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Increased Throughput by Aisle Zoning in End-of-Aisle Order Picking AS/R Systems

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Edward D. McDowell

A simulation study of end-of-aisle order picking AS/R systems is made with special emphasis on improving the system throughput by introducing a zone near the home (Input/Output) location on each side of the aisle, for storing partially picked pallets. The study considered class-based-turnover assignment policies, one with a zone and one without any zone for handling partially picked pallets. A simulation model is devised sufficiently flexible to simulate both systems. The simulation is based on discrete simulation principles using FORTRAN and the GASP IV Simulation language. Both systems are simulated under similar conditions and the effects of the three factors, average order size, number of items stored and the pick frequency of the items, each at two levels are studied and analyzed. Steady State results of the simulation with two independent replications are reported and subjected to statistical analysis. Result and analyses indicate that the introduction of zones for handling partially picked pallets does improve the system throughput by decreasing the crane

travel time, ranging from seven to 20 percent depending upon the prevailing conditions.

INCREASED THROUGHPUT BY AISLE ZONING IN END-OF-AISLE ORDER PICKING AS/R SYSTEMS

by

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CHAPTER I

INTRODUCTION

BACKGROUND

Since time immemorial mankind has been faced with the problem of moving men and materials from place to place. But it is only since World War II that materials handling has been subjected to systematic analytical techniques yielding safe, efficient, and economically implemented materials handling systems. Compared with the development of, say, the highly advanced technology of the internal combustion engine which is now about 100 years old, knowledge about materials handling is still near the beginning of the "learning curve". In the 1950s, rapidly expanding use of forklift trucks replaced the hand barrow and almost eliminated the manual off-loading of vehicles. Perhaps the most significant development in materials handling since then has been the introduction of the automatic warehouse. Several levels of warehouse automation, from complete automation without human intervention, to automation within practicable limits, has resulted in what is now widely known as Automated Storage/Retrieval Systems.

AS/R SYSTEMS

ANSI B30 Committee and the Automated Storage/Retrieval Systems (AS/RS) Product Section of the Material Handling Institute, Inc., define an AS/R System as:

> A combination of equipment and controls which handles, stores, and retrieves materials with precision, accuracy, and speed under a defined degree of automation. Systems vary from relatively simple, manually controlled order-picking machines operating in small storage structures to giant, computer-controlled storage/retrieval systems totally integrated into the manufacturing and distribution process.

A typical AS/R System consists of a storage structure capable of supporting multiple levels of loads. A recent trend has been to use a storage structure to support the roof and the skin of the building. Aisles are designed so that they not only align and stabilize the S/R machine within the storage structure, but also maintain proper operating clearances and effective distribution of floor and rack loading. Depending on the type of S/R machine used within an aisle, one or more rails are installed. The floor rails are installed either into, or on top of, floor level (Figure I-1). The top guide rail(s) stabilizes the S/R machine and minimizes the side loading imposed onto the storage structure. Mechanical end stops are located at the extreme travel limits of the S/R machine aisle. Slow down and stop sensor activators are provided at each end of the aisle. These sensors bring the S/R machine to a safe and smooth stop position before coming in contact with the end stop.

Storage/Retrieval (S/R) Machine or Stacker Crane's function in an AS/R System is to store and retrieve loads. The typical S/R machine (crane) consists of a structural frame (Figure I-2) of either a single or multiple mast construction. The structural frame of the S/R machine guides the carriage for accurate locating of the load as it is raised and lowered in the aisle of the storage structure. The carriage carries the shuttle which is the load supporting mechanism which transfers the load from the center of the aisle to the storage locations on either side of the aisle. The shuttle also transfers the loads from the racks to the center of the aisle and is capable of transferring loads to and from Input/output (I/O) stations or Home Position. AS/R Systems where a single crane serves more than one aisle, an aisle transfer car is provided to transfer the crane(s) between aisles. An aisle transfer car consists of a structure which facilitates necessary support and alignment for the transfer of the crane.

Input/output (I/O) station or "home location" is a location at which loads to and from the storage area are supported for handling by the S/R machine. An I/O station provides a suitable space beneath the load to allow an S/R machine pick-up device free access to the load. For mini-load systems the loads are slid in and out of the I/O station with little or no space required under the load. I/O stations are sometimes permanently located at the end of the aisle/storage structure, mounted on an aisle transfer car, or a part of the storage structure itself. Most I/O stations have provisions to accommodate one or more loads at any single time.

A variety of storage modules are used in AS/R systems depending on the material to be handled, and the configuration in which the

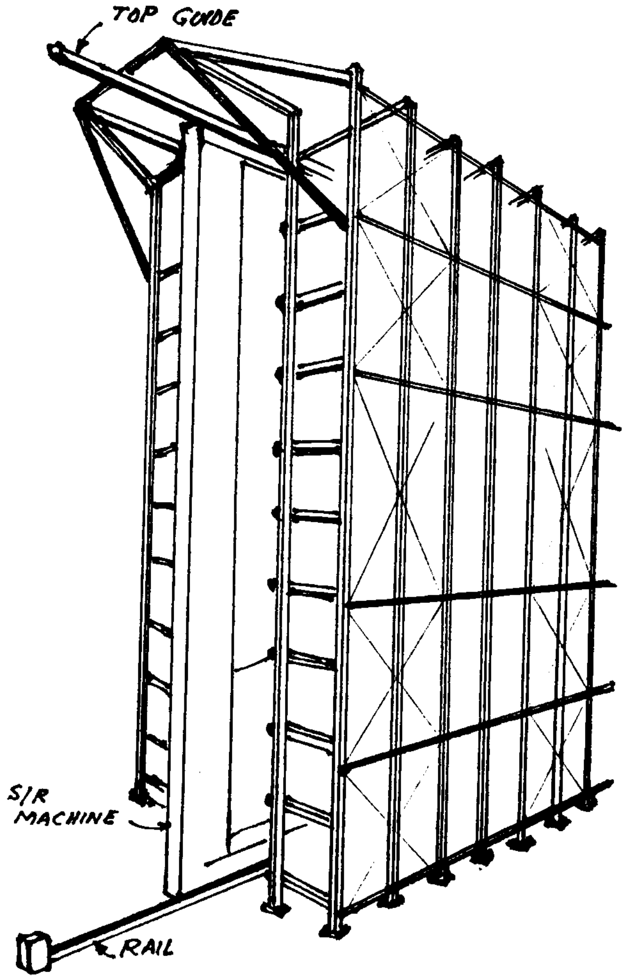


Figure I-1. A typical AS/RS aisle.

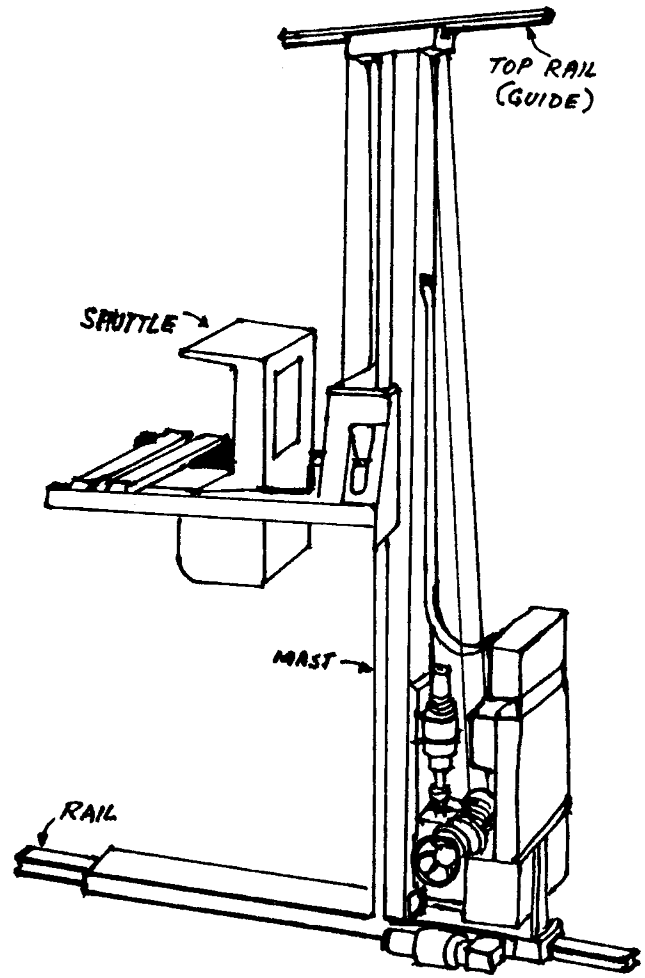


Figure I-2. A typical S/R machine (crane).

material is transferable by a S/R machine, conveyable, and storable in high-rise storage racks. Pallets made of wood or plastic, welded wire or corrugated steel containers, steel or plastic bins and totes, and self-contained loads (barrels, drums, etc.) are the main types of storage modules used in AS/R Systems.

Numerous options are available in controlling the equipment, material, and material flow in an AS/R System. Such options include completely manually controlled systems, entirely computer-controlled systems, or a combination of the two. Normally minicomputers are used to select an open location and to direct the crane to store a load. Upon receipt of a request the crane is directed to the desired location to retrieve the load and bring it to an I/O station to deposit. The link between the warehouse and source or destination of items is provided typically by a conveyor through an I/O station. Currently five different types of AS/R Systems are in use. In a Full Load Storage/Retrieval System (Figure I-3), full loads (unit loads) are handled without end-of-aisle order-picking or recycling of partial loads back into the system after order picking. End-of-Aisle Order-Picking System (Figure I-4) differs in that the loads are brought to the aisle end for order-picking and the partially picked load is put back into storage after order-picking. The third type is known as Remote Order Picking System (Figure I-5). In this system loads are deposited by the crane at the end of aisle and then routed to remote order-picking stations, using conveyors or other transportation means. The partially picked loads are routed back to storage. The fourth type of system is commonly known as In-Aisle Order Picking. This system

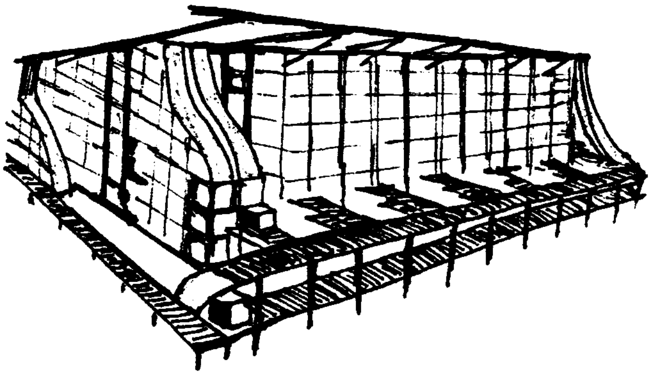


Figure I-3. Full load storage/retrieval.

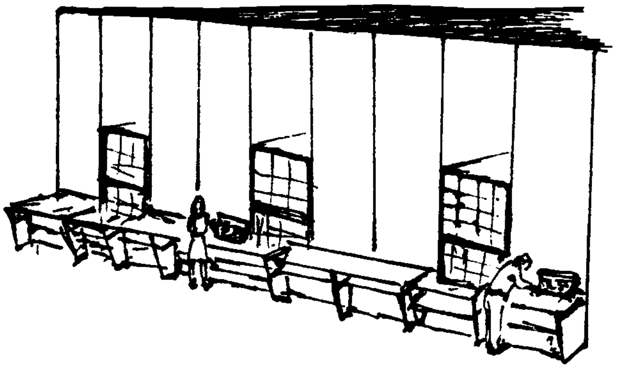


Figure I-4. End of aisle order picking.

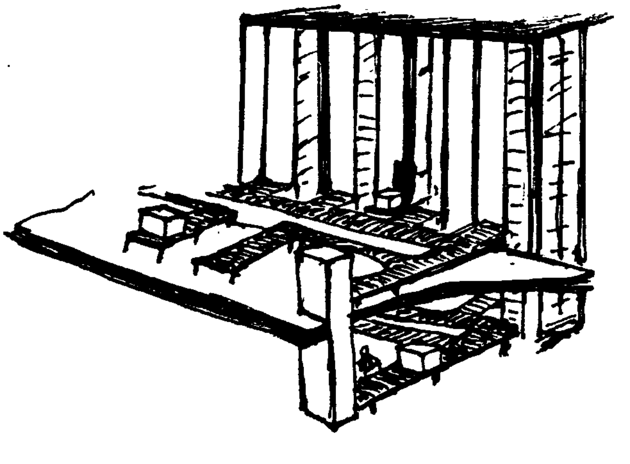


Figure I-5. Remote order picking.

utilizes a man ridden S/R machine, with an operator on board, which is manually, automatically or semi-automatically controlled. The S/R machine transports the operator to the desired rack location where the order picking is performed. The fifth type of system is called Combination System, which may consist of two or more of the previously described systems, used together.

The proper selection of any particular AS/R System would depend on the specific plant lay-out, present material-handling practices, types of loads handled, and the desired throughput rate as well as numerous other factors.

JUSTIFICATION AND OPPORTUNITIES FOR IMPROVEMENT

It is a well known fact that AS/R Systems have completely revolutionized conventional storage methods. According to some reports, Wiegand (1977), the AS/RS industry has been growing at a rate of 20 percent per year since its beginning in 1959. Others, Rygh (1981), suggest that AS/R Systems may improve floor space utilization by as much as three to five hundred percent over conventional methods. Besides improved space utilization, lower operating costs, reduced pilferage, reduced product damage, lower energy consumption, and many other benefits add to the growing popularity of AS/R Systems. Growing interest in AS/R Systems has resulted in a number of design related improvements in cranes, warehouse structures and system controls. A major portion of these developments are sponsored by the manufacturers of AS/R Systems, who seem to be advising the user on everything but scheduling of the system. Obviously, scheduling of the warehouse is left to the choice of the user.

The realization of the maximum benefits from an AS/R System depends upon an integrated approach to the design as well as the management of the system. Unfortunately, less attention has been paid to the management of AS/R Systems. There is a growing need for extensive research in this area from the perspective of the users.

Although system design would depend on careful selection of such things as number of cranes, horizontal and vertical speeds of cranes, aisle size, number of aisles, rack structure, etc., optimality is not guaranteed unless system management is also optimized. An optimal management policy in an AS/R System would be a combined approach to pallet assignment, i.e., the assignment of more than one item to the same pallet; storage assignment, i.e., the assignment of pallet loads to storage locations; and interleaving, i.e., the rules of sequencing storage and retrieval requests.

It has already been shown by Hausman and Schwarz (1976) that a Class-Based Turnover Assignment policy is superior to a Random Assignment of items; pallet assignment was not considered—with or without interleaving. However, the system considered by Hausman and Schwarz handles full loads and recycling of the partially picked loads is not permitted. Although they mention that their results could be extended to suit any AS/R System, further improvements may be possible in other than full load systems. In fact, a large number of users of AS/R Systems cannot use full load (unit load) handling systems because of such constraints as size, configuration, weight and number of different types of items to be stored. The electronic industry is a good example of such users of AS/R Systems who quite frequently have to deal with a large number of different types of small size, light weight, hand-picked items. Such a situation necessitates using either an In Aisle, End of Aisle, or Remote Order Picking System, and recycling all partially picked loads.

The focus of this study is an End of Aisle order picking AS/R system which, besides using the Class-Based Turnover assignment policy, can be further improved by decreasing the crane travel times by reducing the travel distance to the partially picked pallets. This can be made possible by introducing a zone nearest to the I/O station, for the recycled or partially picked pallets. The resulting savings in crane travel time are of greatest interest to the user of such systems because crane travel time directly affects throughput capacity, which means how many pallets per unit time the system can simultaneously receive and store (input) and retrieve and ship (output). A reduction in crane travel time would mean an increase in throughput capacity of the system, which can be indirectly used either in the design of new systems or modification of the existing systems to achieve a more appropriate balance between the system throughput and storage capacity. Undoubtedly, from the user's point of view, higher throughput and consequent smaller storage space capacities would be some of the most attractive improvements in AS/R Systems.

CHAPTER II

PROBLEM ANALYSIS

LITERATURE REVIEW

Numerous studies dealing with design improvements, systems control, installation and justification of AS/R Systems are published regularly in the literature of industrial engineering, material handling, management science, and operations research. The majority of these studies are either put together by the manufacturers, or are case studies narrated by individuals dealing with the setting-up of such systems. Although there is an abundance of such general papers, books and articles, some of which are listed in the Bibliography, there are very few research papers dealing with the analysis of AS/R Systems with regard to the optimization of such systems.

Hausman, Schwartz and Graves seem to be the pioneers in research concerning optimal storage assignments in AS/R Systems. In their first work, published in 1976, they considered two storage assignment rules. First, a Random Storage Assignment rule, to approximate the "closest-open-location" rule commonly used in practice, according to which pallets are randomly stored in any of the rack locations. Second, a Turnover-Based Assignment rule, which implies that highest-turnover pallet is assigned to the closest location (in time). The superiority of the Turnover-Based Assignment rule over the Random Assignment rule was reported to range from 26 percent to

71 percent for 20/60 to 20/90 turnover distributions taken from an ABC curve. A 20/60 turnover policy means that 20 percent of the items constitute 60 percent of the demand and 20/90 turnover means that 20 percent of the items make up 90 percent of the demand. They next examined Class-Based Turnover Assignments which implies that racks and pallets are partitioned into two or more classes based on one-way crane travel times, and turnover, respectively. Pallets are then assigned to a class of storage according to their class of turnover (e.g., highest turnover class of pallets assigned to the closest location). This type of storage assignment produced about 70 percent and 85 percent of the potential gain of a fully turnover-based system for two-class assignment and three class assignment respectively (Figure II-1). In their conclusion they write

> . . as the measure of skewness of inventory distribution increases, the error involved in continuous approximation increases significantly. . . .Note, however, that although the continuous approximation is relatively poor in some cases, the actual improvement from class-based storage assignment remains quite substantial in those cases.

