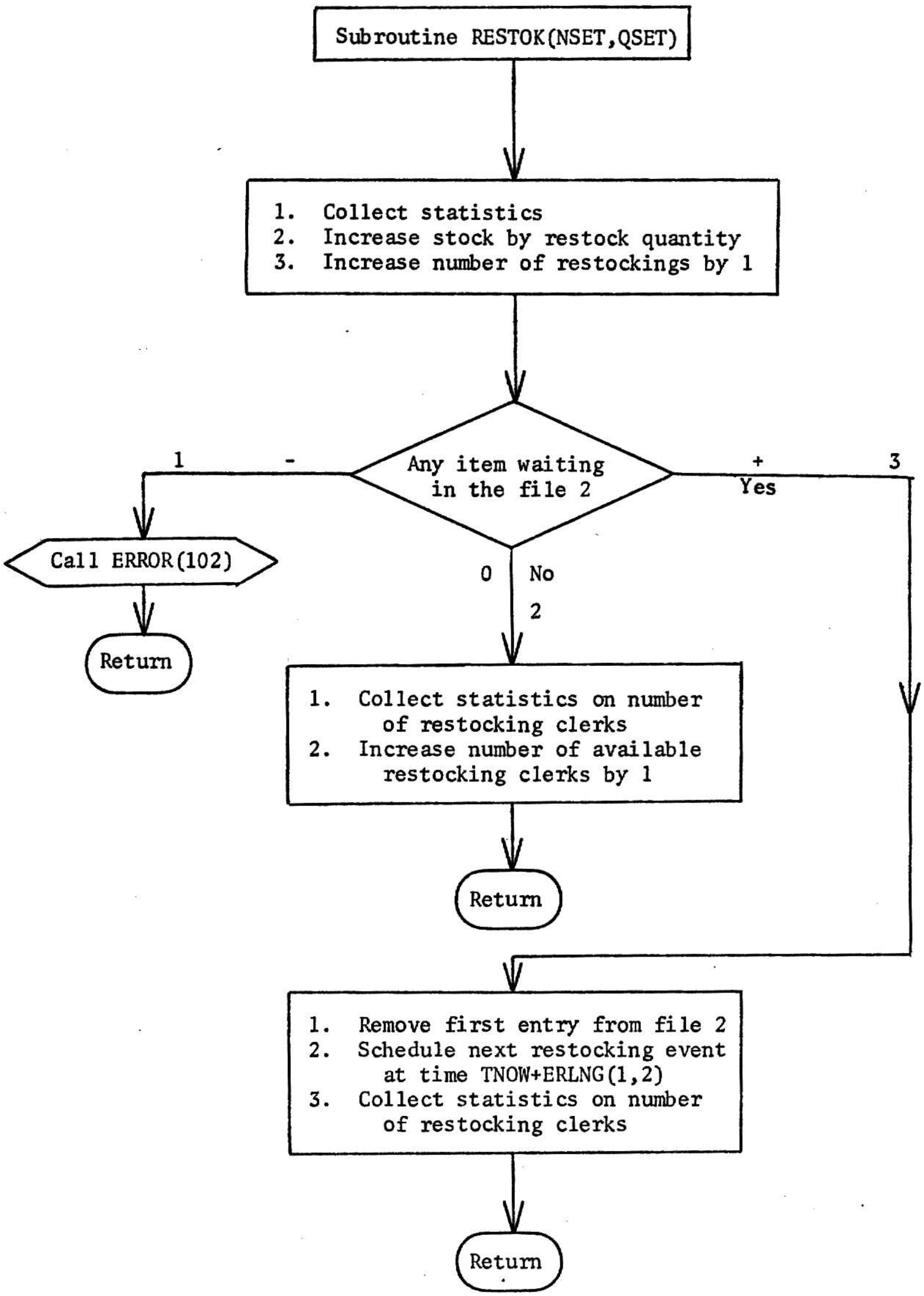

Main program
Initialize non-GASP variables
Calculate cell width for each type of items
Assign initial stocks to each type of items by calling random number
Call GASP
End



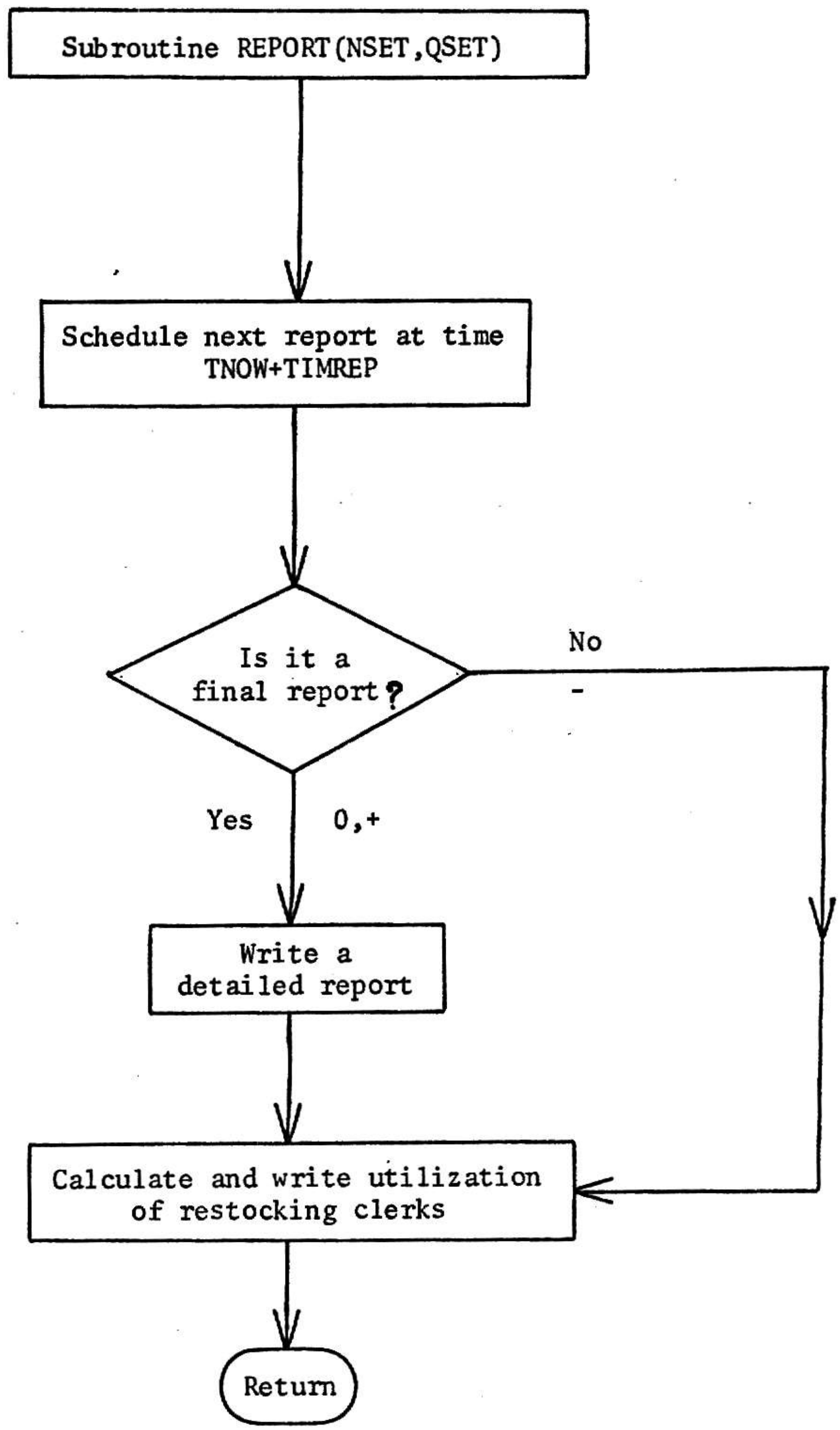
Subroutine EVNTS(IT,NSET,QSET)
Go to (1,2,3),IT
IT = 1
IT = 2
IT = 3
Call ORDERS
Call RESTOK
Call REPORT
Return

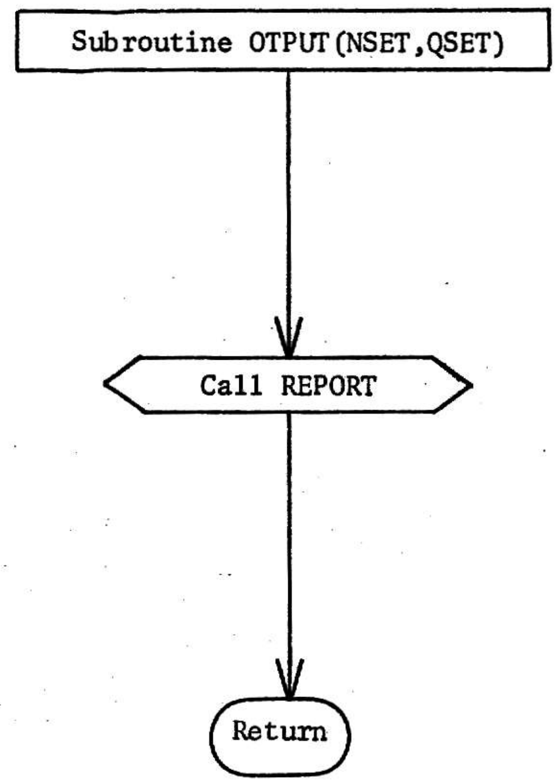

Subroutine ORDERS(NSET,QSET)
1. Schedule next order to occur at TNOW+1/ODPERH
2. Generate the number of items in the current order by calling function NPOSN
A
Check each item of the current order whether it is fast, slow or occasional demand variety
S Slow
Fast
O Occ.
S,O: Similar logic is followed for these two varieties of items.
Assign stock number to each item
Is there a stock on hand
-
0
No
Call ERROR(101)
+
Yes
Increase lost sales by 1
Return
1. Increase sale by one
2. Decrease stock on hand by one
Check the restock point and quantity
B


B
A
Is inventory position less than or equal to reorder point
+
No
0
-
Yes
Any item waiting in file 2
-
+
Yes
Put current item in file 2
Call ERROR(102)
Return
0
No
Any restocking clerk available
-
-
No
Call ERROR(103)
Return
+
Yes
Schedule next restocking event at time TNOW+ERLNG(1,2)
When all the items on an order are over increase orders by 1
Return



Subroutine RESTOK(NSET,QSET)
1. Collect statistics
2. Increase stock by restock quantity
3. Increase number of restockings by 1
Any item waiting in the file 2
1
-
+
3
Yes
Call ERROR(102)
Return
0
No
2
1. Collect statistics on number of restocking clerks
2. Increase number of available restocking clerks by 1
Return
1. Remove first entry from file 2
2. Schedule next restocking event at time TNOW+ERLNG(1,2)
3. Collect statistics on number of restocking clerks
Return


Subroutine REPORT(NSET,QSET)
Schedule next report at time TNOW+TIMREP
Is it a final report?
No
-
Yes
0,+
Write a detailed report
Calculate and write utilization of restocking clerks
Return



Subroutine OTPUT(NSET,QSET)
Call REPORT
Return

APPENDIX C

LISTINGS OF COMPUTER PROGRAMS

```
C
C       MAIN PROGRAM
C
C
C       THIS IS THE MAIN PROGRAM FOR THE AUTOMATIC ORDER PICKING
C       SIMULATION.  THIS INITIALIZES THE NON GASP VARIABLES,
C       ASSIGNS INITIAL STOCKS RANDOMLY TO EACH ITEM AND CALLS
C       SUBROUTINE GASP, WHICH THEN CONTROLS THE COMPLETE
C       SIMULATION RUN.
C
C
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS,ATRIB(10),
     3ENQ(14),INN(14),JCELS(10,30),KRANK(14),MAXNQ(14),MFE(14),
     4MLC( 14) ,NCELS(5),NQ(14),PARAM(20,4),QTIME(14),SSUMA(10,5),SUMA(
     50,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR,JTRIB(12),IX(8),MLE(14)
      COMMON/RAJ/NF1,NS11,NO11,NS22,NO22,FNS01,FNO01,NRSPQU,NRSPHA,NRSP
     1Q,NRSQQU,NRSQHA,NRSQTQ,ODPERH,TIMREP,NSTOCK(2500),NSLOST(2500),NS
     2LE(2500),NRSTOK(2500),NONORD(2500),NORDER,NF22,IZ,NRSC,FFAST,FSLO
     3P,NTLREP,NUMRST
      COMMON/RKD/CELLF,CELLS,CELLO,NQFAST,NQSLOW,NQOCCD,KOUNT,FNRSCS
      DIMENSION NSET(3000),QSET(1000)
C
C
C       DEFINITION OF THE NON-GASP VARIABLES
C
C       ODPERH=NUMBER CF ORDERS PER HOUR
C       TIMREP=TIME BETWEEN REPORTS
C       NORDER=NUMBER CF ORDERS
C       NF1   =NUMBER CF ITEMS OF FAST VARIETY 1/4 INCH THICK
C       NF2   =NUMBER OF ITEMS OF FAST VARIETY 1/2 INCH THICK
C       NF3   =NUMBER CF ITEMS OF FAST VARIETY 3/4 INCH THICK
C       NS1   =NUMBER CF ITEMS OF SLOW VARIETY 1/4 INCH THICK
C       NS2   =NUMBER OF ITEMS OF SLOW VARIETY 1/2 INCH THICK
C       NS3   =NUMBER OF ITEMS OF SLOW VARIETY 3/4 INCH THICK
C       NO1   =NUMBER CF ITEMS OF OCC. DEMAND VARIETY 1/4 INCH THICK
C       NO2   =NUMBER OF ITEMS OF OCC. DEMAND VARIETY 1/2 INCH THICK
C       NO3   =NUMBER CF ITEMS OF OCC. DEMAND VARIETY 3/4 INCH THICK
C       NSTOCK=STOCK ON HAND OF ANY ITEM
C       NSALE =SALES MADE OF ANY ITEM
C       NSLOST=LOST SALES OF ANY ITEM
C       NRSTOK=NUMBER CF RESTOCKINGS OF ANY ITEM
C       NONORD=NUMBER CF UNITS OF ANY ITEM ON ORDER BUT NOT RESTOCKED
C       NRSPQU=RESTOCK POINT OF 1/4 INCH THICK ITEMS
C       NRSPHA=RESTOCK POINT OF 1/2 INCH THICK ITEMS
C       NRSPTQ=RESTOCK POINT OF 3/4 INCH THICK ITEMS
C       NRSQQU=RESTOCK QUANTITY OF 1/4 INCH THICK ITEMS
C       NRSQHA=RESTOCK QUANTITY OF 1/2 INCH THICK ITEMS
```

```
C         NRSQTQ=RESTOCK QUANTITY OF 3/4 INCH THICK ITEMS
C         FREQS =SALES FREQUENCY OF SLOW VARIETY ITEMS
C         FFAST =PERCENTAGE MOVEMENT OF FAST VARIETY ITEMS
C         FSLOW =PERCENTAGE MOVEMENT OF SLOW VARIETY ITEMS
C         FOCCD =PERCENTAGE MOVEMENT OF OCC. DEMAND VARIETY ITEMS
C         FRACF =FRACTION OF THE FAST VARIETY ITEMS
C         FRACS =FRACTION OF THE SLOW VARIETY ITEMS
C         FRACO =FRACTION OF THE OCC. DEMAND VARIETY ITEMS
C         NTLREP=NUMBER OF THE LAST DETAILED REPORT REQUIRED
C         NUMRST=TOTAL NUMBER OF RESTOCKINGS MADE
C         CELLF =CELL WIDTH OF FAST MOVING ITEMS
C         CELLS =CELL WIDTH OF SLOW MOVING ITEMS
C         CELLO =CELL WIDTH OF OCC. DEMAND MOVING ITEMS
C         NQFAST=NUMBER OF FAST VARIETY ITEMS SELECTED
C         NQSLOW=NUMBER OF SLOW VARIETY ITEMS SELECTED
C         NQOCCD=NUMBER OF OCC. DEMAND VARIETY ITEMS SELECTED
C         KOUNT =SERIAL NUMBER OF THE REPORTS
C         NRSC  =NUMBER OF RESTOCKING CLERKS AT ANY TIME
C         FNRSCS=TOTAL NUMBER OF CLERKS INITIALLY EMPLOYED
C
      READ 1,ODPERH,TIMREP
      PRINT 1,ODPERH,TIMREP
    1 FORMAT(2F15.5)
      READ 2,NF1,NF2,NF3,NS1,NS2,NS3,NO1,NO2,NO3
      PRINT 2,NF1,NF2,NF3,NS1,NS2,NS3,NO1,NO2,NO3
    2 FORMAT(9I8)
      READ 3,NSTQU,NSTHA,NSTTQ
      PRINT 3,NSTQU,NSTHA,NSTTQ
    3 FORMAT(3I10)
      READ 3,NRSPQU,NRSPHA,NRSPTQ
      PRINT 3,NRSPQU,NRSPHA,NRSPTQ
      READ 3,NRSQQU,NRSQHA,NRSQTQ
      PRINT 3,NRSQQU,NRSQHA,NRSQTQ
      READ 4,FRACF,FRACS,FRACO
      PRINT 4,FRACF,FRACS,FRACO
    4 FORMAT(3F10.6)
      READ 6,NTOTAL
      PRINT 6,NTOTAL
    6 FORMAT(I10)
      FTOTAL=NTOTAL
      READ 7,FREQS
      PRINT 7,FREQS
    7 FORMAT(F5.1)
      READ 9,NRSC
      PRINT 9,NRSC
      FNRSCS=NRSC
      READ 9,NTLREP
      PRINT 9,NTLREP
    9 FORMAT(I10)
      FREQF=FREQS*FREQS
```

```
      SUMFRQ=1.0+FREQS+FREQF
      FFAST=FREQF/SUMFRQ
      FSLOW=FREQS/SUMFRQ
      FOCCD=1.0/SUMFRQ
      FSLOWP=FSLOW+FFAST
      CELLF=FFAST/(FTOTAL*FRACF)
      CELLS=FSLOW/(FTOTAL*FRACS)
      CELLO=FOCCD/(FTOTAL*FRACO)
      PRINT 4,FFAST,FSLCW,FOCCD
      PRINT 4,CELLF,CELLS,CELLO
      IZ=81143
C
C        INITIALIZING OF THE NON GASP VARIABLES
C
      NCRDR=1
      NPRNT=3
      NORDER=0
      NUMRST=0
      NQFAST=0
      NQSLOW=0
      NQOCCD=0
      KOUNT=0
      DO 5 I=1,NTOTAL
      NONORD(I)=0
      NRSTOK(I)=0
      NSALE(I)=0
      NSLOST(I)=0
    5 CONTINUE
C
C        ASSIGNING OF INITIAL STOCK TO EACH ITEM BY CALLING RANDOM
C        NUMBER YFL. ' INITIAL STOCK=RESTOCK POINT+YFL*RESTOCK QUANTITY
C
      DO 10 I=1,NF1