In their second paper, published in 1977, Hausman, Schwarz and Graves extended their work to include interleaving; i.e., the sequencing of storage and retrieval requests. In other words, the crane was supposed to be capable of visiting up to two rack locations between successive returns to an I/O station or home position. They tested various alternative policies using a continuous simulation model. The results showed that a three-class storage assignment with mandatory interleaving and a first-come, first-serve (FcFs) retrieval queue priority gives lower crane round-trip times. An FcFs retrieval

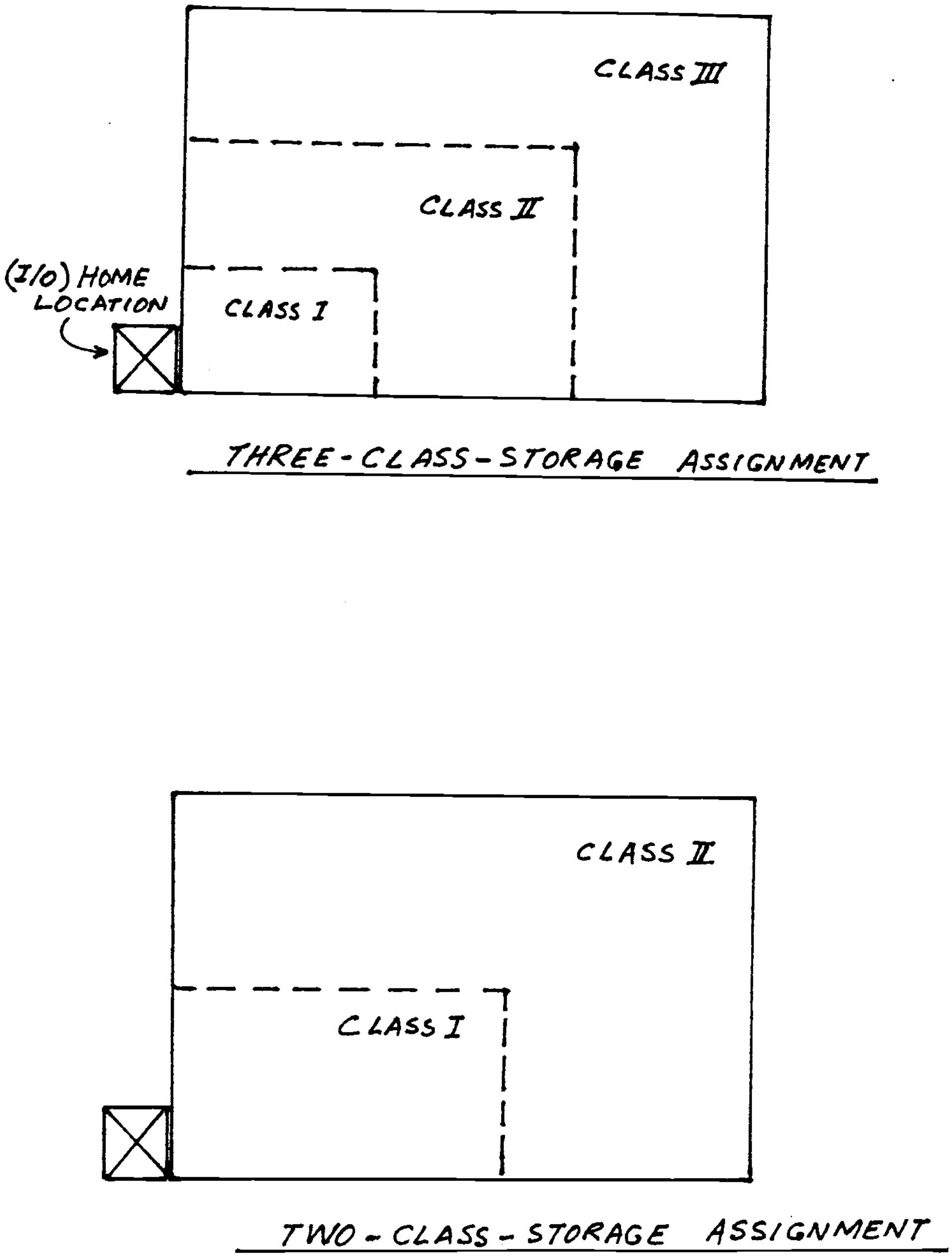


Figure II-1. Class-based storage assignments.

queue rule restricts the retrievals to be chosen from the queue of retrievals on the basis of first-come, first-serve. A full turnover-based storage assignment with interleaving and FcFs retrieval queue gives the least crane round-trip time, but this case is of theoretical importance only because as the authors admit,

> It would be unrealistic to assume that the turnover of every pallet to be stored in the system will be known and/or constant over time.

Again, as in the cases without interleaving, the two- and three-class models produced approximately 70 percent and 85 percent respectively of the gain obtained from full-turnover-based policy as compared to the conventional random or "closest-open-location" policy (allowing interleaving).

The third paper written by Schwarz, Graves and Hausman (1978) reported the results of a computer simulation examining the results of earlier analytical work on scheduling policies for AS/R Systems. The results of these last two papers were theoretical and set up in a deterministic environment. This paper looked at the assignment policies, discussed in the last two papers, under stochastic conditions. The results of simulation provided ample evidence in support of the proposed analytical models. For instance, they reported

> The reduction in round-trip time by using a two-class system is 28 percent (the theoretical reduction was 30 percent), and the additional reduction in upgrading a two-class to a three-class system is nine percent (both simulated and theoretical). Thus, the simulation has demonstrated that class-based storage assignment policies are indeed worthy of exploration if one wishes to make a significant reduction in crane travel time.

Furthermore, the authors concluded, "However, the actual improvement is, in general, slightly smaller than that predicted for the system, after end-of-aisle or remote order-picking, would affect the performance of these scheduling policies.

It seems that there is little contribution to the literature regarding, in particular, the end-of-aisle or remote order-picking AS/R Systems. The users of such AS/R Systems would be interested in further reduction in crane round-trip times, and increased throughput. Obviously a class-based storage assignment would be the best scheduling policy for any AS/R System, but because of the recycling nature of partially picked loads as opposed to nonrecycled full loads, further opportunities for improvement of scheduling policies exist.

PROBLEM FORMULATION

Consider a typical end-of-aisle order-picking AS/R System in which, upon a retrieve request, the crane retrieves the desired pallet and desposits it at the home location. After order-picking a partially picked load is restored to the system by the crane, at the same location from where it was picked or at the empty rack nearest to home (I/O) location. Using a class-based-turnover policy, pallets of higher turnover items can be assigned to the class of rack locations, in aisles, closest to the home (I/O) location. By doing so, a scheduling policy is put into effect, the "optimality" of which (Hausman, Schwarz and Graves, 1977) has already been established. But is it really optimal in the case considered here? Of course not! Carefully studying the recycling phenomenon of partially picked

Text continued on page 17

pallets in the system, an alternative can be found with further reduction in crane travel times.

One way of doing this is to introduce zones in aisles which consist of racks nearest to the home location for the handling of the partially picked pallets only. If the scheduling policy for both zones is again a class-based-turnover policy, this alternative should give lesser crane travel times than the case considered earlier. The reason for this, obviously, is the reduction in crane travel time for partially picked pallets in the subsequent store-and-retrieve requests. For the sake of simplicity, let the former alternative be called a Single Zone (S-Zone) and the latter a Double Zone (D-Zone).

An in-depth study of S-Zone and D-Zone systems can reveal how far zoning of aisles can decrease the crane travel time and hence help to increase throughput. It is worth mentioning here that all material handling activities are measured in terms of the efficient use of motion, time, quantity and space. In order to measure and compare the responses of two alternatives in this study, crane cycle time seems to be the most appropriate indicator to look at. Changes in movements in the two systems, from location to location, directly affect the crane travel times which, in turn, reflect upon the quantity handled (throughput) and the storage space requirements.

The responses of both systems are expected to vary under the influence of different factors. Some of these factors which are the focus of this study are related to the number of item types, demand or pick frequency of an item, and average number of units per order. It is important to look at the two systems in view of these factors because a factor may favor one system more than the other. For example, a large number of item types may not favor zoning as much as a few item types, because of the increase in crane travel times to retrieve or store.

Similarly, pick frequency, depending on how often an item is demanded, can have a profound effect on the crane travel time by mostly restricting crane travels to a particular section of the aisle or spreading the travel randomly to all rack locations in the aisle. Also, if the average size of an order is a small proportion of the total units carried by pallets, zoning may prove more effective than if the average size of orders is approaching closer to the total number of units carried by pallets.

STATEMENT OF OBJECTIVES

The primary objective of this study is to examine the effects of the introduction of a D-Zone, which handles partially picked loads closer to the home (I/O) location in an aisle of an end-of-aisle order-picking AS/R System on throughput. Throughput, being a measure of system performance, may be defined here as the rate at which pallets can be stored and retrieved from the system. All components of the system, such as crane travel time, maintenance and repair time of the crane, location of I/O station, and many other factors, can be considered in determining the throughput. However, in this study, throughput is measured in terms of crane travel times or number of orders which may be processed over a period of time, while all other factors remain unchanged.

The secondary objective of this study is aimed at looking into the effect of three different factors—type of items stored in aisles, pick frequency of items required, and mean number of units of any item type required per order—each at two different levels, on the two alternative systems under study.

CHAPTER III

ASSUMPTIONS AND GENERAL APPROACH

ASSUMPTIONS

Before developing the models and examining the responses, several assumptions are made without losing the generality of the problem. It is assumed that the system considered consists of a single one-sided aisle. The analysis and results for a single two-sided aisle as well as for multi-aisle systems carry over directly. In other words, an actual system, which usually consists of several single cranes serving a number of identical two-sided aisles, is viewed as several independent single one-sided aisle systems. All storage locations are the same size. Pallets are assumed to be of the same size, and contain units of only one type of item. This means that pallet assignment, i.e., grouping items to share a multi-item pallet, is not considered in the analysis. It is also assumed that any pallet can carry the same number of units of any item type, and the number of units is fixed. Empty pallets are not stored back into the system. The Home (I/O) Station is assumed to have space to accumulate a two-pallet queue ahead of the crane. After order picking, each partially picked pallet is picked up, according to first-in, first-out (FIFO) priority, and stored back into the system.

The storage locations closest to home position based on one-way crane travel time are assigned to the highest-turnover item type pallets. It is assumed that there is an infinite backlog of orders. This eliminates the interarrival time for orders. The system is assumed to work on a perpetual supply of each item, to fulfill the orders. In other words, as soon as the last pallet of a particular type of item leaves the system, full pallets are replenished at all locations except in the zone for partially picked items in a D-Zone aisle policy. For desired retrieve or store requests, a crane always moves to the closest to the home locations. A crane is assumed to take the same amount of time in deposit, extraction, or retrieval of a load. It is also assumed that the crane's X and Y axes work independently, and the travel time is the longer of the X or Y axis to complete its move. The crane is assumed to be working on a dual cycle which implies that the crane is capable of visiting up to two rack locations between successive returns to the home (I/O) location. This is equivalent to what the interleaving systems or "dual address" (Hausman and Schwarz, 1977) system offers. The only difference is that the storage requests are filled not from the pallets arriving from outside the system, but from the queue of partially picked pallets at the home (I/O) location. In this way the crane takes a partially picked load from its home (I/O) location, stores it at the desired location, and then moves directly to another location for the next retrieve without returning to the home location.

The pick frequency of each item type and number of item types stored in the system are assumed known and fixed over a time period. The number of units picked per order are assumed to follow a truncated

Poisson distribution, with a minimum of one unit, thus eliminating the orders with zero units.

Keeping these assumptions in mind, a computer simulation program is developed, sufficiently flexible to accommodate the modeling of both S-Zone and D-Zone systems under differing conditions. The program is written to model these systems as specified in the following sections.

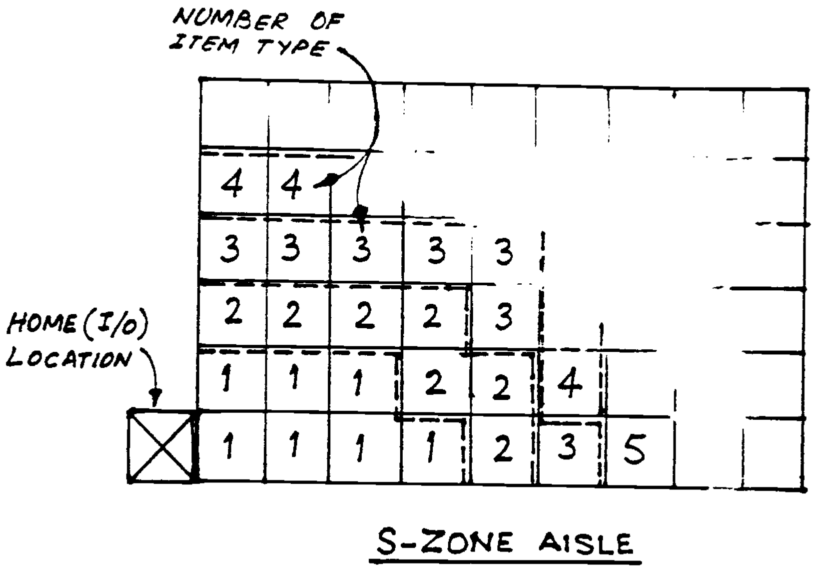
SYSTEM SPECIFICATIONS

Crane and Aisle

The storage rack, consisting of a single one-sided aisle, has five tiers and 12 bays with 60 storage locations. Pallets are all 48"x48"x48" size, and a clearance and rack size of six inches give a pallet center-to-center distance of four-and-a-half feet, in both the horizontal and the vertical directions. The number of units of any type of item on a pallet are fixed to be 20.

The crane's traverse rate in the X-axis is taken to be 5.833 feet per second and in the Y-axis as 3.5 feet per second. The crane's acceleration (deceleration) in X-axis and Y-axis is 1.0 feet/second/second and 0.75 feet/second/second, respectively. The crane's extraction, retrieval, or deposit time is considered to be six seconds. Manual order-picking at the home (I/O) location is taken as 30 units per minute.

General layout of a S-Zone aisle system and that of a D-Zone aisle system is shown in Figure III-1. Pallets are numbered according



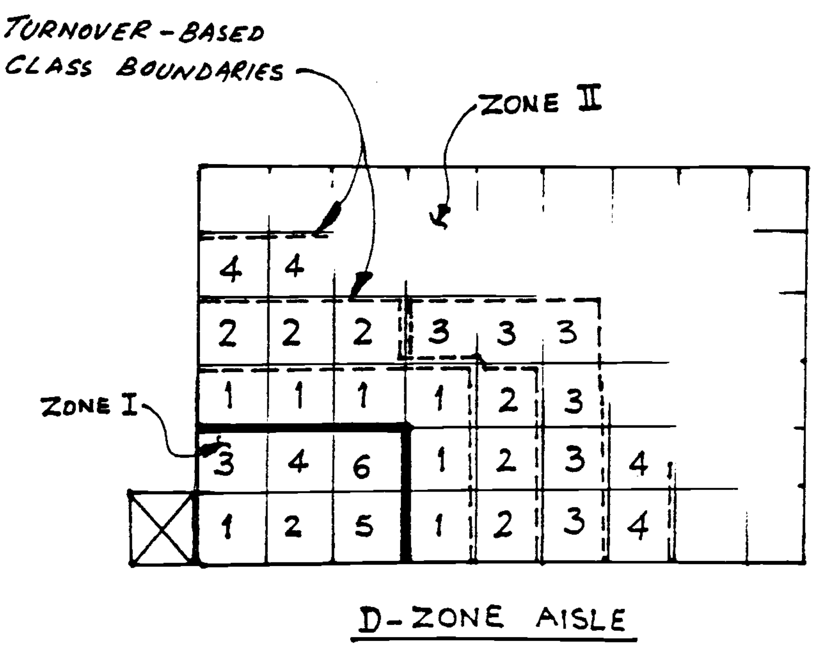


Figure III-1. General layout of Single and Double Zone Aisles.

to their demand or turnover frequency, one being the highest and so on. An aisle with no zones, i.e., S-Zone, has the pallets containing the highest turnover frequency item class assigned to the class of locations closest to the home (I/O) location. On the other hand the aisle with zones, i.e., D-Zone, has its Zone I, which handles the recycled or partially picked pallets is located closest to the home (I/O) location. Note that pallets with items of highest turnover class are assigned to the class of locations closest to the home location, within both Zone I and Zone II. This makes both S-Zone and D-Zone follow the same scheduling policy except that D-Zone handles the partially picked loads in a separate zone, whereas S-Zone does not.

Closeness to the home location is based on one-way crane travel times. In order to establish the exact closeness ratings for each rack location in the aisle a FORTRAN program "ASIGN" was written. This program gives the one-way travel time of the crane from home location to each location in the aisle. A program listing and flow charts are provided in Appendices B-1 and B-5 respectively. Specific layouts of S-Zone and D-Zone systems with the specified number of items are shown in Appendices B-9 through B-12.

Crane Cycle Time

A complete cycle of the crane working on the dual cycle, as assumed earlier, may be divided into three phases. As shown in Figure III-2, the first phase consists of extraction of a partially picked pallet from home (I/O) location, moving to a storage location, and depositing the pallet at its storage location. The second phase of the crane cycle is the travel time to another storage location and retrieval of a pallet from that location. The third phase is the travel time to the home position and the depositing of the pallet there. Referring again to the Figure III-2 travel time from point A to point B, extraction time, and storage time are added to get what is termed in this study the Replacement Time. The sum of the travel time from point B to point C and the retrieval time is named as Access Time. And the time taken by the crane in traveling from point C to point D and depositing the pallet at its home location is called Return Time.

Crane Cycle Time is the sum of Replacement Time, Access Time and Return Time. The time of travel between two points is measured as the longer of the times for the X-axis or the Y-axis to complete its move; both axes are considered to be working independently. As shown in Figure III-3 the crane has a constant rate of acceleration and deceleration. The travel between two points, in X or Y axis, consists of an acceleration to traverse speed at aconstant rate, traverse at a constant speed, and a deceleration at a constant rate until stopped.

COMPUTER SIMULATION PROCEDURE

The system under study is simulated as a discrete model. This means that the time being the only independent variable all the dependent variables such as scheduling of a new order, take place discretely at specified points in time. This specified point in time is considered to be the completion of the crane cycle time for the last

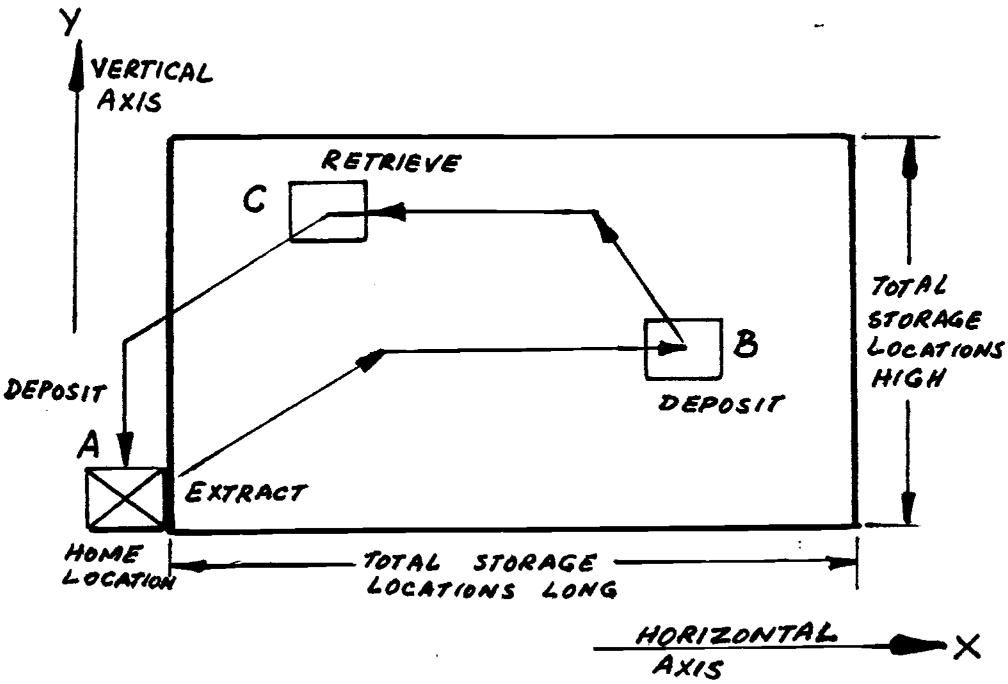


Figure III-2. A typical crane cycle.