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPQU+YFL*NRSQQU
   10 CONTINUE
      NF12=NF1+1
      NF22=NF2+NF1
      DO 20 I=NF12,NF22
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPHA+YFL*NRSQHA
   20 CONTINUE
      NF23=NF22+1
      NF33=NF3+NF22
      DO 30 I=NF23,NF33
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPTQ+YFL*NRSQTQ
   30 CONTINUE
      NS01=NF33+1
      FNS01=NS01
```

```
      NS11=NS1+NF33
      DO 40 I=NS01,NS11
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPQU+YFL*NRSQQU
   40 CONTINUE
      NS12=NS11+1
      NS22=NS11+NS2
      DO 50 I=NS12,NS22
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPHA+YFL*NRSQHA
   50 CONTINUE
      NS23=NS22+1
      NS33=NS22+NS3
      DO 60 I=NS23,NS33
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPTQ+YFL*NRSQTQ
   60 CONTINUE
      NO01=NS33+1
      FNO01=NO01
      NO11=NO1+NS33
      DO 70 I=NO01,NO11
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPQU+YFL*NRSQQU
   70 CONTINUE
      NO12=NO11+1
      NO22=NO11+NO2
      DO 80 I=NO12,NO22
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPTQ+YFL*NRSQTQ
   80 CONTINUE
      NO23=NO22+1
      NO33=NO22+NO3
      DO 90 I=NO23,NO33
      CALL RANDN(IZ,IY,YFL)
      NSTOCK(I)=NRSPHA+YFL*NRSQHA
   90 CONTINUE
      CALL GASP(NSET,QSET)
      STOP
      END
```

```
      SUBROUTINE EVNTS(IT,NSET,QSET)
C
C        THIS SUBROUTINE SELECTS THE APPROPRIATE EVENTS AT SCHEDULED
C        TIMES.
C
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS,ATRIB(10),
     3ENQ(14),INN(14),JCELS(10,30),KRANK(14),MAXNQ(14),MFE(14),
     4MLC( 14) ,NCELS(5),NQ(14),PARAM(20,4),QTIME(14),SSUMA(10,5),SUMA(
     50,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR,JTRIB(12),IX(8),MLE(14)
      DIMENSION NSET(1),QSET(1)
C
C        SELECT THE EVENT 1 IF IT=1, EVENT 2 IF IT=2, EVENT 3 IF IT=3
C
      GO TO  (1,2,3),IT
    1 CALL ORDERS(NSET,QSET)
      RETURN
    2 CALL RESTOK(NSET,QSET)
      RETURN
    3 CALL REPORT(NSET,QSET)
      RETURN
      END
```

```
      SUBROUTINE ORDERS(NSET,QSET)
C
C        THIS SUBROUTINE SIMULATES ORDERS IN THIS AUTOMATIC ORDER
C        PICKING SYSTEM.  ORDERS ARE SCHEDULED AT THE INTERVALS OF
C        1/NUMBER OF ORCERS PER HOUR.
C
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS,ATRIB(10),
     3ENQ(14),INN(14),JCELS(10,30),KRANK(14),MAXNQ(14),MFE(14),
     4MLC( 14) ,NCELS(5),NQ(14),PARAM(20,4),QTIME(14),SSUMA(10,5),SUMA(
     50,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR,JTRIB(12),IX(8),MLE(14)
      COMMON/RAJ/NF1,NS11,NO11,NS22,NO22,FNS01,FNO01,NRSPQU,NRSPHA,NRSP
     1Q,NRSQQU,NRSQHA,NRSQTQ,ODPERH,TIMREP,NSTOCK(2500),NSLOST(2500),NS
     2LE(2500),NRSTOK(2500),NONORD(2500),NORDER,NF22,IZ,NRSC,FFAST,FSLO
     3P,NTLREP,NUMRST
      COMMON/RKD/CELLF,CELLS,CELLO,NQFAST,NQSLOW,NQOCCD,KOUNT,FNRSCS
      DIMENSION NSET(1),QSET(1)
C
C        SCHEDULE NEXT CRDER.
C
      ATRIB(1)=TNOW+1.0/ODPERH
    8 CALL FILEM(1,NSET,QSET)
      TNOW=ATRIB(1)
C
C        GENERATE ITEMS IN THE CURRENT ORDER BY CALLING NPOSN
C
      NOITEM=NPOSN(1,1)
      FNITEM=NOITEM
      CALL HISTO(FNITEM,1.0,1.0,1)
      IF(NOITEM-0) 2,2,1
    1 CONTINUE
C
C        CHECK EACH ITEM IN THE CURRENT ORDER WHETHER IT IS FAST
C        MOVING, SLOW MOVING OR OCC. DEMAND MOVING.
C
      DO 10 I=1,NOITEM
      CALL RANDN(IZ,IY,YFL)
      IF (YFL-FFAST) 11,11,12
C
C        FAST VARIETY ITEMS
C
C
C        ASSIGN STOCK NUMBER TO THE ITEM
C
   11 NST=YFL/CELLF+1.0
      NQFAST=NQFAST+1
C
C        TEST STOCK LEVEL TO SEE IF THE CURRENT DEMAND CAN BE MET,
C
```

```
      IF (NSTOCK(NST)) 22,23,24
C
C        IF STOCK IS NEGATIVE CALL ERROR(101).
C
   22 CALL ERROR  (101,NSET,QSET)
      RETURN
C
C        IF STOCK IS ZERO INCREMENT LOST SALES BY ONE
C
   23 NSLOST(NST)=NSLOST(NST)+1
      GO TO 400
C
C        IF STOCK IS GREATER THAN ZERO  INCREMENT NUMBER OF SALES
C        BY ONE AND DECREMENT THE STOCK ON HAND BY ONE.
C
   24 NSALE(NST)=NSALE(NST)+1
      NSTOCK(NST)=NSTOCK(NST)-1
C
C        CHECK THE RESTOCKING POINT AND QUANTITY.
C
  400 IF(NST-NF1) 100,100,110
  100 NRESTP=NRSPQU
      NRESTQ=NRSQQU
      GO TO 54
  110 IF(NST-NF22) 120,120,130
  120 NRESTP=NRSPHA
      NRESTQ=NRSQHA
      GO TO 54
  130 NRESTP=NRSPTQ
      NRESTQ=NRSQTQ
   54 JTRIB(2)=1
      JTRIB(4)=NRESTQ
C
C        CALCULATE POSITION BY ADDING STOCK ON HAND AND NUMBER OF
C        ITEMS ON ORDER. IF THE POSITION IS LESS THAN OR EQUAL TO
C        THE RESTOCK POINT ,GO TO NEXT ITEM ON ORDER. OTHERWISE CHECK
C        IF THERE IS ANY ITEM WAITING TO BE RESTOCKED IN FILE 2.
C
   55 NPOS=NSTOCK(NST)+NONORD(NST)
      IF(NPOS-NRESTP) 59,59,10
   59 CONTINUE
C
C        IF SO PUT THE CURRENT ITEM IN THE FILE 2. IF NO ITEM WAITING
C        CHECK TO SEE IF ANY RESTOCKING CLERK IS AVAILABLE. IF SO
C        SCHEDULE RESTOCKING OF THE CURRENT ITEM.
C        IF NO RESTOCKING CLERK IS AVAILABLE PUT CURRENT ITEM IN
C        THE FILE 2.
C
      IF(NQ(2)) 510,515,530
  510 CALL ERROR(102,NSET,QSET)
```

```
      RETURN
    ͻ IF(NRSC) 540,530,550
   +0 CALL ERROR(103,NSET,QSET)
      RETURN
  530 ATRIB(2)=TNOW
      JTRIB(3)=NST
      CALL FILEM(2,NSET,QSET)
      NONORD(NST)=NRESTC+NONORD(NST)
      GO TO 10
  550 ATRIB(1)=TNOW+ERLNG(1,2)
      FNRSC=NRSC
      CALL TMST(FNRSC,TNOW,1,NSET,QSET)
      NRSC=NRSC-1
      JTRIB(1)=2
      JTRIB(3)=NST
      CALL FILEM(1,NSET,QSET)
      NONORD(NST)=NRESTC+NONORD(NST)
      GO TO 10
C
C
C         SLOW VARIETY ITEMS
C
   12 IF(YFL-FSLOWP) 13,13,14
C
C         ASSIGN STOCK NUMBER TO THE ITEM
C
   13 NST=(YFL-FFAST)/CELLS+FNS01
      NQSLOW=NQSLOW+1
C
C         TEST STOCK LEVEL TO SEE IF THE CURRENT DEMAND CAN BE MET,
C
      IF(NSTOCK(NST)) 32,33,34
C
C         IF STOCK IS NEGATIVE CALL ERROR(101).
C
   32 CALL ERROR  (101,NSET,QSET)
      RETURN
C
C         IF STOCK IS ZERO INCREMENT LOST SALES BY ONE
C
   33 NSLOST(NST)=NSLOST(NST)+1
      GO TO 410
C
C         IF STOCK IS GREATER THAN ZERO  INCREMENT NUMBER OF SALES
C         BY ONE AND DECREMENT THE STOCK ON HAND BY ONE.
C
   34 NSALE(NST)=NSALE(NST)+1
      NSTOCK(NST)=NSTOCK(NST)-1
C
C         CHECK THE RESTOCKING POINT AND QUANTITY.
```

```
C
  410 IF(NST-NS11) 200,200,210
  200 NRESTP=NRSPQU
      NRESTQ=NRSQQU
      GO TO 56
  210 IF(NST-NS22) 220,220,230
  220 NRESTP=NRSPHA
      NRESTQ=NRSQHA
      GO TO 56
  230 NRESTP=NRSPTQ
      NRESTQ=NRSQTQ
   56 JTRIB(2)=2
      JTRIB(4)=NRESTQ
      GO TO 55
C
C
C         OCC. DEMAND VARIETY ITEMS
C         ASSIGN STOCK NUMBER TO THE ITEM
C
   14 NST=(YFL-FSLOWP)/CELLO+FN001
      NQOCCD=NQOCCD+1
C
C         TEST STOCK LEVEL TO SEE IF THE CURRENT DEMAND CAN BE MET,
C
      IF(NSTOCK(NST)) 42,43,44
C
C         IF STOCK IS NEGATIVE CALL ERROR(101).
C
   42 CALL ERROR  (101,NSET,QSET)
      RETURN
C
C         IF STOCK IS ZERO INCREMENT LOST SALES BY ONE
C
   43 NSLOST(NST)=NSLOST(NST)+1
      GO TO 420
C
C         IF STOCK IS GREATER THAN ZERO  INCREMENT NUMBER OF SALES
C         BY ONE AND DECREMENT THE STOCK ON HAND BY ONE.
C
   44 NSALE(NST)=NSALE(NST)+1
      NSTOCK(NST)=NSTOCK(NST)-1
C
C         CHECK THE RESTCCKING POINT AND QUANTITY.
C
  420 IF(NST-NO11) 300,300,310
  300 NRESTP=NRSPQU
      NRESTQ=NRSQQU
      GO TO 57
  310 IF(NST-NO22) 320,320,330
  320 NRESTP=NRSPHA
```

```
      NRESTQ=NRSQHA
      GO TO 57
  330 NRESTP=NRSPTQ
      NRESTQ=NRSQTQ
   57 JTRIB(2)=3
      JTRIB(4)=NRESTQ
      GO TO 55
   10 CONTINUE
C
C        IF ALL THE ITEMS ARE OVER  INCREASE NUMBER OF ORDERS BY
C        ONE AND RETURN.
C
    2 NORDER=NORDER+1
      RETURN
      END
```

```
      SUBROUTINE RESTOK(NSET,QSET)
C
C        THIS SUBROUTINE RESTOCKS ITEMS WHENEVER ASKED TO DO.
C
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS,ATRIB(10),
     3ENQ(14),INN(14),JCELS(10,30),KRANK(14),MAXNQ(14),MFE(14),
     4MLC( 14) ,NCELS(5),NQ(14),PARAM(20,4),QTIME(14),SSUMA(10,5),SUMA
     50,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR,JTRIB(12),IX(8),MLE(14)
      COMMON/RAJ/NF1,NS11,NO11,NS22,NO22,FNS01,FNO01,NRSPQU,NRSPHA,NRS
     1Q,NRSQQU,NRSQHA,NRSQTQ,ODPERH,TIMREP,NSTOCK(2500),NSLOST(2500),N
     2LE(2500),NRSTOK(2500),NONORD(2500),NORDER,NF22,IZ,NRSC,FFAST,FSL
     3P,NTLREP,NUMRST
      DIMENSION NSET(1),QSET(1)
C
C        INCREMENT THE STOCK ON HAND BY RESTOCK QUANTITY AND DECREMENT
C        THE QUANTITY ON HAND BY THE SAME.
C
      LN=JTRIB(2)
      NSTR=JTRIB(3)
      STOCKN=NSTOCK(NSTR)
      CALL COLCT(STOCKN,LN,NSET,QSET)
      NONORD(NSTR)=NONORD(NSTR)-JTRIB(4)
      NSTOCK(NSTR)=NSTOCK(NSTR)+JTRIB(4)
      NRSTOK(NSTR)=NRSTCK(NSTR)+1
      NUMRST=NUMRST+1
C
C        TEST TO SEE IF THERE IS ANY ITEM WAITING TO BE RESTOCKED,
C        IF NEGATIVE CALL ERROR(103).
C
      IF(NQ(2)) 1,2,3
    1 CALL ERROR(101,NSET,QSET)
      RETURN
C
C        IF ZERO INCREMENT THE NUMBER OF AVAILABLE RESTOCKING CLERKS
C        BY ONE AND RETURN.
C
    2 FNRSC=NRSC
      CALL TMST(FNRSC,TNOW,1,NSET,QSET)
      NRSC=NRSC+1
      RETURN
C
C        IF SOME ITEM WAITING , REMOVE FIRST ENTRY FROM FILE 2 AND
C        SCHEDULE RESTOCKING FOR THAT ITEM AND RETURN.
C
    3 MFE2=MFE(2)
      CALL RMOVE(MFE2,2,NSET,QSET)
      ATRIB(1)=TNOW+ERLNG(1,2)
      JTRIB(1)=2
```

```
CALL FILEM(1,NSET,QSET)
FNRSC=NRSC
CALL TMST(FNRSC,TNOW,1,NSET,QSET)
RETURN
END
```

```
      SUBROUTINE REPORT(NSET,QSET)
C
C        THIS SUBROUTINE PRINTS OUT SIMULATION REPORT WHENEVER CALLED.
C
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS,ATRIB(10),
     3ENQ(14),INN(14),JCELS(10,30),KRANK(14),MAXNQ(14),MFE(14),
     4MLC( 14) ,NCELS(5),NQ(14),PARAM(20,4),QTIME(14),SSUMA(10,5),SUMA(
     50,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR,JTRIB(12),IX(8),MLE(14)
      COMMON/RAJ/NF1,NS11,NO11,NS22,NO22,FNS01,FNO01,NRSPQU,NRSPHA,NRSP
     1Q,NRSQQU,NRSQHA,NRSQTQ,ODPERH,TIMREP,NSTOCK(2500),NSLOST(2500),NS
     2LE(2500),NRSTOK(2500),NONORD(2500),NORDER,NF22,IZ,NRSC,FFAST,FSLO
     3P,NTLREP,NUMRST
      COMMON/RKD/CELLF,CELLS,CELLO,NQFAST,NQSLOW,NQOCCD,KOUNT,FNRSCS
      DIMENSION NSET(1),QSET(1)
      KOUNT=KOUNT+1
      PRINT 11,KOUNT,TNCW
   11 FORMAT(1HO,10X,' SIMULATION REPORT NUMBER ',I3,' AT TIME ',F6.2,'
     1HOURS',//)
      ATRIB(1)=TNOW+TIMREP
      JTRIB(1)=3
      CALL FILEM(1,NSET,QSET)
      IF(SSUMA(1,1)) 6,6,7
    7 IF(KOUNT-NTLREP) 3,4,4
    4 CONTINUE
      PRINT 12
   12 FORMAT(1H ,' STOCK NUMBER    STOCK ON    TOTAL NUMBER   NUMBER
     1F   NUMBER  OF',/,20X,'HAND',8X,'OF SALES',5X,'RESTOCKINGS',3X,'L
     2ST SALES',//)
      DO 10 I=1,2500
      PRINT 22,I,NSTOCK(I),NSALE(I),NRSTOK(I),NSLOST(I)
   22 FORMAT(1H ,5(I9,5X))
   10 CONTINUE
      PRINT 5,NQFAST,NQSLOW,NQOCCD
    5 FORMAT(1HO,' NUMBER OF FAST MOVING ITEMS SELECTED ARE  ',I8,/,'
     1UMBER OF SLOW MOVING ITEMS SELECTED ARE  ',I8,/,'  NUMBER OF OCC.
     2DEMAND ITEMS SELECTED ARE  ',I8)
      PRINT 1,NORDER
    1 FORMAT(1HO,' TOTAL NUMBER OF ORDERS IS ',I8,//)
C
C        CALCULATION OF RESTOCKING CLERKS UTILIZATION.
C
    3 VARNW=SSUMA(1,2)/SSUMA(1,1)
      AUTLZ=(1.0-VARNW/FNRSCS)*100.00
      PRINT 2,AUTLZ,NRSC,MAXNQ(2),NQ(2),NUMRST
    2 FORMAT(' AVERAGE UTILIZATION IS ',F6.2,/,' NUMBER OF RESTOCKING C
     1ERKS AVAILABLE IS ',I4,/,' MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2
     2IS ',I4,I8,/,' NUMBER OF RESTOCKINGS IS ',I6,//)
    6 RETURN
      END
```

```
      SUBROUTINE OTPUT(NSET,QSET)
C
C        THIS SUBROUTINE CALLS THE FINAL SIMULATION REPORT.
C
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(14),IMM,MAXQS,MAXNS,ATRIB(10),
     3ENQ(14),INN(14),JCELS(10,30),KRANK(14),MAXNQ(14),MFE(14),
     4MLC( 14) ,NCELS(5),NQ(14),PARAM(20,4),QTIME(14),SSUMA(10,5),SUMA
     50,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR,JTRIB(12),IX(8),MLE(14)
      DIMENSION NSET(1),QSET(1)
      CALL REPORT(NSET,CSET)
      RETURN
      END
```