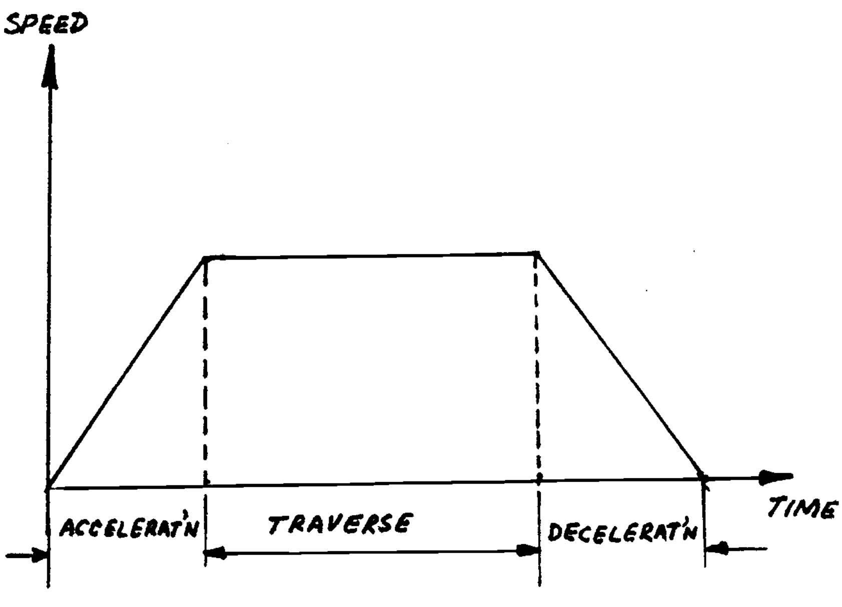


Figure III-3. Crane move between two points.

order in addition to any crane waiting time. A very simplified flow chart of this simulation procedure is shown in Figure III-4, the details of which are discussed in the following sections. Simulation language used in this study is GASP IV, Pritsker (1974). In order to fully understand how the simulation works, it would be essential to look at the data storage and handling in GASP IV.

File Structure

The system under study can be broken down into entities such as aisle, pallets, crane, operator, etc., and events of scheduling of an order to be processed. The entities are identified by their attributes, for example, the X and Y coordinates of a location in the aisle, the number of item type carried by a pallet, etc. Similarly, the event is also recognized by its attributes such as time of occurence of an event. In GASP IV entities and events are stored through the use of the file storage arrays NSET/QSET and file processing routines. Time events and their associated attributes are stored in File 1. Entities and their associated attributes are stored in File 2 through the number of files in the storage array NSET. Events and entities are stored in the files as entries. The attributes of the entries in the files for the system under study are given in Table III-1.

Input data for entries related to different files is shown in Appendices C-2 and C-5. A sample of file storage area at time zero is shown in Appendix C-3. File(1) in this storage area has the first entry with Atrib(1) = 0, Atrib(2) = 3, and Atrib(3) = 2. A second

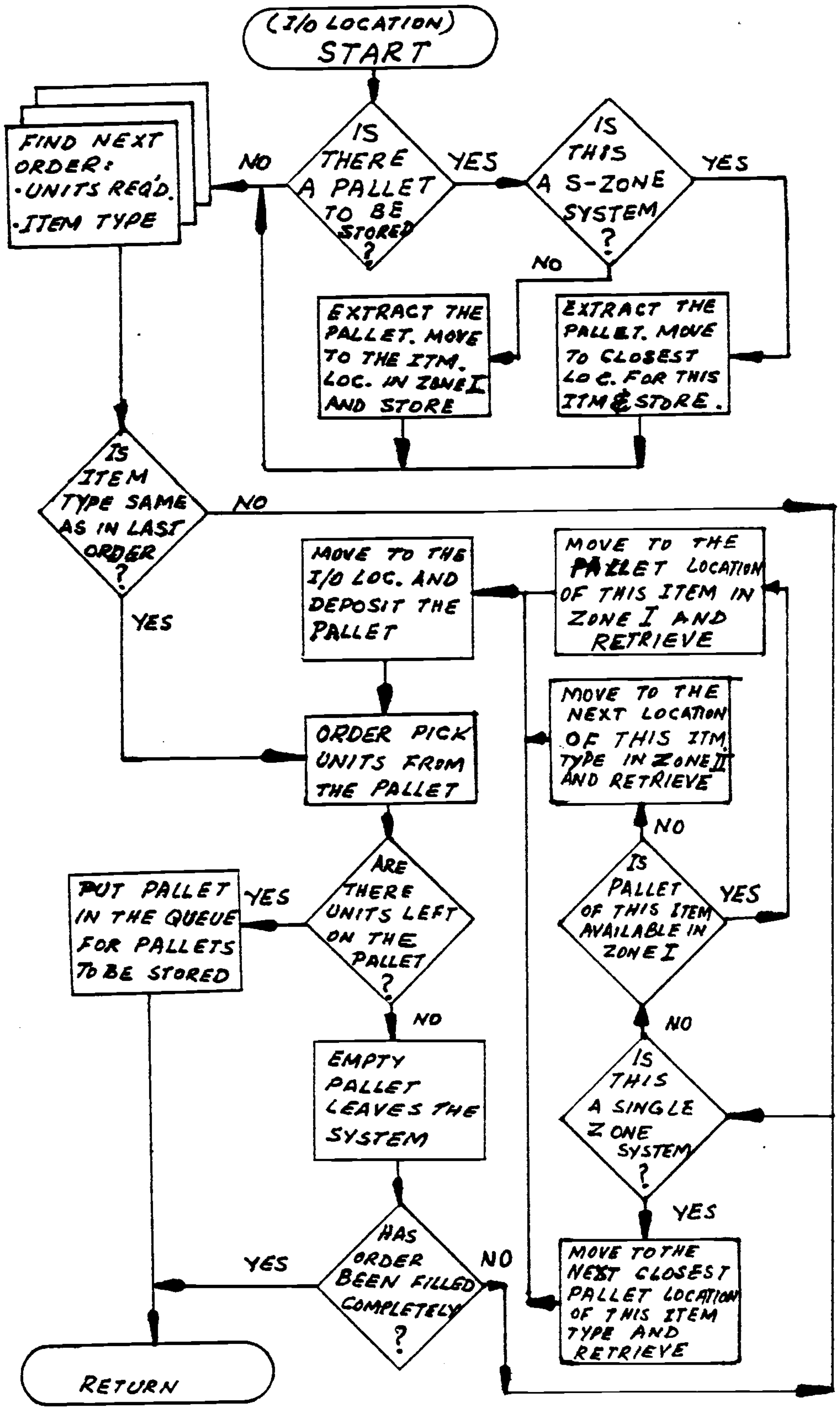


Figure III-4. General flow diagram of simulation procedure.

TABLE III-1

FILES AND ATTRIBUTES OF ENTRIES

File Number	Attributes	Definitions
1 (Event File)	ATRIB(1)	Time of event (i.e., scheduled order)
	ATRIB(2)	Type of item required
	ATRIB(3)	Number of units required
2 (First pallet location of all types of items)	ATRIB(1)	Pallet number (always "1")
	ATRIB(2)	Type of item on pallet (priority: Least Value First (LVF))
	ATRIB(3)	X - coordinate of pallet location
	ATRIB(4)	Y - coordinate of pallet location
	ATRIB(5)	Number of units on pallet
J(3, N) (Each file for all pallet locations of an item type) N = Number of items types plus 2	ATRIB(1)	Pallet Number (priority: LVF)
	ATRIB(2)	Type of item on pallet
	ATRIB(3)	X - coordinate of pallet location
	ATRIB(4)	Y - coordinate of pallet location
	ATRIB(5)	Number of units on pallet
L = N+1 (Status of pallets at home position)	ATRIB(1)	Pallet Number (priority: FIFO)
	ATRIB(2)	Operator's time to pick units required
	ATRIB(3)	X - coordinate of pallet location
	ATRIB(4)	Y - coordinate of pallet location
	ATRIB(5)	Number of units on pallet

entry is related to the clearing of statistical arrays at time 10,000. This is the last entry in the input data shown in Appendices C-2 and C-5. At time 10,000 (ATRIB(1)), with a Code -2(ATRIB (2)) through the use of GASP subroutine MONTR all the statistical arrays are set to zero. Further on, in the file storage area, it can be seen that File (2) is empty at this stage. Files (3) through (7) contain all the entries related to the aisle locations, i.e., X, Y coordinates, and pallets. File (8) is empty at time zero. At time 20,000, as shown in Appendix C-4, the same file storage area looks different. Notice File (2), which was empty at time zero, has entries for all the first locations of all the item types accessed by crane during the past 20,000 time units of simulation run. Files (3) through (7) have all the entries of the remaining or to-be-replenished pallets. In these entries, values corresponding to ATRIB(1) can reveal how many pallets of a particular type of item have left the system. For example, File (7) shows that six pallets of Item (5) have left the system and the seventh pallet has 19 units left on it. It can also be observed that the seventh pallet is stored at the closest to the home location, since its X and Y coordinates, i.e., ATRIB(3) and (4), are the same as those of the first location of Item (5) in File (2). File (8) has the entries of the pallets to be order-picked at home location. How all this is accomplished and how the whole filing mechanism takes care of the essentials of the system under study is fully described in the next section.

D-Zone and S-Zone systems have the same filing structure except that the D-Zone replinished pallets are provided in the locations outside Zone I, because Zone I handles the partially picked pallets only. This can be seen (Appendix C-6) in Files (4), (5), (6), etc., where, at time 10,000 the storage areas have the fifth pallet missing (ATRIB(2)). Since the entries (pallets) in the files are numbered according to their closeness to home location, and are arranged on a least value first basis, after the first four pallets the fifth, ninth and so on, are not going to be replenished, and therefore are missing from the file storage area.

Program Description

The program consists of user-written subroutines, shown in double rectangles in Figure III-5, and GASP IV subprograms which are shown in single rectangles. The user and GASP subprograms interact to simulate the system under study. In this figure the direction of the arrows indicates that the subprogram, towards which the arrow is pointed, is called by the subprogram that it is linked with. Each of the user-written subprograms are described thoroughly in this section. GASP IV subprograms are also defined where appropriate.

Program Main sets card reader and printer number and sets the simulation run number to zero. The data which is fixed for the whole length of the simulation such as frequency distribution of items, crane acceleration (deceleration), velocity, etc., are read in this program, and GASP is called.

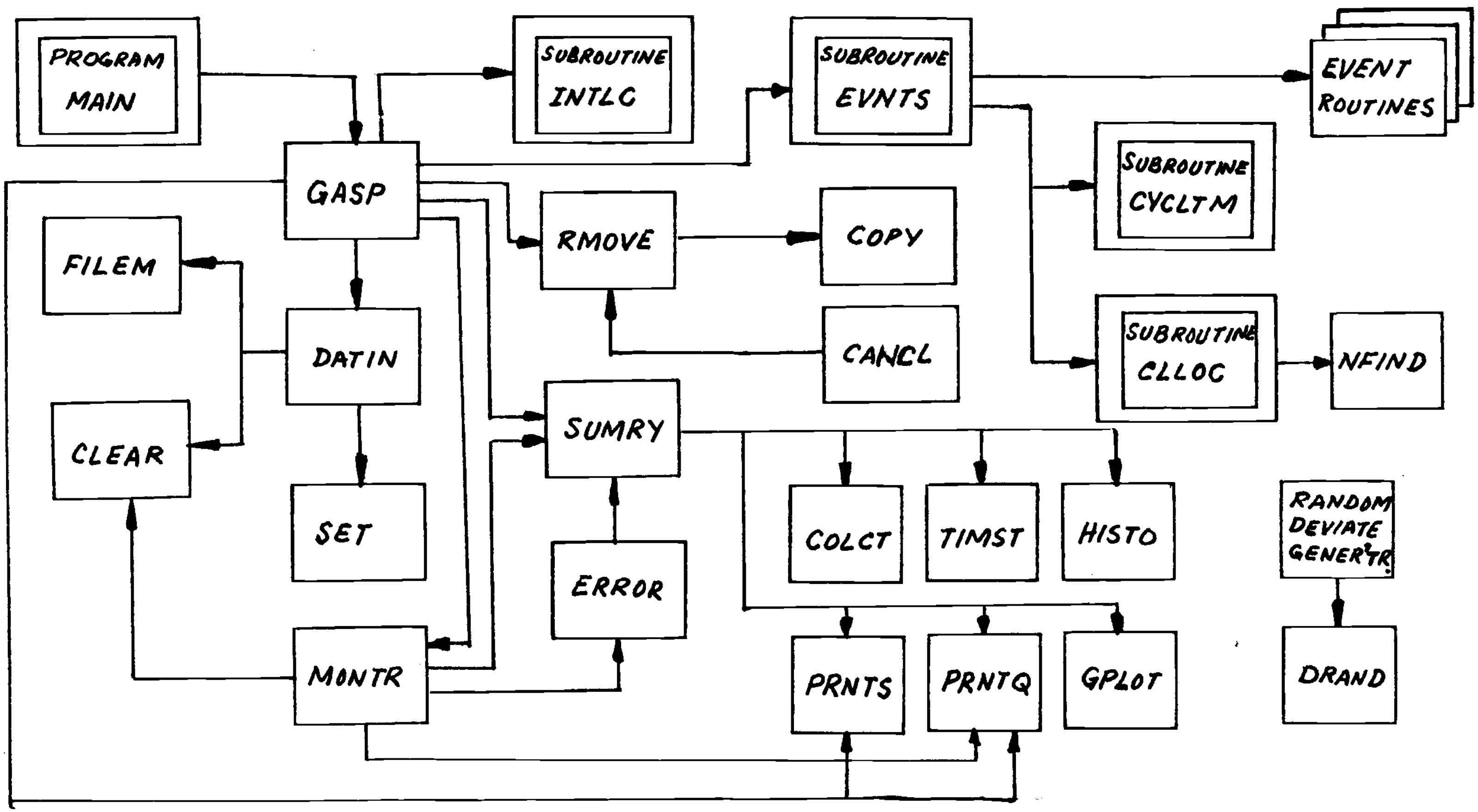


Figure III-5. Interaction between GASP and user-written subroutines.

In this computer program GASP is the main executive routine for advancing time and the status of the simulation. GASP calls DATIN which initializes GASP IV variables and reads all the data cards. DATIN calls INTLC which is used to initialize all non-GASP variables. It also creates the first order by setting ATRIB(1) = Tnow, i.e., zero, and setting ATRIB(2) and ATRIB(3) equal to the random deviate generators, DPROB(FX, XVAL, NVAL, ISTREAM) and NPSSN (IPAR, ISTRM) respectively. DPROB is a deviate generator for obtaining samples from a probability mass function using random numbers stream (ISTRM = 1). Fx is the vector for cumulative probability values; XVAL is the vector containing possible deviates that can be obtained, e.g., 1, 2, 3, 4, etc., and NVAL is the number of values in the vectors.

Function NPSSN is a Poisson deviate generator using random numbers stream (ISTRM=2) and parameters from the set (IPAR=1). The values stored in array PPARM are Column (1) = Mean - Lowest value; Column (2) = lowest value; and Column (3) = maximum value. This is read in data card PAR, shown in Appendix C-1. This scheduled event is then stored in File (1) by calling FILEM(1).

In subroutine INTLC, K is set equal to 1 or 2, etc. as the runs proceed. In this study the simulation is run twice, first for the D-Zone system and then for the S-Zone system; therefore TIMST is called to collect the statistics of variables, PALL, PALL2, and TRIP at time zero. TIMST is used to collect the statistics on time persistent variable, i.e., the variable that is assumed to have maintained a constant value over a time interval.

The FORTRAN listings of INTLC is given in Appendix B-6. Subroutine SET is called by DATIN to initialize the filing arrays and subroutine EVNTS is called by GASP. A flow chart of EVNTS is given in Appendix B-2. Since this study involves only one event, i.e., a new order, EVNTS is used as the event routine, which works as described below.

Before describing the mechanism of EVNTS, different subprograms called by EVNT and CLLOC are explained briefly as follows:

GASP Subroutines

FILEM (I FILE) files an entry into I FILE.

RMOVE (NTRY, IFLE) removes entry NTRY from file I FILE.

COPY (NTRY) puts attributes of entry NTRY into buffer storage array ATRIB without removing the entry from the file.

COLCT (XX, ICLCI) records value of XX variable as an observation on variable number ICLCT.

TIMST (XX, T, ISTAT) integrates variable number ISTAT assuming the value during the intervals up to time T is the value of XX at the last call to TIMST for variable ISTAT.

HISTO (XX, IHIST) determines the cell number associated with the value XX for variable IHIST and increases the cell content by 1.

GPLOT (XX, T, IPLOT) stores values of the dependent variable XX for a value of the independent variable T with IPLOT being the plot number.

GASP Functions

NFIND (XVAL, MCODE, IFILE, JATT, TOL) locates an entry in file IFILE whose JATT attribute is related to the value XVAL according to the MCODE (1-5 available), e.g., MCODE = 5: Value equals to SVAL ± TOL where TOL = tolerance.

NPSSN (IPAR, ISTRM) is a Poisson deviate generator and uses Stream ISTM and parameter set IPAR.

DPROB (CPROB, VALUE, NVAL, ISTRM) is a deviate generator for obtaining samples from a probability mass function using Stream ISTRM; CPROB is a vector for the cumulative probability values for the probability mass function. Value contains the possible deviate that can be obtained from DPROB; NVAL is the number of values in the vector CPROB and VALUE.

User-written Subroutines

CYCLTM finds the maximum of times that a crane takes, in X and Y direction, to travel between two locations. It also changes the crane's X and Y coordinates to the new location coordinates. The flow chart is given in Appendix B-3.

CLLOC basically schedules pallets to be replenished. For any particular item type, whenever a pallet is accessed for the first time, a pallet with the same coordinates but different number is scheduled in the file of that item type. This ensures the perpetual availability of the items. If it is other than the first pallet of any type item, then its location is changed to the closest to the home location. It also collects statistics on trips to Zone II or other than first location in the case of S-Zone. The flow chart is provided in Appendix B-4.

EVNTS updates the number of orders received, and calls TIMST and GPLOT to collect statistics on orders. It uses COLCT and HISTO to collect statistics on units required and item type. It then finds the file containing pallets of item type required. Now the first entry in file is found which corresponds to the closest to home pallet location. This entry is removed from the file using RMOVE. If it is the very first location of any item type, the entry is stored in File (2), by calling FILEM(2), otherwise not. In any case, however, the travel time to access the location from the present location of crane (ACT), and from this location to home position (RHT) are found by calling CYCLTM. At this point replacement time of the pallet in the previous order, from home position to the replacement location, is known (RCT; it equals zero if no pallet was replaced from home position, e.g., pallet was empty and left the system). CYCLE TIME is calculated by adding RCT, ACT and RHT statistics collected on these parameters by calling appropriate GASP subroutines. Units on pallets are updated. Meanwhile cycle time per order is found (TCYT) and updated in case a second pallet is accessed for the same order. In the case when the present order requires the same item type as the previous one and can be met completely or partially by the present pallet, cycle time per order is only equal to the RCT of the last pallet replaced. It is important to note here that whenever CYCLE TIME is zero per order or consists only of RCT/order, it is not included in the statistics in CYT, in order to get a fair sample of complete crane cycles in CYT. By calling FILEM(J) the updated entry is now stored back into the file. Based on number of units picked by the operator, and the units available on the pallet, operator picking time and any units still unpicked, if the pallet did not contain enough units, are determined.