APPENDIX D

EXPLANATION OF THE INPUT TO THE COMPUTER PROGRAM

I. Explanation and values of the non-GASP variables read in by the main program. The formats are given below each variable.

Input card number									
1	ODPERH F 15.5				TIMREP F 15.5				
2	NF1 I8	NF2 I8	NF3 I8	NS1 I8	NS2 I8	NS3 I8	NO1 I8	NO2 I8	NO3 I8
3	NSTQU I 10	NSTHA I 10	NSTTQ I 10						
4	NRSPQU I 10	NRSPHA I 10	NRSPTQ I 10						
5	NRSQQU I 10	NRSQHA I 10	NRSQTQ I 10						
6	FRACF F 10.6	FRACS F 10.6	FRACD F 10.6						
7	N TOTAL I 10								
8	FREQS F 5.1								
9	NRSC I 10								
10	NTLREP I 10								

Values of the variables for Model I

Input card number									
1	1200.0			0.25					
2	1700	200	100	340	40	20	85	10	5
3	240	120	80						
4	80	40	20						
5	160	80	60						
6	0.80	0.16	0.04						
7	2500								
8	8.0								
9	2								
10	200								

Values of the variables for Model II

Input card number									
1	1200.0			0.25					
2	1700	200	100	340	40	20	85	10	5
3	240	120	80						
4	20	20	20						
5	220	100	60						
6	0.80	0.16	0.04						
7	2500								
8	8.0								
9	2								
10	200								

INPUT GASP DATA

ECHO CHECK CN INPUT DATA

NAME	NPROJ	MON	NDAY	NYR	NRUNS
DHINGRA,R.K	1	6	5	1970	1

NPRMS	NHIST	NCLCT	NSTAT	ID	IM	NOQ	MXC	IMM
2	1	3	1	500	4	2	30	2

NCELS

28

KRANK

1 2

INN

1 1

PARAM

7.5000 0.0 100.0000 0.0

PARAM

C.0250 0.0001 0.2500 1.0000

MSTOP	JCLR	NORPT	NEP	TBEG	TFIN	NSEED
1	1	0	7	0.0	50.00C	1

SEEDS FOR RANDOM NUMBER GENERATION

81143

INITILIZATION OF THE FILES

FILE NC., ATTRIBUTES

-1	0	0	0	0
1	1	0	0	0
C.C	0.0			
1	3	0	0	0
C.2500	0.0			
0	0	0	0	0

APPENDIX E

SAMPLES OF THE SIMULATION RESULTS

AND GASP SUMMARY REPORTS

SAMPLE OF INTERMEDIATE SIMULATION RESULTS MODEL I

```
          SIMULATION REPORT NUMBER   1 AT TIME   0.25 HOURS

AVERAGE UTILIZATION IS  67.72
NUMBER OF RESTOCKING CLERKS AVAILABLE IS    2
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS    4        0
NUMBER OF RESTOCKINGS IS     21

          SIMULATION REPORT NUMBER   2 AT TIME   0.50 HOURS

AVERAGE UTILIZATION IS  63.45
NUMBER OF RESTOCKING CLERKS AVAILABLE IS    1
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS    4        0
NUMBER OF RESTOCKINGS IS     37

          SIMULATION REPORT NUMBER   3 AT TIME   0.75 HOURS

AVERAGE UTILIZATION IS  69.71
NUMBER OF RESTOCKING CLERKS AVAILABLE IS    0
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS    5        5
NUMBER OF RESTOCKINGS IS     52

          SIMULATION REPORT NUMBER   4 AT TIME   1.00 HOURS

AVERAGE UTILIZATION IS  77.83
NUMBER OF RESTOCKING CLERKS AVAILABLE IS    0
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS   14       10
NUMBER OF RESTOCKINGS IS     69

          SIMULATION REPORT NUMBER   5 AT TIME   1.25 HOURS

AVERAGE UTILIZATION IS  80.60
NUMBER OF RESTOCKING CLERKS AVAILABLE IS    0
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS   14        5
NUMBER OF RESTOCKINGS IS     90
```

SAMPLE OF INTERMEDIATE SIMULATION RESULTS MODEL II

SIMULATION REPORT NUMBER 1 AT TIME 0.25 HOURS

AVERAGE UTILIZATION IS 76.32
NUMBER OF RESTOCKING CLERKS AVAILABLE IS 2
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS 3 0
NUMBER OF RESTOCKINGS IS 16

SIMULATION REPORT NUMBER 2 AT TIME 0.50 HOURS

AVERAGE UTILIZATION IS 53.28
NUMBER OF RESTOCKING CLERKS AVAILABLE IS 1
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS 3 0
NUMBER OF RESTOCKINGS IS 27

SIMULATION REPORT NUMBER 3 AT TIME 0.75 HOURS

AVERAGE UTILIZATION IS 44.39
NUMBER OF RESTOCKING CLERKS AVAILABLE IS 0
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS 3 2
NUMBER OF RESTOCKINGS IS 34

SIMULATION REPORT NUMBER 4 AT TIME 1.00 HOURS

AVERAGE UTILIZATION IS 51.21
NUMBER OF RESTOCKING CLERKS AVAILABLE IS 0
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS 3 0
NUMBER OF RESTOCKINGS IS 49

SIMULATION REPORT NUMBER 5 AT TIME 1.25 HOURS

AVERAGE UTILIZATION IS 54.49
NUMBER OF RESTOCKING CLERKS AVAILABLE IS 2
MAXIMUM NUMBER OF ITEMS IN THE QUEUE 2 IS 3 0
NUMBER OF RESTOCKINGS IS 67

GASP SUMMARY REPORT **MODEL I**

SIMULATION PROJECT NO. 1 BY DHINGRA,R.K

DATE 6/ 5/ 1970 RUN NUMBER 1

PARAMETER NO.	1	7.5000	0.0	100.0000	0.0
PARAMETER NO.	2	0.0250	0.0001	0.2500	1.0000

GENERATED DATA

CODE	MEAN	STD.DEV.	MIN.	MAX.	OBS.
1	66.4254	22.1242	17.0000	80.0000	2976
2	65.7466	22.3392	19.0000	80.0000	367
3	63.3913	23.5074	20.0000	80.0000	46

TIME GENERATED DATA

CODE	MEAN	STD.DEV.	MIN.	MAX.	TOTAL TIME
1	0.3053	0.6150	0.0	2.0000	49.9996

GENERATED FREQUENCY DISTRIBUTIONS

CODE	HISTOGRAMS
1	337 5281248236338515749754086098563750758553915235112l5
	228 72 22 4 5 0 0 0 0 0 0 0 0 0

FILE PRINTOUTS

FILE PRINTOUT, FILE NO. 1

AVERAGE NUMBER IN FILE WAS	3.6933
STD. DEV.	0.6117
MAXIMUM	4

FILE CONTENTS

NSET

2	3	0	0	0	1	9999
1	1	0	0	0	7	2
7	2	1	1883	80	9	1
9	2	2	2218	160	7777	7

QSET

2	0.500000E 02	0.0
1	0.500007E 02	0.0
7	0.500078E 02	0.497930E 02
9	0.500452E 02	0.497658E 02

FILE PRINTOUT, FILE NO. 2

AVERAGE NUMBER IN FILE WAS	3.8051
STD. DEV.	4.5055
MAXIMUM	25

GASP SUMMARY REPORT **MODEL II**

SIMULATION PROJECT NO. 1 BY DHINGRA,R.K

DATE 6/ 5/ 1970 RUN NUMBER 1

PARAMETER NO.	1	7.5000	0.0	100.0000	0.0
PARAMETER NO.	2	0.0250	0.0001	0.2500	1.0000

GENERATED DATA

CODE	MEAN	STD.DEV.	MIN.	MAX.	OBS.
1	19.8217	0.4497	17.0000	20.0000	2299
2	19.8750	0.3517	18.0000	20.0000	288
3	19.9459	0.2292	19.0000	20.0000	37

TIME GENERATED DATA

CODE	MEAN	STD.DEV.	MIN.	MAX.	TOTAL TIME
1	0.7218	0.8135	0.0	2.0000	49.9713

GENERATED FREQUENCY DISTRIBUTIONS

CODE HISTOGRAMS

1 323 5221208229038668573875628627859775105811392024441194
228 82 25 2 3 0 0 0 0 0 0 0 0 0

FILE PRINTOUTS

FILE PRINTOUT, FILE NO. 1

AVERAGE NUMBER IN FILE WAS	3.2758
STD. DEV.	0.8047
MAXIMUM	4

FILE CONTENTS

NSET

2	3	0	0	0	1	9999
1	1	0	0	0	7777	2

QSET

2	0.500000E 02	0.0
1	0.500007E 02	0.0

FILE PRINTOUT, FILE NO. 2

AVERAGE NUMBER IN FILE WAS	1.0595
STD. DEV.	2.0732
MAXIMUM	15

FILE CONTENTS

FILE IS EMPTY

SAMPLE OF THE FINAL SIMULATION REPORT MODEL II

SIMULATION REPORT NUMBER 200 AT TIME 50.00 HOURS

STOCK NUMBER	STOCK ON HAND	TOTAL NUMBER OF SALES	NUMBER OF RESTOCKINGS	NUMBER OF LOST SALES
1	160	180	1	0
2	152	181	1	0
3	239	197	1	0
4	104	189	1	0
5	181	231	1	0
6	56	183	0	0
7	129	204	1	0
8	104	182	1	0
9	186	180	1	0
10	73	234	1	0
11	95	188	1	0
12	152	198	1	0
13	128	178	1	0
14	147	202	1	0
15	217	215	1	0
16	65	185	1	0
17	32	189	0	0
18	58	208	1	0
19	34	193	0	0
20	108	191	1	0
21	146	186	1	0
22	41	215	1	0
23	53	216	1	0
24	45	227	1	0
25	176	212	1	0
26	34	189	0	0
27	23	195	0	0
28	206	203	1	0
29	157	206	1	0
30	138	176	1	0
31	82	163	1	0
32	31	205	0	0
33	178	185	1	0
34	73	193	1	0
35	152	190	1	0
36	215	201	1	0
37	238	210	1	0
38	171	210	1	0
39	204	185	1	0
40	89	191	1	0
41	190	204	1	0
42	75	194	1	0
43	119	207	1	0
44	238	174	1	0
45	66	221	1	0

APPENDIX F

PLOTS OF THE SIMULATION RESULTS

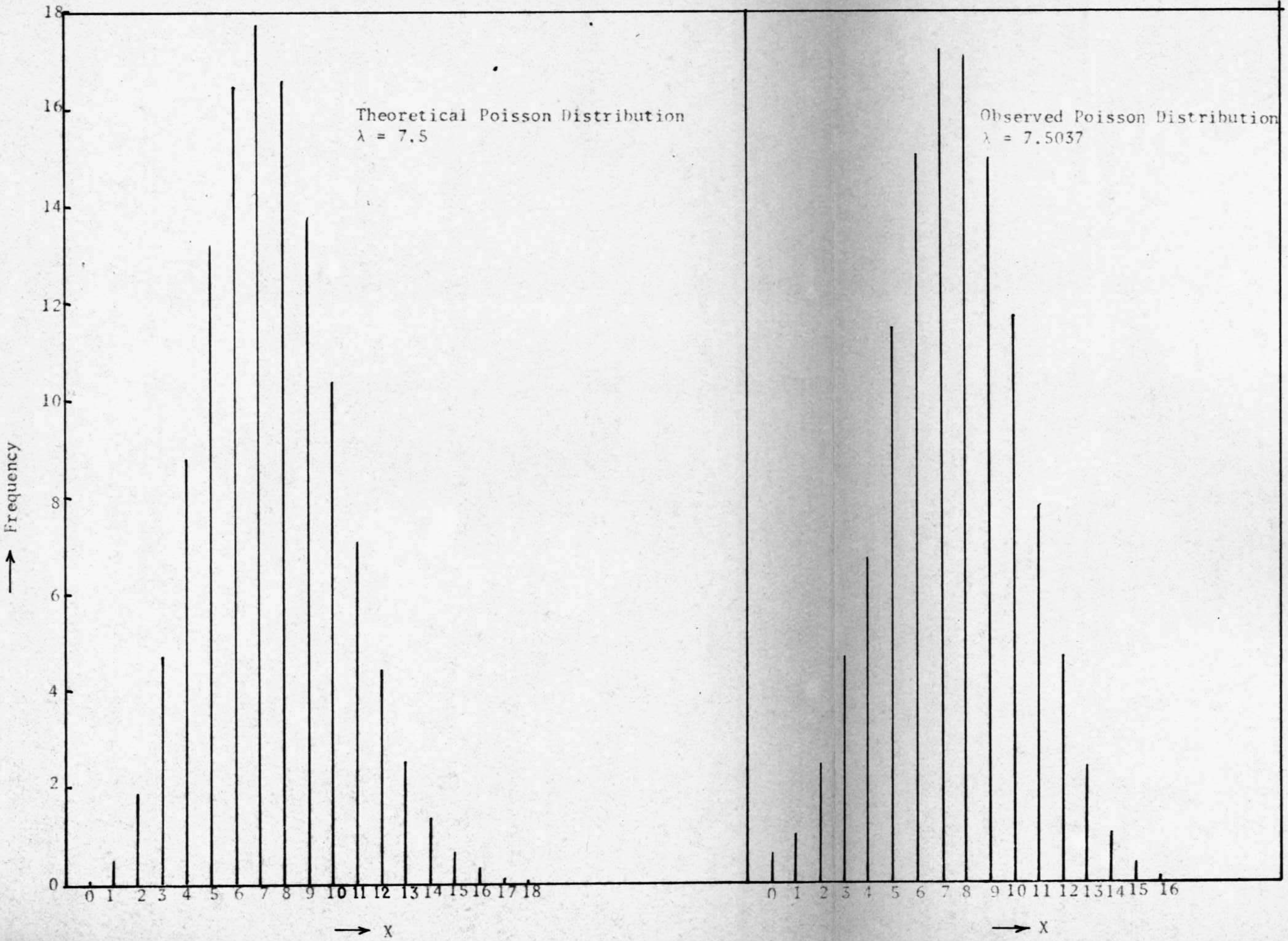


Figure 8. Theoretical and observed histograms of number of items per order

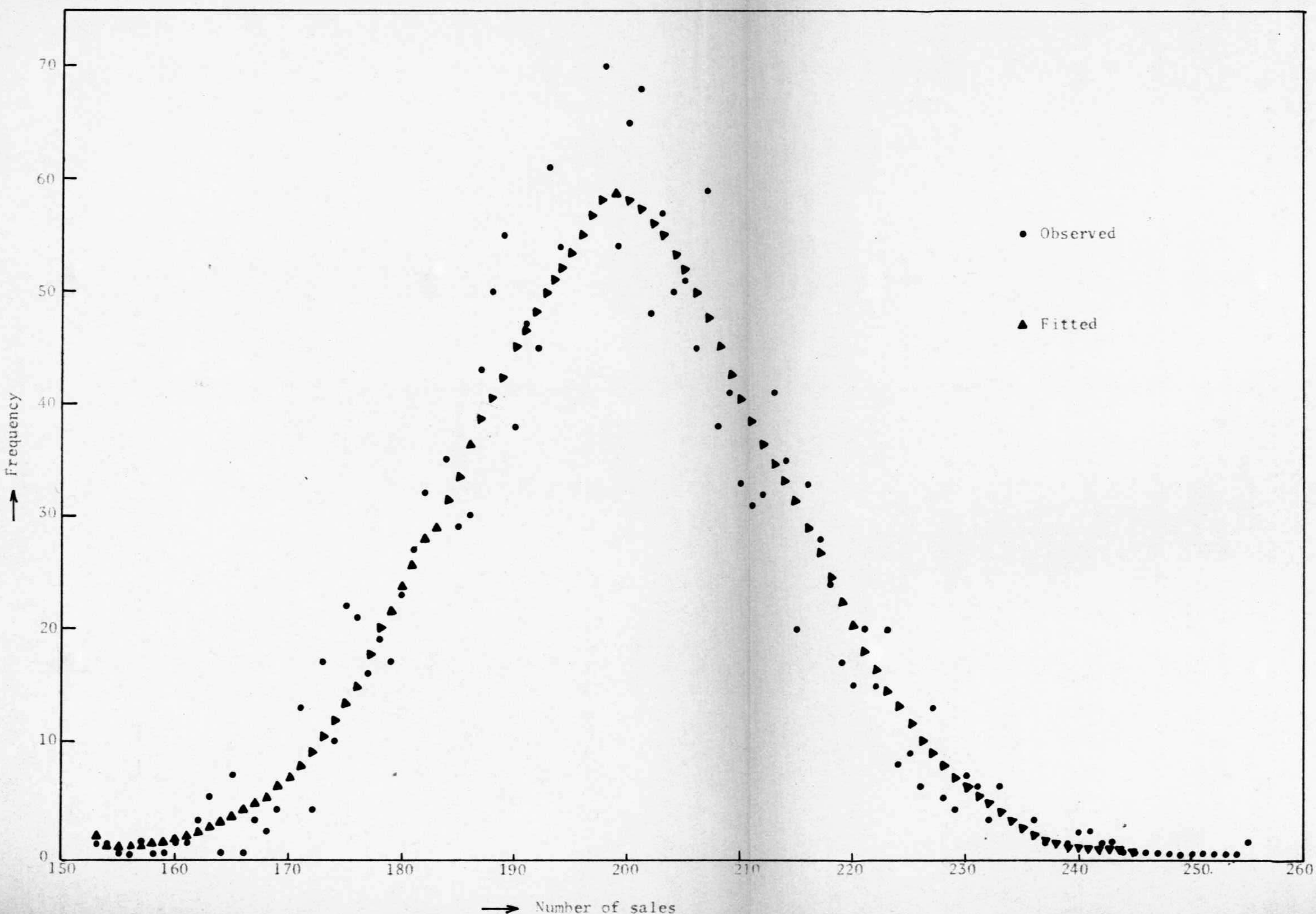


Figure 9. Distribution of the number of sales made of the fast moving items.