If this is the first time the present pallet is accessed or, in other words, if this is the first time this entry is removed from the file an entry with same location coordinates is stored in the file at the end of the present entries, by calling CLLOC, with the one exception of D-Zone, when the first entry of any file is not restored. In other words, the replenishment in Zone II with the first pallets of each item type are not made. By calling CLLOC, the location coordinates of the pallet are changed to the closest to home location where this pallet is going to be stored back. Once the units from the pallet have been picked it is stored in File (L) by calling FILEM(L). When the crane brings the pallet for the next order at home position it removes the first stored pallet entry from File (L) by using RMOVE. The entry is now in buffer array ATRIB. At this point crane and operator waiting times are calculated and statistics collected. If the pallet does not have any units left on it, it is removed from the system. Statistics are collected on the number of pallets leaving the system. In case the units required were not fulfilled by this leaving pallet the remaining units to be picked are processed by removing the next entry of this item type and repeating the above mentioned procedure. If the leaving pallet did satisfy the

Use of 90%
Utilization —
References
(Lee's thesis)

units required replacement time, i.e., RC
order is scheduled, and statistics on the
is collected by calling COLCT. If the pa
left on it, the pallet is replaced back t
tion and time of travel (RCT) of the cran

Whenever there is no more than on

is zero. Statistics on RCT are collected and the next order is scheduled and stored in File (1) by calling FILEM(1). Notice that time for next order is TNOW + TCYT + CWT. FORTRAN listing of subroutines EVNTS, CYCLTM and CLLOC are given in Appendices B-7 and B-8.

FACTORS CONSIDERED

A number of factors may influence the relative performance of the S-Zone and the D-Zone under study. But the three carefully chosen factors to be considered in this study, as discussed earlier, are mainly considered in the two simulated systems. These factors can be classified as:

A - Number of items stored in the aisle,

B - Pick frequency of an item,

and C - Average number of units picked per order.

Each of these three factors is chosen at two levels, thus resulting in a total of eight treatments, as shown in Table III-2. Besides these treatments, two more levels of factor 'C' are also considered which are: an average of five units per order (CL1), and an average of 15 units per order (CH1). Different methods employed in generation of these treatments are described in the following section.

TABLE III-2

TREATMENTS CONSIDERED

Treatment Symbol	Description
AL	5 types of items stored in the aisle
AH	15 types of items stored in the aisle
BL	20% of items picked 80% of the time (20/80)
BH	Each item having equal chance of being picked (equally/likely)
CL	An average of 2 units per order (Poisson distributed)
CH	An average of 10 units per order (Poisson distributed)

Generation of Different Levels of Factors

In order to have five (AL) item types stored in the aisle, 12 pallets are assigned to each item type. The resulting five classes of pallets are assigned to the five classes of locations as there are 60 locations in the system, such that pallets belonging to the highest turnover class are assigned to the class of locations closest to the home (I/O) location. Each item is labeled one to five according to its class, based on least numbers to the highest turnover class, and the resulting aisle layout for D-Zone and S-Zone is shown in Appendices B-9 and B-10, respectively. Note that in the D-Zone, to initialize the system, one pallet each of the item types is placed in the zone meant for handling partially picked pallets. The procedure is repeated for 15 (AH) units of storage and the resulting layouts are shown in Appendices B-11 and B-12.

Knowing the cumulative frequency of an item to be picked, GASP subprogram DPROB can be employed to generate deviates from the given probability mass function. For a 20/80 (BL) situation the cumulative probabilities are obtained from an 'ABC' curve, taken from Hausman and Schwartz (1976), shown in Figure III-6. The ABC curve ranks all the items in an inventory by their contribution to total demand, with 'A' items representing high volume items, 'B' the medium-volume items and 'C' the low-volume items. The value 'S' for a 20/80 situation can be found by solving $0.8 = (0.2)^S$, because 20 percent of the items represent 80 percent of the total demand. Knowing the value of factor 'S' the demand rate (D(i)), pallets per unit time of item i, is calculated as $S(i)^{S-1}$. From this value the frequency of demand for each item type is found as $D(i)/\Sigma(D(i))$. The cumulative of which for each item type is read in the input data to give a very close approximation to a 20/80 policy. Table III-3 shows the results for a 15-item storage situation. The input is displayed in Appendix C-1, as the cumulative frequency and the corresponding item type.

In the case of equal chances of any item being picked, the probability is known and is again treated the same way to get a discrete uniform distribution. For instance, for a five-item type the probability of each item to be picked is one-fifth, the resulting cumulative probability of each item is input in the form shown in Appendix C-1.

TABLE III-3

CUMULATIVE PICK FREQUENCY OF ITEMS (20/80)

ITEM NUMBER	(i) FRACTION OF TOTAL ITEMS	D(i) DEMAND RATE OF ITEM	F(i) PICK FREQUENCY OF ITEM	CUMMULATIVE FREQUENCY
1	1/15	1.425	0.255 1.425/5.58	0.255
2	2/15	0.789	0.141	0.396
3	3/15	0.556	0.100	0.496
4	4/15	0.433	0.078	0.574
5	5/15	0.358	0.064	0.638
6	6/15	0.306	0.055	0.693
7	7/15	0.268	0.048	0.741
8	8/15	0.239	0.043	0.784
9	9/15	0.216	0.039	0.823
10	10/15	0.197	0.035	0.858
11	11/15	0.182	0.033	0.891
12	12/15	0.168	0.030	0.921
13	13/15	0.157	0.028	0.949
14	14/15	0.147	0.026	0.975
15	15/15	0.139	0.025	1.000

Σ 5.58

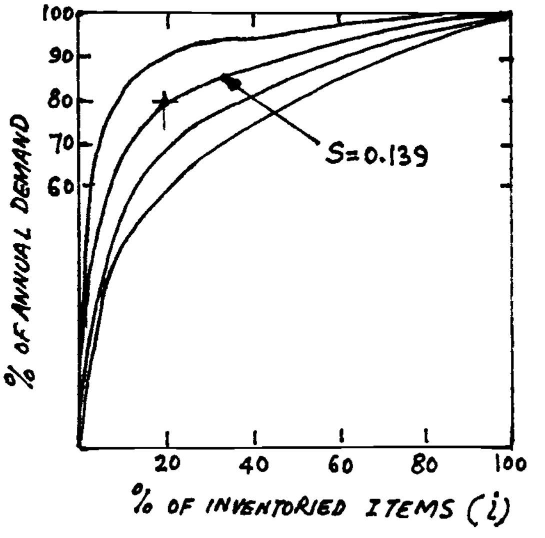
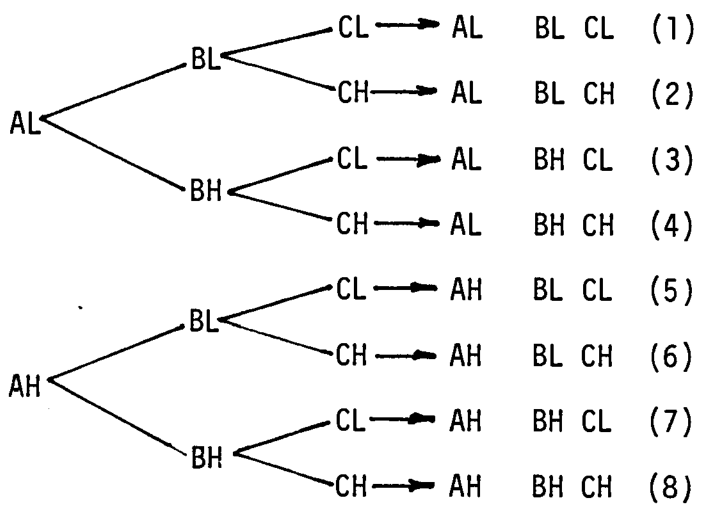


Figure III-6. ABC curves.

Average order size is approximated to follow a truncated Poisson distribution with mean units of, e.g., 2(CL), 10(CH), etc.; a minimum of one unit and a maximum of total number of units on the pallet, i.e., 20.

With the type of treatments in view, the possible factorial combinations are shown below (the symbols used are the same as in Table III-2). Note that elsewhere in this study the factorial comb-



inations are referred to as numbers, i.e., (1), (2), etc., as alphabetical combinations such as ALBL CL, etc., or as a full description. There were a total of 34 simulation runs made in this study. Once for each factorial combination corresponding to each of the two alternatives, i.e., S-Zone and D-Zone, runs for two different sequences of random number seed sets, adds up to 32 runs. Two further runs are made for the factorial combinations of AL BL CL1 (five units/order) and AL BL CH1 (15 units/order), making a total of 34 runs. Each simulation run is 40 to 50 thousand time units long (a time unit equals a second).

After an initial running of 10,000 time units (in some cases 20,000 units) to remove any bias due to initial conditions, the remainder of the run lengths are used to obtain experimental results.

SIMULATION STATISTICS COLLECTED

The superiority of one alternative over the other is judged by comparing the average crane cycle time or total number of orders processed, over a steady state simulation run, for the S-Zone and the D-Zone. This is necessary mainly to collect statistics on crane cycle times and the number of orders processed. However, statistics regarding other parameters such as cycle time per order, the crane's travel times from location to location, crane and operator waiting times, pallets leaving the system, etc., are also collected. Since the purpose of this study is to obtain a "feel" or comparison of the alternatives under study, a single replication would suffice. But a set of two independent replications are made with identical inputs, and different random number seed sequences. The independent runs thus obtained allow the use of classical analysis techniques with increased statistical accuracy in grand sample averages and reduced variance. The sample size within each replication is kept sufficiently large, i.e., greater than 100 to have a reasonable basis for the same normal distribution of estimates.

The main purpose of this study is not to identify the "absolute values" of the system responses, but to find the "differences" among system responses. Therefore it would seem reasonable to compare both systems using the same sequence of random numbers. The use of the same random number also yields in the reduction of variance. As a matter of fact this is by far the most popular variance reduction technique used in practice. Apart from the obvious results related to differences in means, statistical data collected are used to investigate the effect of different factors simultaneously. This is done by employing the factorial experimentation technique, and using a fixed effect model of a three-factorial experiment. The fixed effect model is used because each factor is studied at two levels, which are of intrinsic interest in themselves, i.e., these "levels" are not considered a sample from a large population of "levels" of a factor.

CHAPTER IV

RESULTS

INTRODUCTION

In order to reduce the bias due to initial conditions, as described in the previous chapter, the statistical arrays are set to zero after the first 10,000 units of time have lapsed. The only exception being the factorial combinations AH BL CL and AH BL CH, which are cleared at time 20,000. These limits, for discarding the observations, are set by looking at the file storage area, and the plotted data during trial runs. For example, the file storage areas for two samples of factorial combinations, shown in Appendices C-4 and C-6, clearly show that around time 20,000 and 10,000, respectively, almost all the items (files) have been accessed at least once or more than once by the crane. Plot of orders and cycle time against time provides a better feel for unsteady and steady periods in any simulation run. One such example is provided in Appendix C-7. The initial conditions cause an unsteady or transient state between time zero and time 10,000, after which a steady increase in cumulative statistics for O, the number of orders, and T, the crane cycle time, indicates the end of the transient state and a continued steady state period till the end of simulation. To further assure that the simulation results are being taken from a steady state period, summary reports are obtained at intervals of 10,000 time units after clearning the arrays. In Table IV-1 statistics related to the cycle time and units required are tabulated to observe the mean values at different intervals. It is evident from the table that none of the averages for cycle time at time 20,000 (or 30,000) are more than six percent outside the values found at time 40,000 (or 50,000). These results from the subruns confirm that samples are definitely taken from a steady state simulation.

The system responses of S-Zone and D-Zone, in terms of average crane cycle time, are shown in Figure IV-1. Both systems are positively correlated because similar initial conditions and the same random number sequence is used. Such a positive covariance yields a considerable variance reduction (see Kleiznen, 1974). However, Hillier and Lieberman (1974), observe that the use of the same random number sequences results in observations which are not independent and therefore make statistical analysis difficult. But since only two systems are compared in this study, the percentage differences of the two responses are calculated, which are mutually independent and hence easy to analyze.

ANALYSIS OF RESULTS OF MAJOR INTEREST

Crane Cycle Time and Orders Processed

It is obvious from the definition of parameters about which statistics are collected that the crane cycle time is the most significant measure of the system responses and an indicator of the throughput of the two systems. The total number of orders processed is not

TABLE IV-1

STEADY STATE OBSERVATIONS FOR UNITS REQUIRED AND CYCLE TIME AT DIFFERENT INTERVALS OF SIMULATION RUN

FACTORS			RUN LENGTH SECONDS	D-ZONE		S-ZONE	
NUMBER OF ITEMS	PICK FREQUENCY	MEAN ORDER SIZE		UNITS REQ'D.	CYCLE TIME	UNITS REQ'D.	CYCLE TIME
AL (5)	BL (20/80)	CL (2)	20k	1.993	35.35	1.992	44.95
			30k	2.082	35.01	2.036	44.15
			40k	2.076	34.84	2.05	43.71
		CH (10)	20k	9.916	40.82	9.871	47.99
			30k	10.03	40.37	9.997	47.24
			40k	10.03	40.28	10.06	47.09
	BH (EQUALLY LIKELY)	CL (2)	20k	1.986	36.70	1.949	46.41
			30k	2.069	36.86	1.964	47.38
			40k	2.076	36.78	2.053	46.96
		CH (10)	20k	9.861	42.41	10.21	50.25
			30k	9.992	42.26	10.08	50.41
			40k	10.02	42.25	10.10	50.47
AH (15)	BL (20/80)	CL (2)	30k	2.038	41.12	1.972	46.47
			40k	2.077	40.65	2.108	46.73
			50k	2.097	40.62	2.08	46.05
		CH (10)	30k	10.12	44.66	9.902	49.43
			40k	10.16	44.39	10.07	48.39
			50k	10.10	44.35	10.08	48.16
	BH (EQUALLY LIKELY)	CL (2)	20k	1.945	43.51	1.955	51.98
			30k	1.967	43.73	1.972	51.90
			40k	2.055	43.76	2.02	51.92
		CH (10)	20k	10.06	47.61	10.31	54.50
			30k	10.00	47.59	10.07	54.17
			40k	10.08	47.49	10.06	53.84

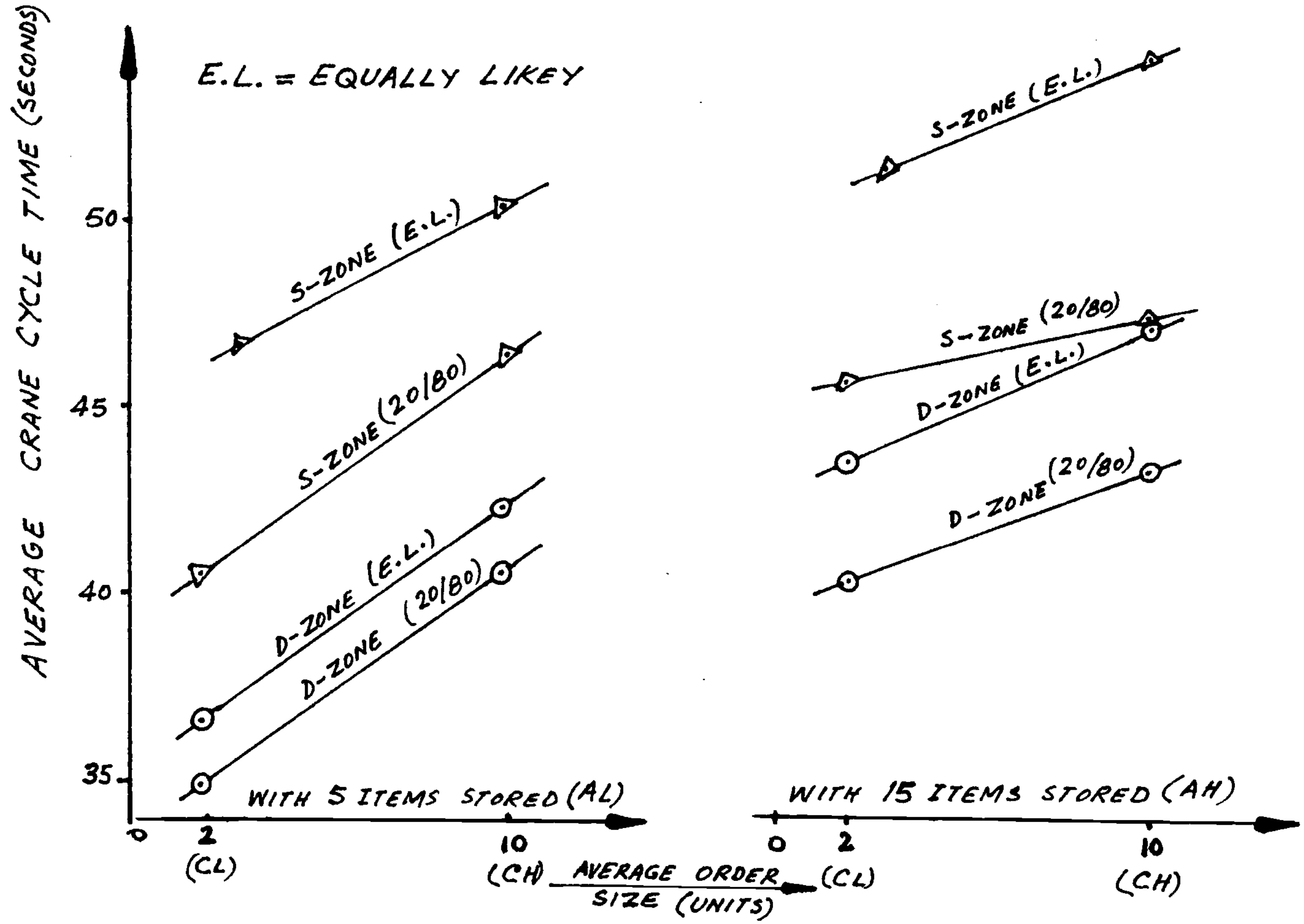


Figure IV-1. Crane cycle time plotted against orders size.

a true representative of throughput because of two main reasons. First, except for the crane cycle time, all other factors such as crane maintenance and repair time, etc., have not been considered in its measure. Second, those orders which involved no crane travel time because the item required was the same as the item on the last order make it a biased estimate of orders processed. On the other hand, he average crane cycle time does not include zero crane travel times, i.e., when the crane was waiting.

It may be worthwhile to define crane cycle time more specifically in addition to the general definition explained in the previous chapter. The crane cycle time could be made up of any of the three distinct situations. The first situation arises when the current order is filled fromthe pallet brought at I/O location for last order, which means the crane cycle time for this order would be zero. The second situation may consist of an order not completely filled from the pallet brought to the I/O location. This means that the crane cycle time would be the sum of the cycle time in bringing the first pallet to I/O location, which partially filled the order and the cycle time in bringing the next pallet to I/O location of the same item type to fill the remaining order. The third type of situation is the most common process of the crane cycle time in bringing only a single pallet to I/O location which filled the order completely. The average crane cycle time is derived from the statistics collected on the crane cycle times other than zero, i.e., the first of the three situations described above.