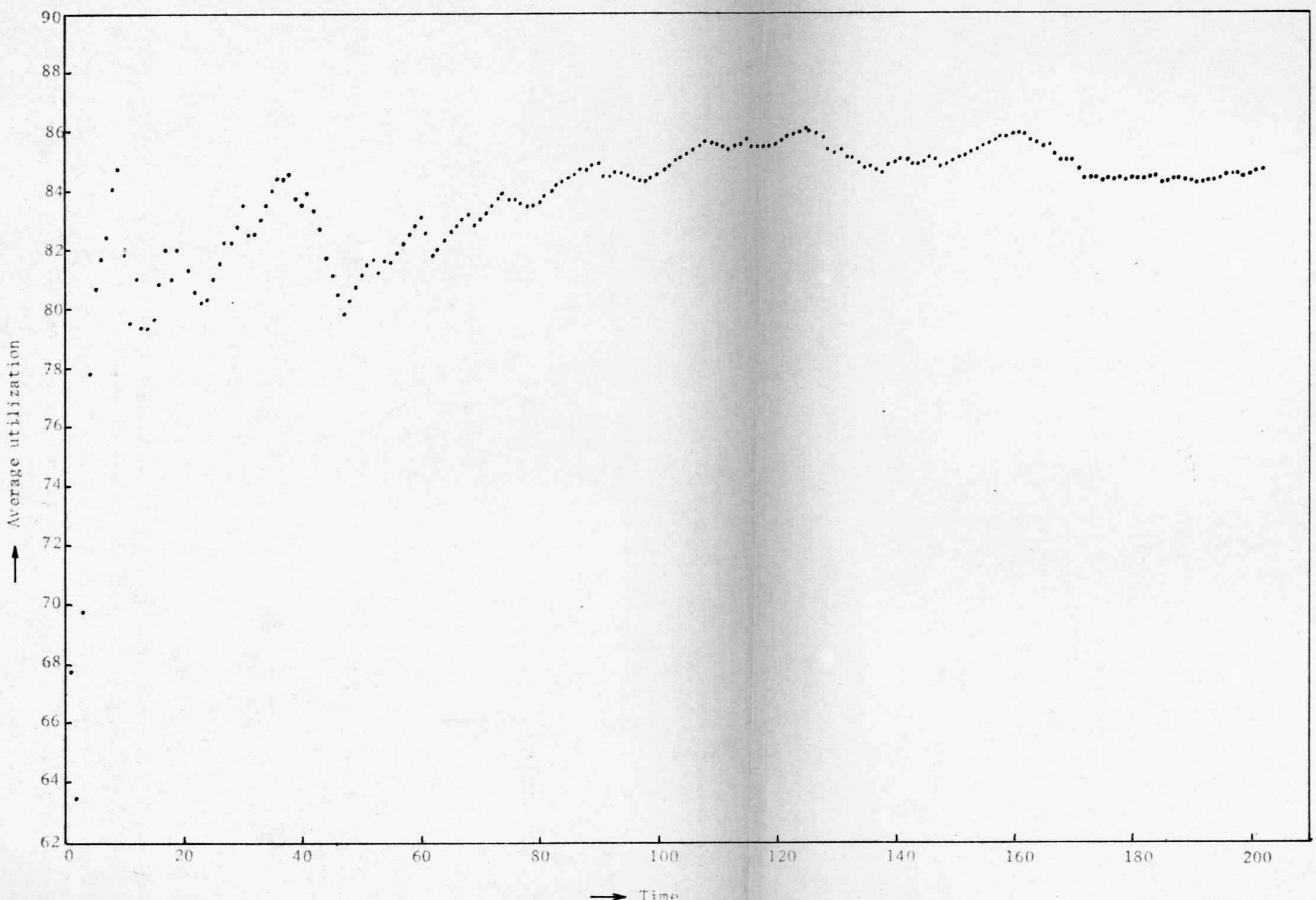


Figure 10. The plot of average utilization of the restocking clerks in Model I.

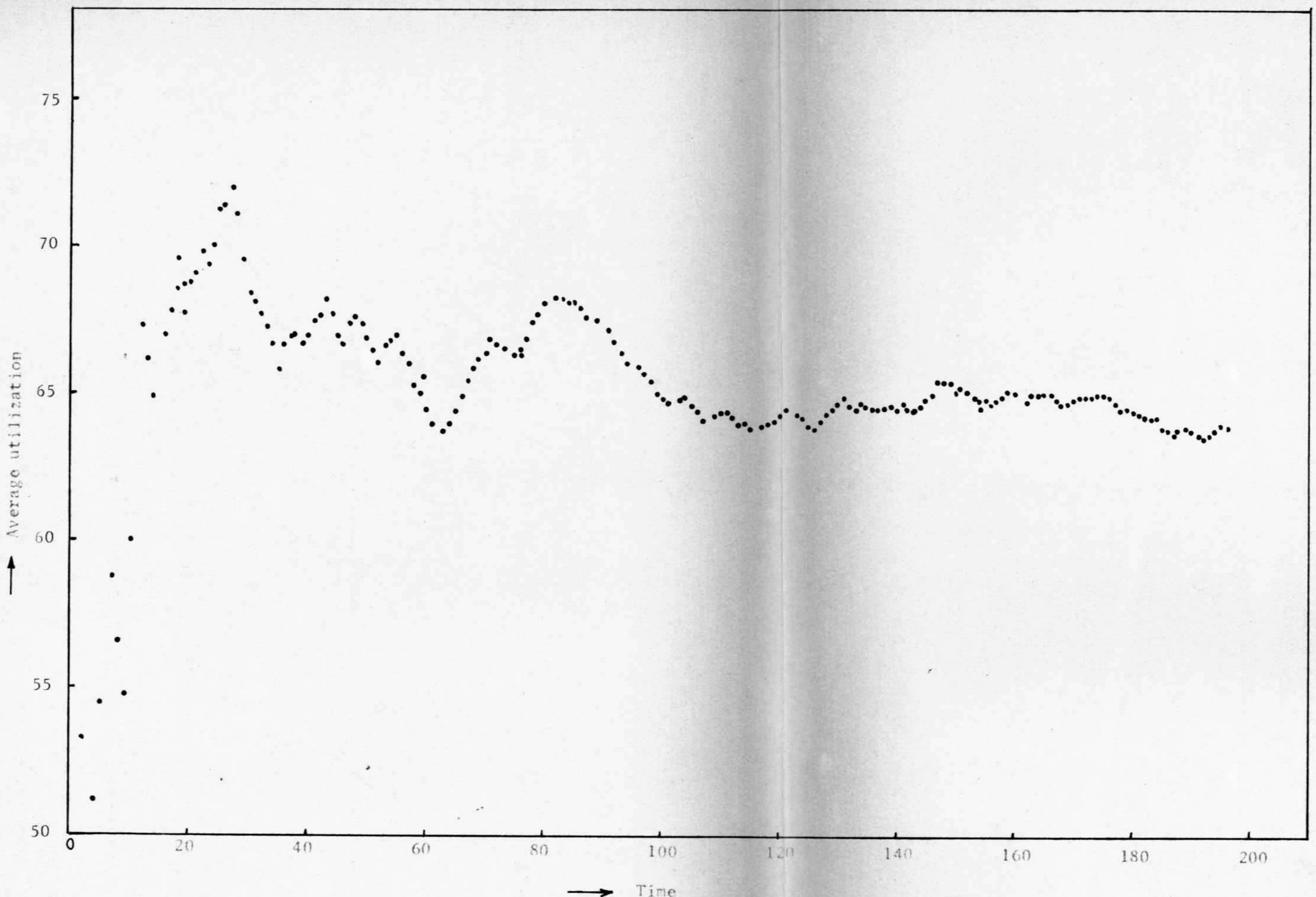


Figure 11. The plot of average utilization of the restocking clerks in Model II.