The average crane cycle times from the results of runs with two different random number seed-sets are presented in Table IV-2. Comparing the means for D-Zone and S-Zone as shown in Figure IV-2, it is evident that for all eight treatments, means for D-Zone are less than those for S-Zone. Obviously, this shows a significant superiority of D-Zone over S-Zone, but before a general conclusion is drawn, the effect of different factors should be studied further. Figure IV-1 illustrates that there are A, B, and C main effects but the response curves are not exactly parallel to conclusively indicate that any kind of interaction is absent. In order to study the responses further and to determine the effect of three factors—types of items (A), pick frequency of an item (B), and the average number of units per order (C)—each at two levels, on the response, i.e., the percentage change in cycle time for two systems, a 2x2x2 factorial experiment is used. A randomized block design with two replications, i.e., two blocks, is used, and the blocks are arranged to allow further elimination of differences due to the random numbers generating process in the computer, if such differences exist. Table IV-3 shows the results of a preliminary ANOVA. These results show that the treatment differences are highly significant, thus allowing for an in-depth study of the main effects and the interactions.

Contrast of treatment totals are used (Daniel, 1976) to calculate the final ANOVA for the percent change data which is shown in Table IV-4. It reveals that neither the AB, the BC, nor the ABC interactions are significant. This means that something can be said about the AC interaction and the B main effect. Notice, however,

TABLE IV-2

AVERAGE CRANE CYCLE TIME

FACTORS			REPLICATION WITH RANDOM NUMBER SEED SET I			REPLICATION WITH RANDOM NUMBER SEED SET II			MEAN OF REPLICATIONS
NUMBER OF ITEMS	PICK FREQUENCY	MEAN ORDER SIZE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE	PERCENT CHANGE
AL (5)	BL (20/80)	CL (2)	34.99	42.98	22.84	34.84	43.71	25.46	24.15
		CH (10)	40.34	46.42	15.07	40.28	47.09	16.91	15.99
	BH (EQUALLY LIKELY)	CL (2)	36.61	46.58	27.23	36.78	46.96	27.68	27.45
		CH (10)	42.01	50.28	19.69	42.25	50.47	19.46	19.57
AH (15)	BL (20/80)	CL (2)	40.09	45.77	14.17	40.65	46.73	14.96	14.56
		CH (10)	43.36	47.24	8.95	44.39	48.39	9.01	8.98
	BH (EQUALLY LIKELY)	CL (2)	43.41	51.38	18.36	43.76	51.92	18.65	18.50
		CH (10)	47.02	53.26	13.27	47.49	53.84	13.37	13.32

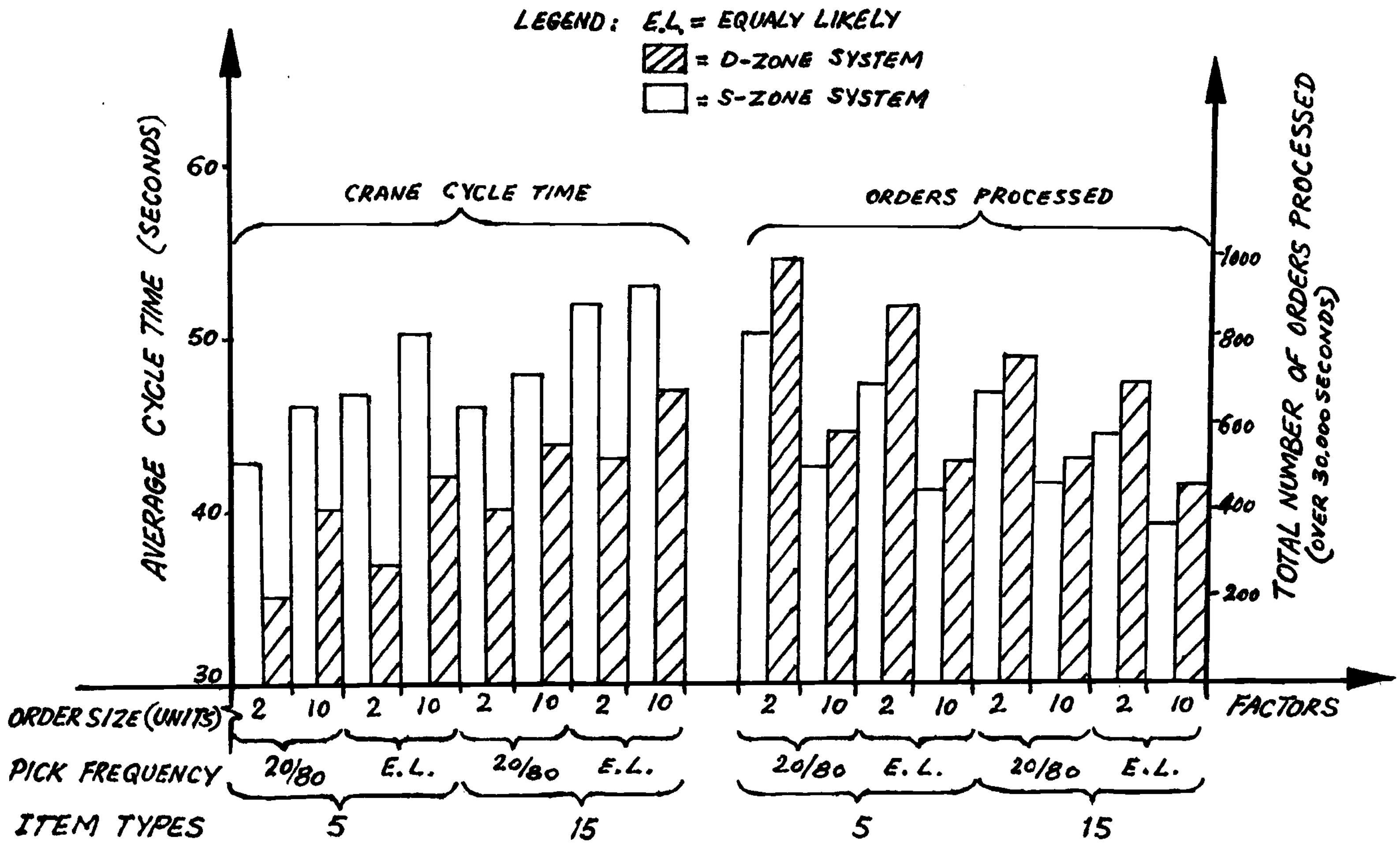


Figure IV-2. Crane cycle times and orders processed (comparison).

TABLE IV-3

PRELIMINARY ANOVA (CYCLE TIME)

Source	df	SS	MS	F
Total	15	503.20		4.480
Blocks	1	2.193	2.193	145.22**
Treatments	7	497.58	71.083	
Error	7	3.427	0.4895	

Coefficient of Variation = 3.926%

Standard error of TMT. Mean = 0.245

TABLE IV-4

THE FINAL "ANOVA" (CYCLE TIME)

Source	df	MS	F
Total	15		
Blocks	1	2.193	4.480
A - main effect	1	252.81	516.46**
B - main effect	1	57.53	117.53**
C - main effect	1	179.69	367.09**
AB interaction	1	0.483	0.99
AC interaction	1	6.94	14.18**
BC interaction	1	0.116	0.24
ABC interaction	1	0.0036	0.007
Error	7	0.4895	

**Significant at the 1% level

A = Number of items; B = Pick frequency; C = Average order size.

that the A and the C main effects are highly significant and it would be meaningful to look at the A and the C main effects as well.

The next significant result to be analyzed is the percentage change in orders processed in the D-Zone as opposed to the S-Zone system. For this purpose again a 2x2x2 factorial experiment is used to look into the percentage increase in the number of orders processed over a period of 30,000 seconds. Using the results of two replications as shown in Table IV-6, the preliminary ANOVA and the final ANOVA are calculated and are given in Tables IV-5 and IV-7. Preliminary ANOVA shows that treatment differences are significant. Final ANOVA reveals that none of the first or second order interactions, i.e., AB, AC, BC and ABC, are significant. However, it shows that the main effects of A, B, and C are highly significant. Thus something can be said about all the main effects.

TABLE IV-5

PRELIMINARY ANOVA (ORDERS PROCESSED)

Source	df	SS	MS	F
Total	15	492.78		
Blocks	1	0.62	0.62	0.21
TMTS	7	471.28	67.33	22.57**
Error	7	20.88	2.98	

Coefficient of variation - 9.76%

TABLE IV-6

MAXIMUM NUMBER OF ORDERS PROCESSED
(OVER A PERIOD OF 30K SECONDS)

FACTORS			REPLICATION WITH RANDOM NUMBER SEED SET I			REPLICATION WITH RANDOM NUMBER SEED SET II			MEAN OF REPLICATIONS
NUMBER OF ITEMS	PICK FREQUENCY	MEAN ORDER SIZE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE	PERCENT CHANGE
AL (5)	BL (20/80)	CL (2)	986	809	21.88	947	748	26.60	24.24
		CH (10)	584	510	14.51	576	490	17.55	16.03
	BH (EQUALLY LIKELY)	CL (2)	872	690	26.38	868	680	27.65	27.01
		CH (10)	533	445	19.78	533	446	19.51	19.64
AH (15)	BL (20/80)	CL (2)	776	675	14.96	741	656	12.96	13.96
		CH (10)	514	466	10.30	480	442	8.60	9.45
	BH (EQUALLY LIKELY)	CL (2)	689	581	18.59	678	580	16.90	17.74
		CH (10)	450	396	13.64	440	388	13.40	13.52

TABLE IV-7

FINAL ANOVA (ORDERS PROCESSED)

Source	df	MS	F
Totals	15		
Blocks	1	0.62	0.21
A	1	260.10	87.28**
B	1	50.73	17.02**
C	1	147.80	49.60**
AB	1	0.54	0.18
AC	1	11.71	3.93
BC	1	0.32	0.11
ABC	1	0.08	0.03
Error	7	2.98	

**Significant at 1% level

A = Number of item types

B = Pick frequency

C - Units (average) picked/order

Report of Statistical Analyses

Crane Cycle Time

The results of the AC interaction and the A and the C main effects are shown in Table IV-8. This table shows that when A is low and C is low, the percent change is at its maximum. The combined effect of one factor at low level and the other at high level seems to have approximately the same response. However, increasing both factors to their highest level decreases the response to the lowest value. Looking at the A and the C main effects independently, it is clear that the main effects are acting in a manner similar to each other. It seems that if the A or the C main factor is at low level it tends to give greater percent change than at higher levels.

TABLE IV-8

FACTORS A AND C (PERCENT CHANGE IN CYCLE TIME)

Factor A	CL (2 units)	CH (10 units)	A Main Effect	Standard Error
AL (5 items)	25.80	17.78	21.79	0.35 (for the AC interaction)
AH (15 items)	16.54	11.15	13.84	0.247 (for the A and the C main effect)
C Main effect	21.17	14.47		

The results of B main effects are tabulated in Table IV-9, which shows that a 20/80 pick frequency (i.e., BL) is less favorable to the high percentage change in the crane cycle time than an equally likely (i.e., BH) picking policy.

TABLE IV-9

FACTOR B (PERCENT CHANGE IN CYCLE TIME)

Factor B	BL (20/80)	BH (Equally likely)	Standard Error
Percent change	15.92	19.71	0.247

Orders Processed

The percentage change in the orders processed (see Tables IV-10 through IV-12 below) very closely resembles the results of cycle time changes except that there is no indication of interaction between factors A and C. It is also apparent these percent changes are almost proportional to the cycle time changes at different levels when comparing the D-Zone and the S-Zone systems. In other words, by not utilizing a D-Zone policy, the percent increase in the crane cycle time causes approximately an equal percentage decrease in the number of orders processed.

TABLE IV-10

PERCENTAGE CHANGE IN ORDERS PROCESSED

FACTOR A

Factor A	AL (5 items)	AH (15 items)	Standard Error
Percentage change in orders processed	21.73	13.67	0.61

TABLE IV-11

PERCENTAGE CHANGE IN ORDERS PROCESSED

FACTOR B

Factor B	BL (20/80)	BH (Equally likely)	Standard Error
Percentage change in orders processed	15.92	19.48	0.61

TABLE IV-12

PERCENTAGE CHANGE IN ORDERS PROCESSED

FACTOR C

Factor C	CL (2 units)	CH (10 units)	Standard Error
Percentage change in orders processed	20.74	14.66	0.61

Blocking has little effect on the experimental error in these trials. Apparently the variation due to random number generator in the computer from run to run is very little. The relative variation among the two replications is also not very excessive (coefficient of variation being 3.926 for cycle times and 9.76 percent for orders processed). A very insignificant ABC interaction can be taken as an error term rather than an interaction.

Access, Return and Replacement Times

The mean values for each of the eight factorial combinations of these parameters are given in Table IV-13. Looking at the observations for each factorial combination for both D-Zone and S-Zone, it can easily be seen that the means of a D-Zone are lower than those of an S-Zone. However, from the calculated percentage differences between means, the following table can be deduced, showing the percentage change in mean time in using D-Zone over S-Zone. From the table

Factorial Combinations (Treatments)	Percent change in		
	Access-TM	Return-TM	Replacement-TM
All "CL" (2 units)	High	Medium	Low
All "CH" (10 units) with "AL" (5 items)	High	Low	Medium
All "CH" (10 units) with "AH" (15 items	Medium	Low	High

TABLE IV-13

MEAN ACCESS, RETURN AND REPLACEMENT TIMES (SECONDS)
(AT 40K SECONDS USING RANDOM NUMBER SEED SET I)

FACTORS			ACCESS TIME			RETURN TIME			REPLACEMENT TIME		
NUMBER OF ITEMS	PICK FREQUENCY	MEAN ORDER SIZE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE
AL (5)	BL (20/80)	CL (2)	10.34	13.46	30.17	11.92	14.76	23.83	17.35	20.57	18.56
		CH (10)	12.70	15.00	18.11	13.42	14.86	10.73	17.28	20.15	16.61
	BH (EQUALLY LIKELY)	CL (2)	10.67	14.21	33.18	12.38	15.92	28.59	17.72	21.81	23.08
		CH (10)	13.05	15.64	19.85	13.88	16.08	15.85	17.69	21.67	22.50
AH (15)	BL (20/80)	CL (2)	11.79	14.05	19.17	12.84	14.56	13.40	18.38	20.45	11.26
		CH (10)	13.39	14.62	9.19	13.95	14.63	4.87	18.33	20.52	11.95
	BH (EQUALLY LIKELY)	CL (2)	12.44	15.04	20.90	13.86	16.53	19.26	19.43	22.55	16.06
		CH (10)	14.05	15.64	11.32	14.93	16.52	10.65	19.35	22.55	16.54

it can easily be seen that replacement time offers little in reducing the overall cycle time if mean units picked per order are low, but it performs better as C is used at higher level especially with factor A at higher level too. Access time is the major reducing factor in crane cycle time, as long as both C and A are not raised to their highest levels. Return-time seems to be responsive only to change in C; at low level of C it offers more reduction than at high level of C.

DISCUSSION OF RESULTS OF PARAMETERS OF LESSER SIGNIFICANCE

The crane and the operator waiting times for both the S-Zone and the D-Zone systems are shown in Table IV-14. The crane waiting time is always found to be much less than the operator waiting time. This is so because orders are scheduled immediately after a crane cycle is completed and the crane does not have to wait for an order to come. The only time the crane has to wait is when more than one consecutive order requires the same type of item and the total time taken by operator to pick these orders gets more than the crane cycle time in bringing the second pallet to the I/O location. Comparison of S-Zone and D-Zone, as illustrated in Figure IV-3, makes it obvious that both the crane and the operator waiting times are lower in the D-Zone than those in S-Zone. The results indicate that the most reduction in the operator waiting time is offered by a combination five-item type, equally likely pick frequency and an average order size of two units, when a D-Zone system is used. A combination of 15-item

TABLE IV-14

AVERAGE CRANE AND OPERATOR WAITING TIMES
(AT 40K SECONDS)

FACTORS			CRANE WAITING TIME			OPERATOR WAITING TIME		
NUMBER OF ITEMS	PICK FREQUENCY	ORDER SIZE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE
AL (5)	BL (20/80)	CL (2)	0.056	0.047	19.15	28.86	36.76	27.37
		CH (10)	0.105	0.090	16.67	32.73	39.10	35.48
	BH (EQUALLY LIKELY)	CL (2)	0.025	0.025	0.00	31.99	41.05	28.32
		CH (10)	0.059	0.062	5.08	35.62	43.02	20.77
AH (15)	BL (20/80)	CL (2)	0.013	0.006	116.67	37.56	43.45	15.68
		CH (10)	0.025	0.027	8.00	39.31	43.03	9.46
	BH (EQUALLY LIKELY)	CL (2)	0.008	0.009	12.50	41.03	48.77	18.86
		CH (10)	0.010	0.011	10.00	42.93	49.03	14.21

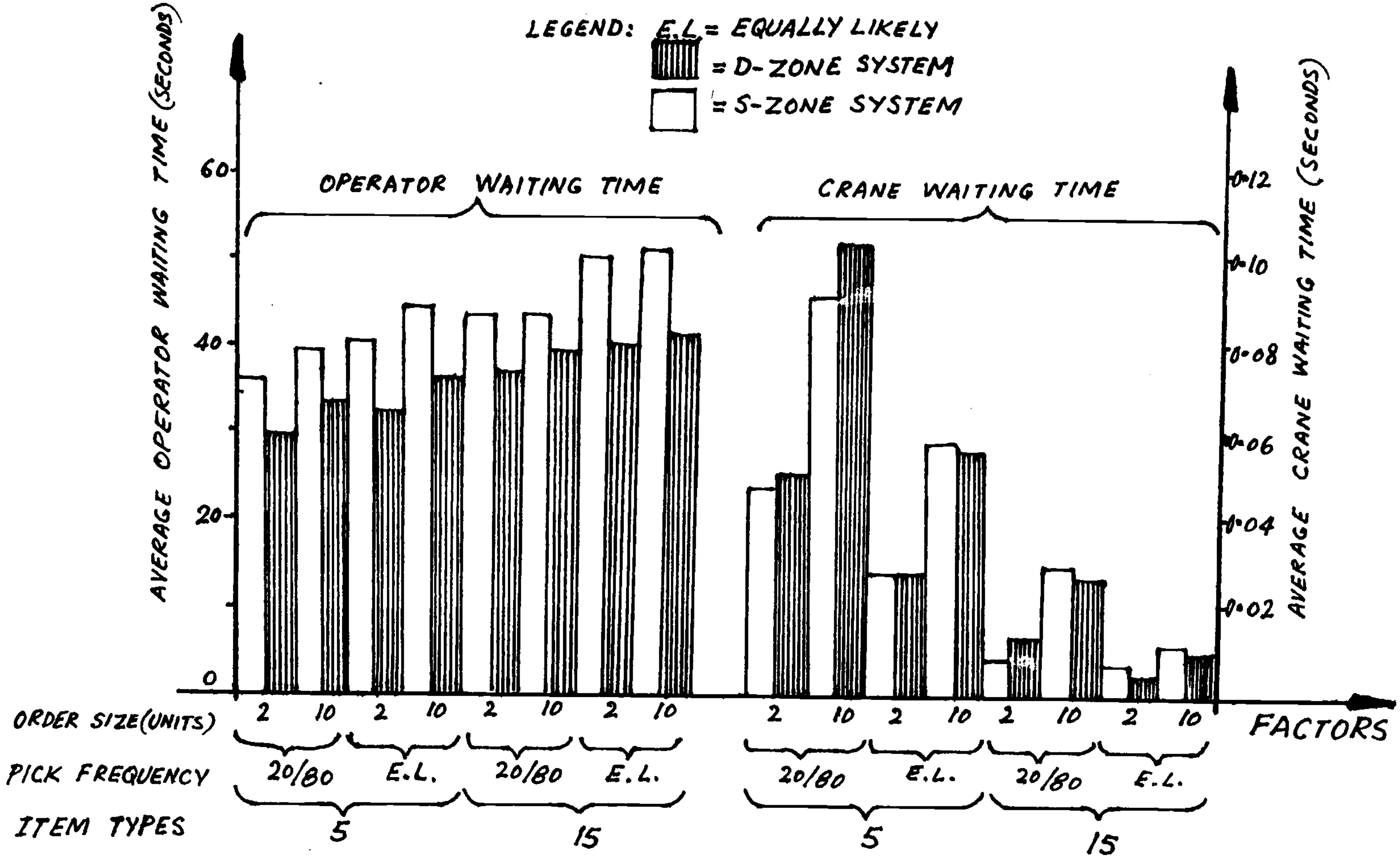


Figure IV-3. Operator and crane waiting times (comparison).

types, 20/80 pick frequency, and the average order size of 10 provides the least reduction in operator waiting times. Overall, the D-Zone is better than the S-Zone system because the D-Zone allows more rapid handling of pallets as a result of reduced crane travel times.