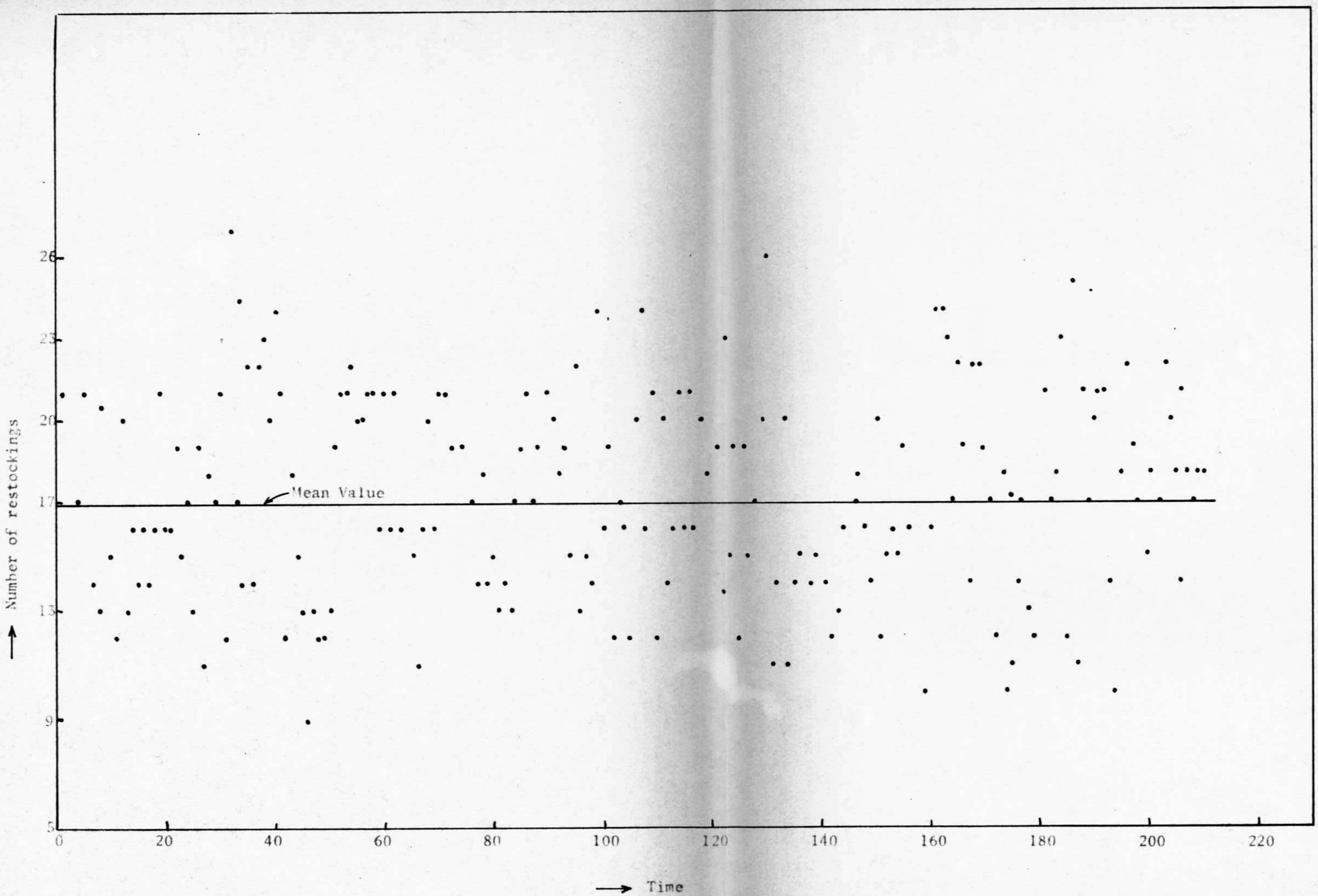


Figure 12. The plot of the number of restockings in 15 minute periods in Model I

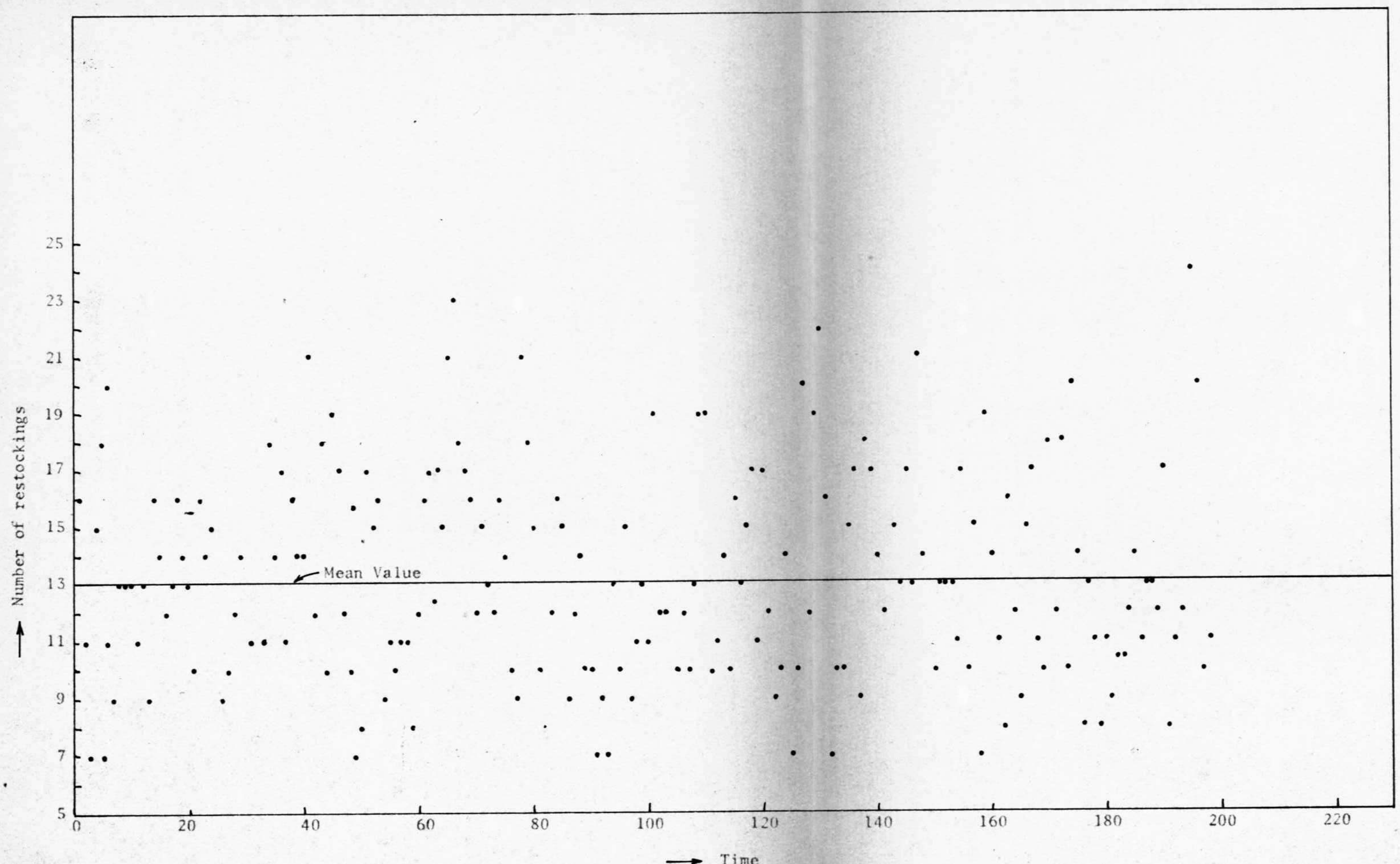


Figure 13. The plot of the number of restockings in 15 minute periods in Model II

APPENDIX G

Estimate of the restocking time for
an item

ESTIMATE OF THE RESTOCKING TIME FOR AN ITEM

The restocking time for an item is assumed to be distributed according to an exponential distribution with a mean and standard deviation of λ. This parameter is estimated by using Methods-Time Measurement (M.T.M.) as shown below.

The M.T.M. is "a procedure which analyzes any manual operation or method into the basic motions required to perform it, and assigns to each motion a pre-determined time standard which is determined by the nature of the motion and conditions under which it is made." [52] The restocking operation is broken down into fundamental motions of reach, move, grasp, etc. Then each motion is assigned pre-determined time standard [52]. The restocking operation is considered to start after the restocking clerk hears the mechanical signal to restock.

Operation	Time in T.M.U.'s *
1. Eye travel to the type-writer terminal	45.6
2. Eye focus	7.3
3. Read the information on the typewriter	278.0 #
4. Stand from the sitting position	43.4
5. Walk to the backup racks for an average distance of 65 feet	344.5
6. Look for the bin in the backup racks	43.4
7. Reach for the bin	222.5 #
8. Grasp the carton	12.9
9. Move the carton	24.3

10.	Open the carton		2.0
11.	Grasp the right number of bundles		50.0
12.	Close the carton and slide back		24.3
13.	Walk to the till needing restocking		106.0
14.	Search for correct till		45.6
15.	Reach the till		222.5
16.	Eye focus		7.3
17.	Grasp the spring		7.3
18.	Moves the spring		27.1
19.	Grasp the bundles		36.5
20.	Open the bundles		61.0
21.	Pull out the pre-punched card out of the bundles		36.5
22.	Grasp all the items		36.5
23.	Put items in the till		133.0
24.	Walk back to the restocking station		238.5
25.	Place the cards in the reader		25.5
26.	Sit down on the chair		34.7
	Total time of all the operations	=	2091.8 T.M.U.'s
		=	75.30 seconds
	Fatigue allowance, 15%	=	11.29 seconds
	Total time of restocking	=	86.53 seconds

Based on this estimate, the average restocking time of an item is taken as 90.0 seconds.

*1 T.M.U. = 0.00001 hour

#These values are estimated

DIGITAL SIMULATION OF AN ORDER PICKING SYSTEM IN AN AUTOMATIC WAREHOUSE

by

RAJ KUMAR DHINGRA

B. TECH (Honours), Indian Institute of Technology, Bombay, 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

ABSTRACT

A model of an order picking system in a computer controlled distribution center has been developed using GASP IIA. This model has been simulated on an IBM 360/50 computer. The distribution center ships a large variety of items in small individual orders. The whole range of items in the distribution center's warehouse has been divided into three groups depending on their relative movements and throughputs. An extensive study of the behaviour of these three groups of items has been made item by item. Simulation runs with full initial stocks and randomly assigned initial stocks have been made. The simulation run with the random assigning of initial stocks showed that the systems tends to attain a steady state in a relatively small amount of time. The number of restocking clerks to do an adequate service was estimated. The plots of their utilization showed that after 25 hours of operation, the system has reached steady state.

The effect of variation in the restock point was also investigated. It was observed that for a fixed till size the lowering of the restock point decreases the number of restockings for the same level of sales. The results of the two models with different restock points show that the restock point has an important bearing on the system. Another important observation from this simulation study is that the computer time is not closely related to the number of items in the system. An increase in order size increases sales activity which in turn increases computer time. On the other hand, the increase in the number of items increases only the record keeping which takes very little time. This study demonstrates the feasibility of the application of computer simulation techniques to the order picking of large variety of items in a warehouse.