Table IV-15 shows the percentage of change in accessing a second pallet for the same order for the S-Zone and the D-Zone systems. These results show that a second pallet is accessed more often in D-Zone than it is in S-Zone. This happens because there are more orders processed in the D-Zone than there are in the S-Zone.

Table IV-15 also shows maximum trips (same as the number of leaving pallets) made to Zone II in the case of a D-Zone and the number of times the next pallet is accessed after the last pallet left the system in the case of the S-Zone. The results again show that since there were more orders processed in the D-Zone the number of pallets leaving the system or the number of times the crane makes a trip to the second zone are higher than those of S-Zone. Under similar conditions, using the same random number seed if the number of orders processed are kept the same the statistics in Table IV-15 would not differ for the D-Zone or S-Zone systems. This point can easily be demonstrated by looking at the ratio of second pallet accessed to the corresponding number of orders processed for the S-Zone and the D-Zone in any factorial combination. For instance, for AL BH CL combination, taking the values of SECON-PA and ORDERS from Tables IV-15 and IV-5, respectively, the SECON-PA:ORDERS ratio for the D-Zone (61/872 = 0.07) and the S-Zone (49/690 = 0.07) turn out to be the same.

TABLE IV-15

STATISTICS COLLECTED ON PALLETS IN MAXIMUM NUMBER
(AT 40K SECONDS WITH RANDOM NUMBER SEED SET I)

FACTORS			SECOND PALLET ACCESSED FOR THE SAME ORDER			TRIPS TO ZONE II SAME AS PALLETS LEAVING THE SYSTEM		
NUMBER OF ITEMS	PICK FREQUENCY	MEAN ORDER SIZE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE
AL (5)	BL (20/80)	CL (2)	57	43	32.56	127	104	22.12
		CH (10)	343	298	15.10	390	338	15.38
	BH (EQUALLY LIKELY)	CL (2)	61	49	24.49	113	90	25.56
		CH (10)	325	271	19.93	360	300	20.00
AH (15)	BL (20/80)	CL (2)	45	39	15.38	93	82	13.41
		CH (10)	288	264	9.09	335	305	9.84
	BH (EQUALLY LIKELY)	CL (2)	39	33	18.18	82	77	6.49
		CH (10)	268	233	15.02	296	261	13.41

The ratios of second pallets accessed as a function of the total orders processed can be used to find out the average cycle time per order, excluding zero crane cycle times. For example, for the same combination AL BH CL, the average crane cycle time for the D-Zone is given in Table IV-2 as 36.61 seconds. Then the average cycle time per order can be found as 36.61 (1 + 0.07) = 39.17 seconds per order. Similarly, for the S-Zone, it would be 46.58 (1.07) = 49.84 seconds per order excluding orders with zero crane cycle time.

The four levels of C, i.e., the average order size, give a much better idea of cycle time and number of orders processed (given in Table IV-16) when plotted as in Figure IV-4. The trend indicates that both the S-Zone and the D-Zone behave similarly to each other and as the number of units picked per order is increased, the cycle time increases and the total number of orders processed declines. However, the D-Zone continually maintains its superiority over the S-Zone, though decreasing as level of C, i.e., order size, gets higher.

TABLE IV-16

AVERAGE CRANE CYCLE TIME AND TOTAL ORDERS PROCESSED
(AT 40K SECONDS USING RANDOM NUMBER SEED SET I)

FACTORS			CRANE CYCLE TIME			TOTAL ORDERS PROCESSED		
NUMBER OF ITEMS	PICK FREQUENCY	MEAN ORDER SIZE	D-ZONE	S-ZONE	PERCENT CHANGE	D-ZONE	S-ZONE	PERCENT CHANGE
AL (5)	BL (20/80)	CL (2)	34.99	42.98	22.84	1305	1074	21.51
		CL1 (5)	37.43	45.04	20.33	1047	869	20.48
		CH (10)	40.34	46.42	15.07	777	676	14.94
		CH1 (15)	42.60	48.52	13.90	621	545	13.94

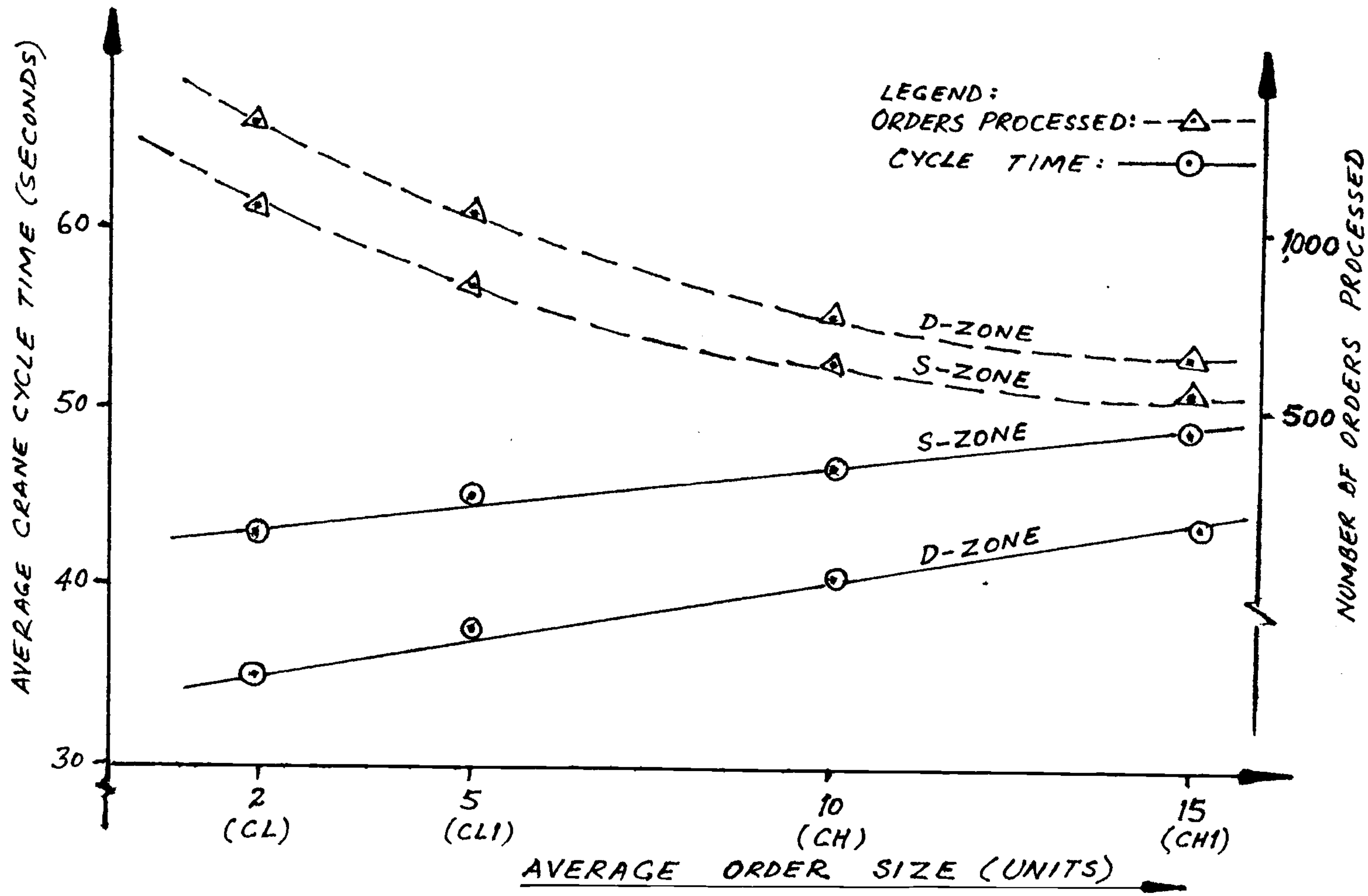


Figure IV-4. Crane cycle time and number of orders processed plotted against order size.

CHAPTER V

CONCLUSIONS

SUMMARY OF RESULTS

Simulation results demonstrate that significant increases in throughput are certainly achievable if a zone for partially picked pallets, located closest to home (I/O) station, is provided in end-of-aisle order picking AS/R Systems. The increases in throughput are achieved by decreases in crane cycle times. The reductions in crane cycle time vary under the influence of different factors considered in this study. Estimation of the confidence intervals for difference of factor means for percentage difference among crane cycle times, of a D-Zone system as opposed to an S-Zone system, provide the following results which can be reported with a 95 percent confidence level.

Percent change in crane cycle time, with five item types stored in the system, is somewhere between seven and eight-and-three-quarters percent higher than that of 15 items stored in the system. With a 20/80 item turnover policy, percent change in crane cycle time is about three to four-and-a-half percent lower than with a policy where each item has an equal chance of being picked. Percent change in crane cycle time with an average order size of two units is somewhere in the range of five-and-three-quarters to seven-and-a-half percent higher than that with an average order size of 10 units.

Crane cycle time is the most important measure of the system response in this study, and almost all other results, such as total orders processed, etc., are directly affected by increase or decrease in crane cycle time. Therefore the discussion in the previous chapter on the results of such parameters is considered sufficient.

The magnitude of results in this study may seem conservatively low as compared to Hausman and Schwarz (1976) paper because the crane cycle time, in this study, includes such factors as the crane acceleration and deceleration times and the crane's extraction and deposit times. The exclusion of these factors from the measurement of the crane cycle time may make the results more attractive but definitely unrealistic and overstated. For example, in a particular run the crane cycle times for the D-Zone and the S-Zone systems are found 34.84 and 43.71 seconds, respectively. The crane cycle time is 25.46 percent more for the S-Zone than that for the D-Zone. If only four extraction and deposit times were excluded from these cycle times, i.e., 24 seconds, the cycle time would have been 10.84 and 19.71 seconds for the D-Zone and the S-Zone systems, respectively. This gives the dramatic result of 81.83 percent more time spent per cycle if zoning is not used. In other words, the results indicate a reduction of 20.29 percent, and 45 percent in the crane cycle time by using the D-Zone system, with and without inclusion of the crane extraction and deposit times, respectively. Similarly, the exclusion of the crane acceleration/deceleration times will further exaggerate the results.

GENERAL CONCLUSIONS

This simulation study substantially supports the raw idea envisaged in the formulation of this problem: That by introducing a zone in the aisle, located closest to home (I/O) location, which handles only the recycled or partially picked pallets in an end-of-aisle order picking AS/R System, crane travel times can be reduced. The scope of this reduction does not seem to be limited to those AS/R Systems which use strictly an end-of-aisle order picking, but where the ratio of average number of units picked per order to total number of units per pallet are low and always less than one. In other words, zoning may not be effective if full pallet loads (unit loads) are to be handled. This is because, as the average units picked per order approach the total number of units on the pallet, the utilization of the zone for partially picked units diminishes, leaving very little difference between the S-Zone and the D-Zone systems. But the results of this study can easily be extended to include remote, and in-aisle order picking systems. "Mini-load" systems, using end-of-aisle, remote, or in-aisle order picking, can further minimize the size of storage space, by zoning the aisles for recycled or partially picked pallets of each item type, thus adding more space to the production areas.

It can be said, fairly confidently, that a reduction in cycle time of about 20 percent can be achieved provided the average units picked per order and total units on pallet ratio is kept as low as 1:10. As this ratio increases to 1:2 the reduction in crane cycle time is dropped to between six to seven-and-a-half percent. Interestingly enough, the number of item types stored in the aisle show similar results. The lower the number of item types stored, the higher the reduction in crane cycle times and vice versa. Apparently this is because, as the number of items grows larger the size of the zone which handles the partially picked pallets also grows larger, thus increasing the crane travel times. With five items the zone closest to home is one-twelfth the size of the aisle, while with 15 items it grows to one-quarter the size of the aisle. Which, in other words, suggests that zone-to-aisle size ratio should also be kept as small as possible to obtain maximum benefits of zoning.

Item turnover or pick frequency seems to give a little under 20 percent of reduction if each item is picked with equal probability rather than a 20/80 situation, which drops the reduction to around 16 percent. This is happening because in a 20/80 situation the crane travel is restricted to 20 percent of the items 80 percent of the time. And in this particular study 20 percent of the items are located almost in the same area of the aisle whether or not zoning is employed. A careful study of layouts in Appendices B-9 through B-12 would make this point more evident. The main factor causing this is the relatively small size of aisle under consideration. In a large size aisle a 20/80 situation will most certainly be more advantageous than an equally likely policy.

The best possible combination of different factors, with the greatest possible reduction in the crane cycle time, is found to be the one which has the least number of item types in the aisle with each item type having equal chances of being picked, and an average order size of one-tenth the total units on the pallets. As opposed to this the system in which a large number of item types are stored with 20 percent of them being picked 80 percent of the time, and the average order size is half a pallet load, carries the least prospects of improvement by zoning. In fact the improvement of about eight percent may not be attainable, in the presence of other factors in actual practice.

In the end it must be pointed out that although this study does prove the increase in throughput by decreasing the crane cycle times in adapting a zoning policy for partially picked pallets, it is limited in scope and explorative in nature. Therefore, one should refrain from deriving any broad-based conclusions. Nevertheless, it is well established that the benefits of zoning would largely depend on not only the order size, number of items stored, or turnover policy but, more specifically, on ratios between order size and units on pallets, zone and aisle sizes, as well as the number of item types and aisle size. The lower these ratios are, the higher will be the reduction in crane cycle time, resulting in increased throughput .

RECOMMENDATIONS

This study can be extended to several areas of Automated Storage and Retrieval Systems, the only restriction being that the system must be operating on order picking and not full load handling. It is, however, strongly recommended that all order picking AS/R Systems should consider zoning of the partially picked pallets (loads) close to the home location in the aisles. In searching for the potential increase in throughput in a particular system, it is recommended to include the following feature in the model to be simulated. The modified model should include two queues, one for orders to be retrieved, and one for orders to be stored, independent of each other. These queues should be in addition to the queue for the partially picked pallets, waiting after order picking, to be stored back into the system. This would be closer to the real world situation, where a single crane may have to handle the replenishments, simultaneously, with the retrieval and storage of existing pallets.

For future research it is recommended to investigate the effects of zoning on the throughput of a system where pallet assignment is permitted. This means that pallets may be carrying units belonging to several different item types. Many users of AS/R Systems utilize this situation where one pallet carries a number of items that are often required together. This way only one pallet is retrieved to fill several requests. Whether or not zoning will help improve the effective throughput of such systems would, perhaps, largely depend on what order picking and replenishment techniques are used. Again, it can be safely said that zoning will certainly improve the throughput if the pallets are picked partially and not fully. However, the exact potential of zoning in this area remains to be explored. These extensions, along with the present study, enhance the existing techniques of increasing throughput available to the users of Automated Storage and Retrieval Systems.

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APPENDICES

APPENDIX A

VARIABLE DEFINITIONS

ACCES-TM	Crane travel time between two locations plus the retrieval time.
ACT	Crane's access time from one location to another (includes one extraction).
ATRIB(I)	Buffer storage for the Ith attribute value to be stored in or removed from file storage area.
AVE-CYT	The crane time per order.
AX	Constant and equal acceleration and deceleration rate in X (horizontal) direction.
AY	Constant and equal acceleration and deceleration rate in Y (vertical) direction.
CRT	Crane retrieval/extraction/deposit time.
CR - WT -TM	Crane waiting time (idle time).
CWT	Crane waiting time.
CYCLE-TM	The sum of one REP-TM, one ACCES-TM and one RETUN-TM.
CYT	Crane cycle time (sum of RCT, ACT and RHT).
DX	Critical ratio in X direction.
DY	Critical ratio in Y direction.
FX	Cumulative probability of an item being picked.
I	The current number of entries in File "L".
ITM-TYP	Type of item required per order.
J	Number of file the item type to be retrieved is stored.
K	Simulation run number.

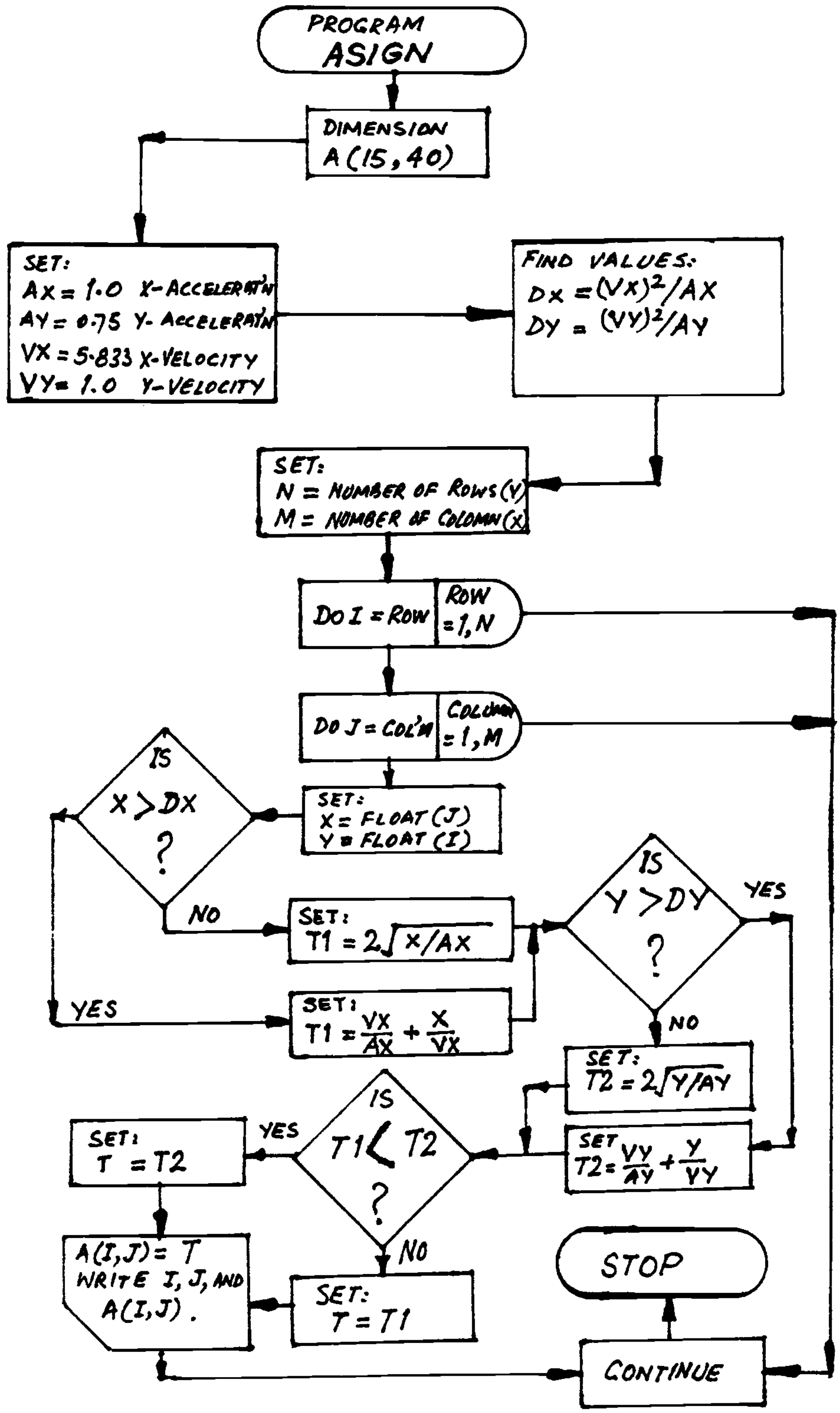
L	Number of last file to carry the attributes of pallets at home position.
LEVIN-PA	Number of pallets leaving the system.
LOC	Location of the entry in a file.
M	Number of bays in the aisle (columns)--Program "ASIGN"
M	Number of item type in a particular order.
MFE(J)	Pointer to the first entry in file J.
N	Number of tiers in the aisle (rows)--Program "ASIGN".
N	Number of file containing last item retrieved.
NCRDR	Card reader number.
NNQ(L)	The current number of entries in file L.
NPRINT	Printer number.
OP-WT-TM	Operator waiting time.
ORD	Number of order.
ORDERS	Total orders.
OWT	Operator waiting time.
PALL	Number of pallets leaving the system.
PAL2	Number of times a second pallet is accessed to fulfill an order.
PRT	Manual rate of picking units from the pallets.
RCT	The time the crane takes to replace a pallet back at a location (includes one extraction and one deposit).
REP-TM	The extraction time of a pallet at home position and travel time to a storage location plus deposit time.
RETUN-TM	Crane travel time between a location and home position plus deposit time.

SECON-PA	Number of times a second pallet is accessed for the same order.
T	Total travel time of the crane.
T1	Time for the X-axis to complete.
T2	Time for the Y-axis to complete.
TNOW	Current time of simulation.
TNPAL	Number of pallets per item type.
TRIP	Number of times a trip to second zone is made (in the case of a D-Zone) or a second pallet closest to home is accessed (in the case of an S-Zone).
TRIPZON2	Number of times a pallet other than first is accessed or trip to the second zone in D-Zone aisle.
TUN	Total number of units each pallet has.
TYP	Item type required for an order.
ULEF	Number of units left after ordered units are picked (negative if order is unfulfilled).
UPIK	Number of units picked per order.
UNR	Number of units required per order.
UTL	Units left on pallet after order has been processed.
UTOT	Total units on a pallet at retrieval.
VX	Constant traverse speed in X direction.
VY	Constant traverse speed in Y direction.
X	Number of columns.
XNEW	Crane's present location (X-coordinate)
XOLD	Crane's previous location (X-coordinate)
XVAL	Number of items to which FX corresponds.
Y	Number of rows.

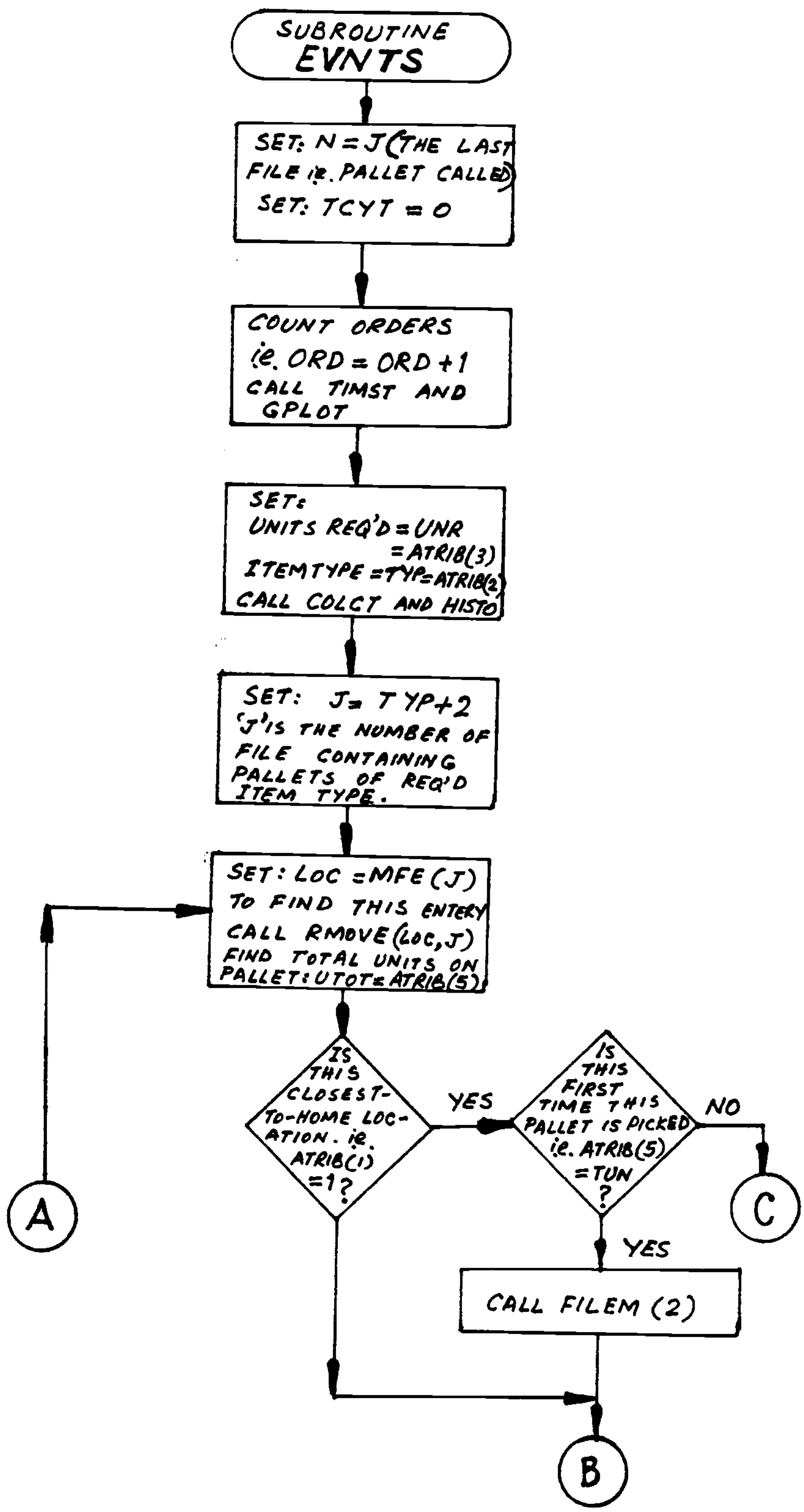
YNEW	Crane's present location (Y-coordinate).
YOLD	Crane's previous location (Y-coordinate).
ZXI	X-coordinate of a location.
ZYI	Y-coordinate of a location.

APPENDIX B

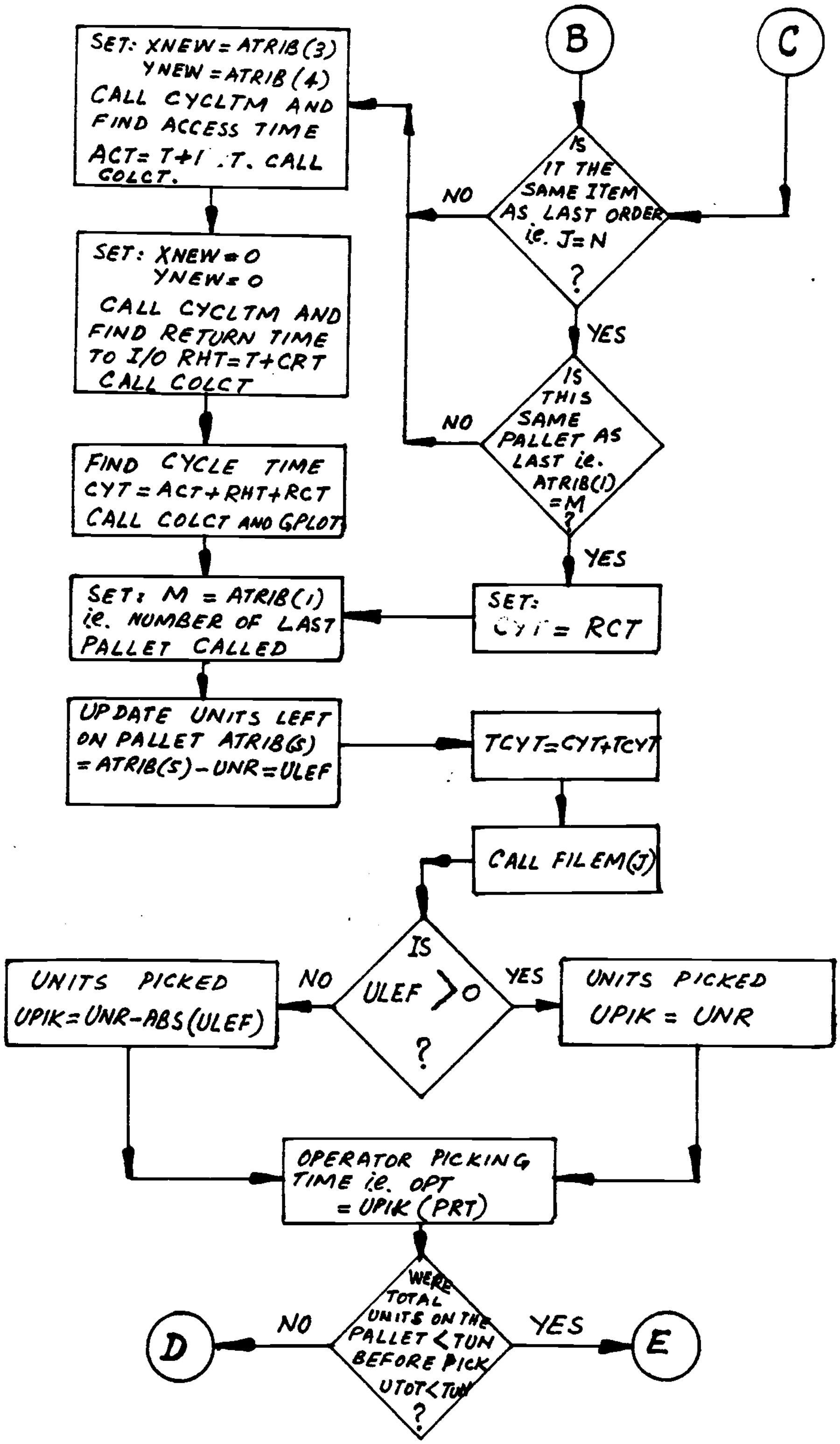
FLOW CHARTS AND PROGRAM LISTINGS



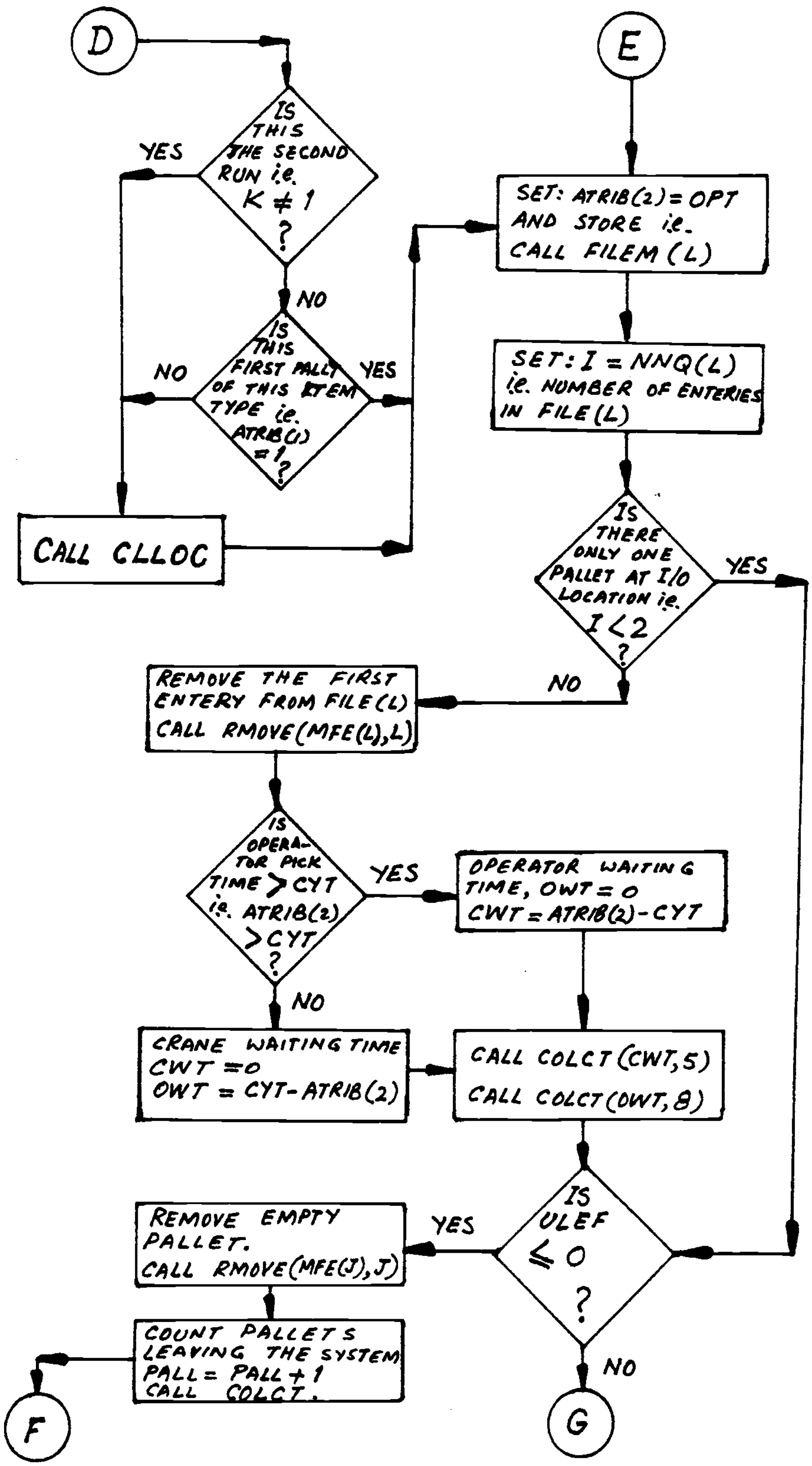
B-1. Flow chart for program "ASIGN".



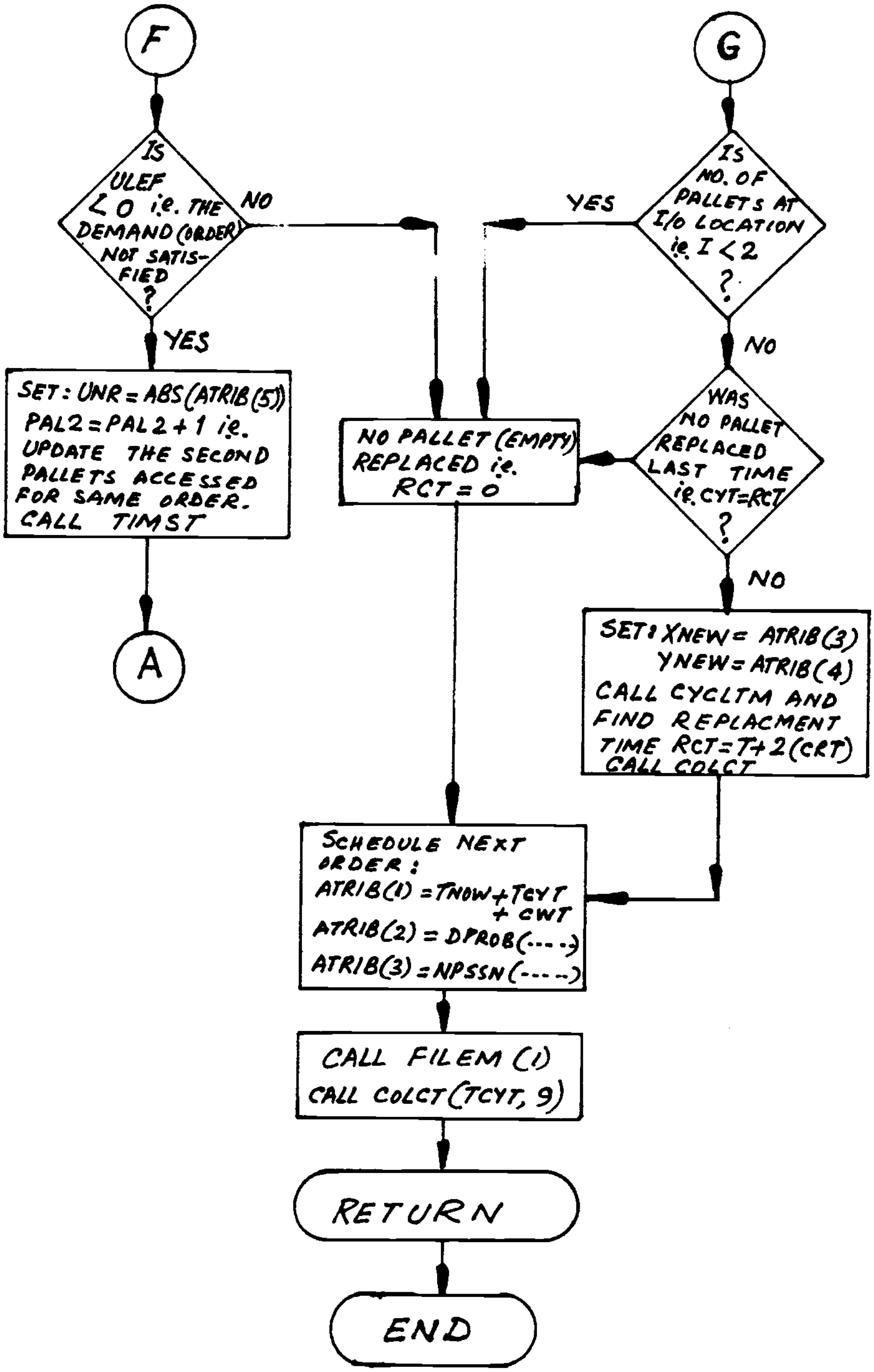
B-2. Flow chart for subroutine "EVNTS".



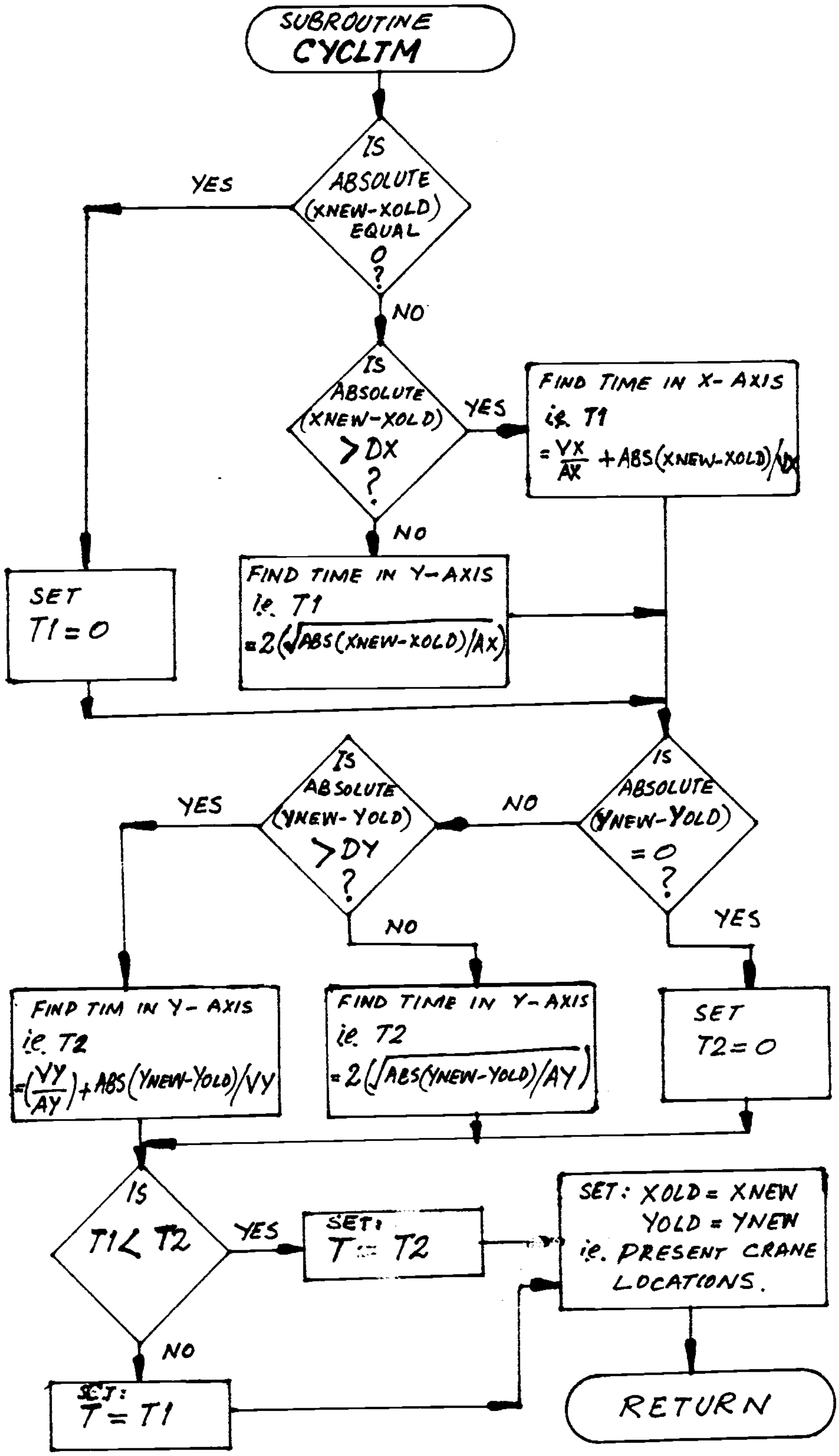
B-2. "EVNTS" (continued)



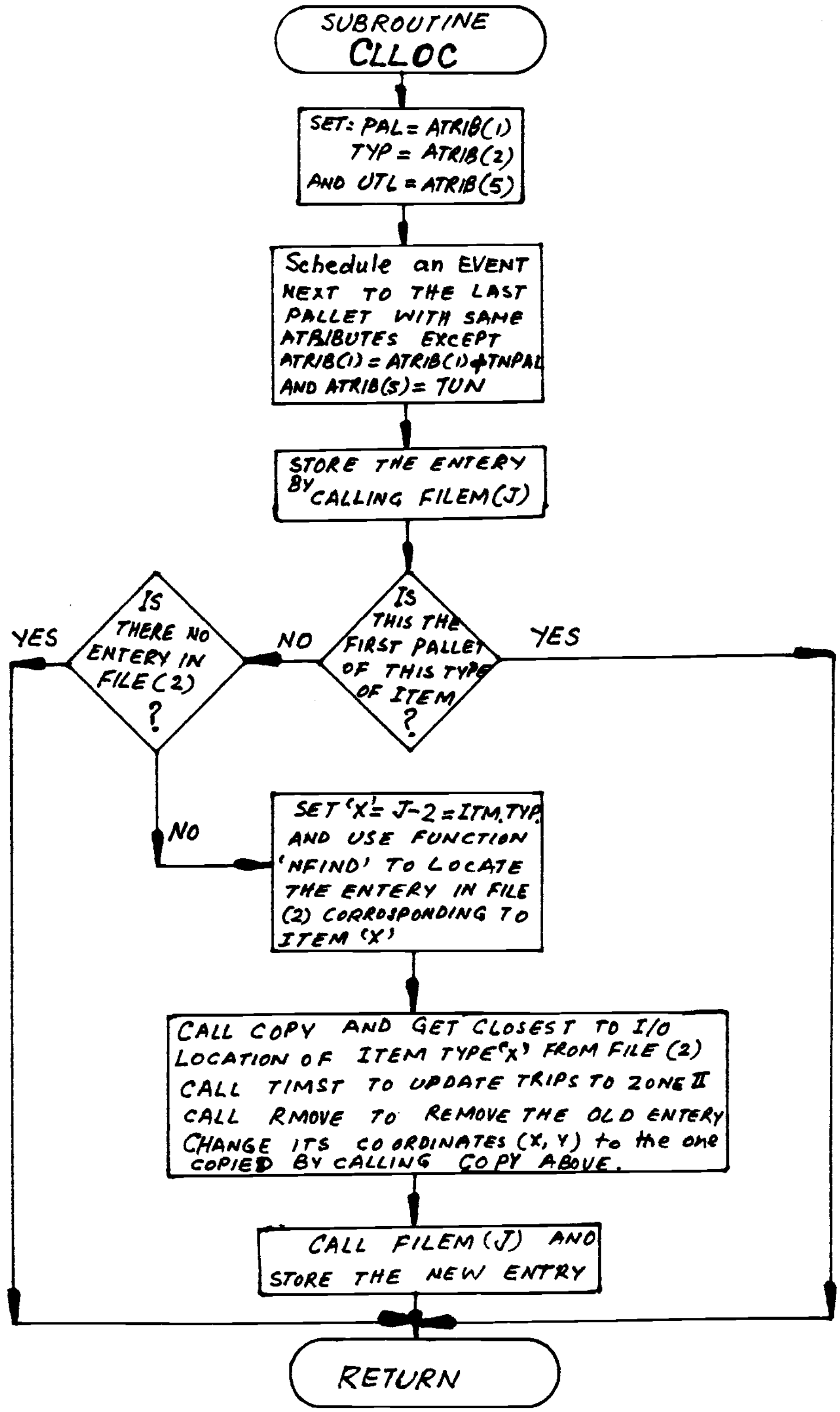
B-2. "EVNTS" (continued)



B-2. "EVNTS" (continued)



B-3. Flow chart for subroutine "CYCLTM".



B-4. Flow chart for subroutine "CLLOC".

```
      PROGRAM ASIGN(OUTPUT,TAPE6=OUTPUT)
      DIMENSION A(15,40)
      AX=1.0
      AY=0.75
      VX=5.833
      VY=1.0
      DX=(VX**2)/AX
      DY=(VY**2)/AY
      M=12
      N= 5
      DO 70 I=1,N
      DO 60 J=1,M
      X=FLOAT(J)
      Y=FLOAT(I)
      IF(X.GT.DX)GO TO 10
      T1=2*SQRT(X/AX)
      GO TO 20
 10   T1=VX/AX+X/VX
 20   IF(Y.GT.DY)GO TO 30
      T2=2*SQRT(Y/AY)
      GO TO 40
 30   T2=VY/AY+Y/VY
 40   IF(T1.LT.T2)GO TO 50
      T=T1
      GO TO 55
 50   T=T2
 55   A(I,J)=T
      WRITE(6,102)I,J,A(I,J)
102   FORMAT(" ",I3,I3,5X,F5.2)
 60   CONTINUE
 70   CONTINUE
      STOP
      END
```

B-5. Listing of program "ASIGN".

```
        PROGRAM MAIN                                          FTN 5.1+538

      PROGRAM MAIN(INPUT,OUTPUT,TAPE1,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      DIMENSION NSET(4000)
      COMMON QSET(4000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,
     1NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,
     2TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/AX,AY,VX,VY,DX,DY,XNEW,YNEW,XOLD,YOLD,PRT,CRT,T,
     1TUN,TNPAL,ORD,PALL,PAL2,TRIP,FX(60),XVAL(60),J,K,L,RCT,M
      EQUIVALENCE (NSET(1),QSET(1))
C
      NCRDR=5
      NPRNT=6
      K=0.
      READ(NCRDR,101) (FX(I),XVAL(I),I=1,15)
      WRITE(NPRNT,101) (FX(I),XVAL(I),I=1,15)
101   FORMAT(12F6.3/12F6.3/6F6.3)
      AX=1.0
      AY=0.75
      VX=5.833
      VY=3.5
      DX=(VX**2)/AX
      DY=(VY**2)/AY
      CALL GASP
      STOP
      END
```

```
        SUBROUTINE INTLC                                      FTN 5.1+538

      SUBROUTINE INTLC
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,
     1NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,
     2TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/AX,AY,VX,VY,DX,DY,XNEW,YNEW,XOLD,YOLD,PRT,CRT,T,
     1TUN,TNPAL,ORD,PALL,PAL2,TRIP,FX(60),XVAL(60),J,K,L,RCT,M
C
      K=K+1.0
      L=18
      M=0.0
      RCT=0.0
      ORD=0.0
      PALL=0.0
      PAL2=0.0
      TRIP=0.0
      CALL TIMST(ORD,TNOW,1)
      CALL TIMST(PALL,TNOW,2)
      CALL TIMST(PAL2,TNOW,3)
      CALL TIMST(TRIP,TNOW,4)
      XNEW=0.0
      YNEW=0.0
      XOLD=0.0
      YOLD=0.0
      PRT=0.5
      CRT=6.0
      TUN=20.0
      TNPAL=4.
      ATRIB(1)=TNOW
      ATRIB(2)=DPROB(FX,XVAL,15,1)
      ATRIB(3)=NPSSN(1,2)
      ATRIB(4)=0.0
      ATRIB(5)=0.0
      CALL FILEM(1)
      RETURN
      END
```

B-6. Listing of program "MAIN" and subroutine "INTLC".

```
SUBROUTINE EVNTS                                          FTN 5.1+538

      SUBROUTINE EVNTS(IX)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,
     1NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,
     2TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/AX,AY,VX,VY,DX,DY,XNEW,YNEW,XOLD,YOLD,PRT,CRT,T,
     1TUN,TNPAL,ORD,PALL,PAL2,TRIP,FX(60),XVAL(60),J,K,L,RCT,M
C
      N=J
      TCYT=0.0
      ORD=ORD+1.0
      CALL TIMST(ORD,TNOW,1)
      CALL GPLOT(ORD,TNOW,1)
      UNR=ATRIB(3)
      CALL COLCT(UNR,1)
      CALL HISTO(UNR,1)
      TYP=ATRIB(2)
      J=TYP+2.0
      CALL COLCT(TYP,2)
      CALL HISTO(TYP,2)
 10   LOC=MFE(J)
      CALL RMOVE(LOC,J)
      UTOT=ATRIB(5)
      IF(ATRIB(1).EQ.1.0)GO TO 12
      GO TO 13
 12   IF(ATRIB(5).NE.TUN)GO TO 13
      CALL FILEM(2)
 13   IF(J.EQ.N)GO TO 14
      GO TO 15
 14   IF(ATRIB(1).NE.M)GO TO 15
      CYT=RCT
      GO TO 16
 15   XNEW=ATRIB(3)
      YNEW=ATRIB(4)
      CALL CYCLTM
      ACT=T+CRT
      CALL COLCT(ACT,3)
      XNEW=0.0
      YNEW=0.0
      CALL CYCLTM
      RHT=T+CRT
      CALL COLCT(RHT,4)
      CYT=ACT+RHT+RCT
      CALL COLCT(CYT,7)
      CALL HISTO(CYT,3)
      CALL GPLOT(CYT,TNOW,1)
 16   M=ATRIB(1)
      ATRIB(5)=ATRIB(5)-UNR
      ULEF=ATRIB(5)
      TCYT=TCYT+CYT
      CALL FILEM(J)
      IF(ULEF.LT.0.0)GO TO 19
      UPIK=UNR
      GO TO 20
 19   UPIK=UNR-ABS(ULEF)
 20   OPT=UPIK*PRT
      IF(UTOT.LT.TUN)GO TO 22
      IF(K.NE.1)GO TO 21
      IF(ATRIB(1).EQ.1.0)GO TO 22
 21   CALL CLLOC
 22   ATRIB(2)=OPT
      CALL FILEM(L)
      I=NNQ(L)
      IF(NNQ(L).LT.2)GO TO 25
      CALL RMOVE(MFE(L),L)
      IF(ATRIB(2).GT.CYT)GO TO 23
      CWT=CYT-ATRIB(2)
      CWT=0.0
      GO TO 24
```

B-7. Listing of subroutine "EVNTS".

```
      SUBROUTINE EVNTS                                    FTN 5.1+538

   23 CWT=0.0
      CWT=ATRIB(2)-CYT
   24 CALL COLCT(CWT,5)
      CALL COLCT(CWT,8)
   25 IF(ULEF.LE.0.0)GO TO 30
      IF(I.LT.2)GO TO 45
      IF(CYT.EQ.RCT)GO TO 45
      XNEW=ATRIB(3)
      YNEW=ATRIB(4)
      CALL CYCLTM
      RCT=T+2*CRT
      CALL COLCT(RCT,6)
      GO TO 50
   30 CALL RMOVE(MFE(J),J)
      PALL=PALL+1.0
      CALL TIMST(PALL,TNOW,2)
      IF(ULEF.LT.0.0)GO TO 40
      RCT=0.0
      GO TO 50
   40 UNR=ABS(ATRIB(5))
      PAL2=PAL2+1.0
      CALL TIMST(PAL2,TNOW,3)
      GO TO 10
   45 RCT=0.0
   50 ATRIB(1)=TNOW+TCYT+CWT
      ATRIB(2)=OPROB(FX,XVAL,15,1)
      ATRIB(3)=NPSSN(1,2)
      ATRIB(4)=0.0
      ATRIB(5)=0.0
      CALL FILEM(I)
      CALL COLCT(TCYT,9)
      RETURN
      END
```

B-7. "EVNTS" (continued).

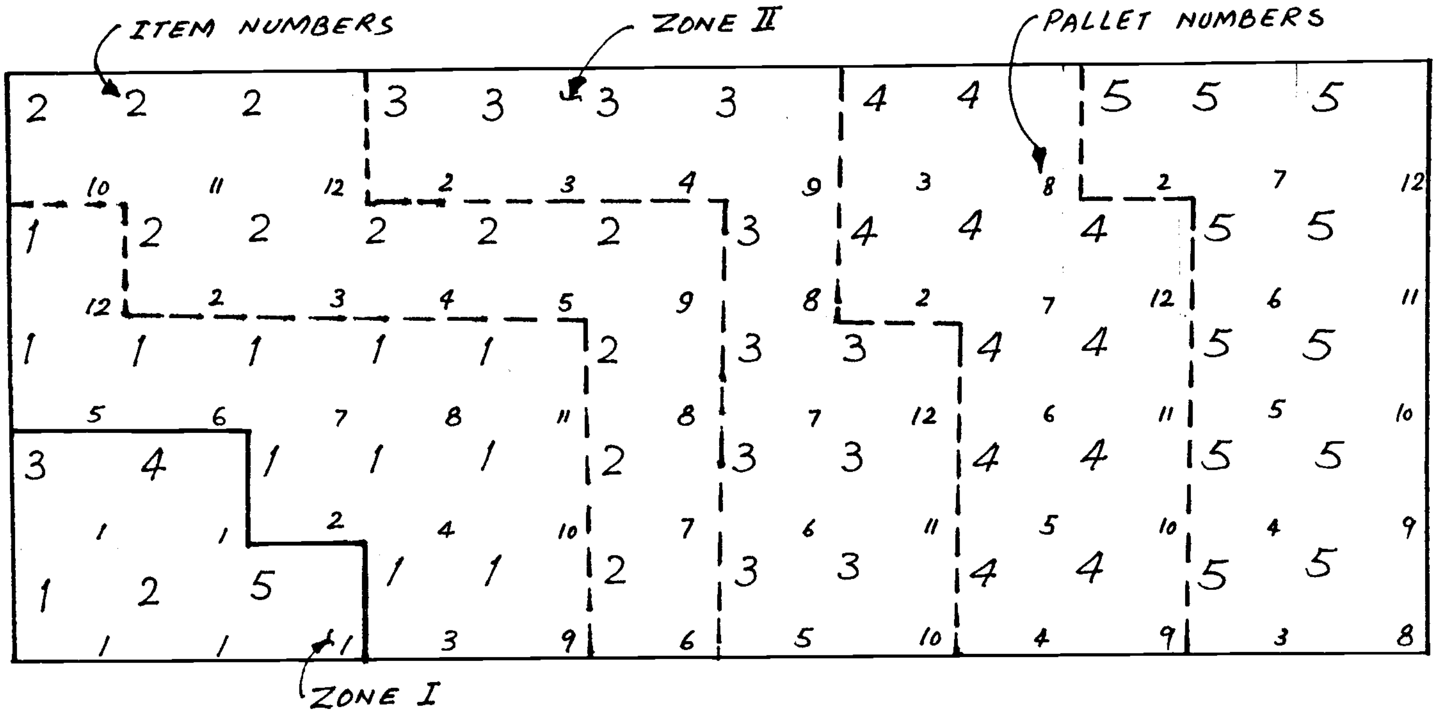
SUBROUTINE CYCLTM FTN 5.1+538

```
      SUBROUTINE CYCLTM
      COMMON/SCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,
     1NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,
     2TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/AX,AY,VX,VY,DX,DY,XNEW,YNEW,XOLD,YOLD,PRT,CRT,T,
     1TUN,TNPAL,ORC,PAL1,PAL2,TRIP,FX(60),XVAL(60),J,K,L,RCT,M
C
      IF(ABS(XNEW-XOLD).EQ.0.0)GO TO 5
      IF(ABS(XNEW-XOLD).GT.DX)GO TO 10
      T1=2*SQRT(ABS(XNEW-XOLD)/AX)
      GO TO 20
    5 T1=0.0
      GO TO 20
   10 T1=(VX/AX)+ABS(XNEW-XOLD)/VX
   20 IF(ABS(YNEW-YOLD).EQ.0.0)GO TO 25
      IF(ABS(YNEW-YOLD).GT.DY)GO TO 30
      T2=2*SQRT(ABS(YNEW-YOLD)/AY)
      GO TO 40
   25 T2=0.0
      GO TO 40
   30 T2=(VY/AY)+ABS(YNEW-YOLD)/VY
   40 IF(T1.LT.T2)GO TO 50
      T=T1
      GO TO 60
   50 T=T2
   60 XOLD=XNEW
      YOLD=YNEW
      RETURN
      END
```

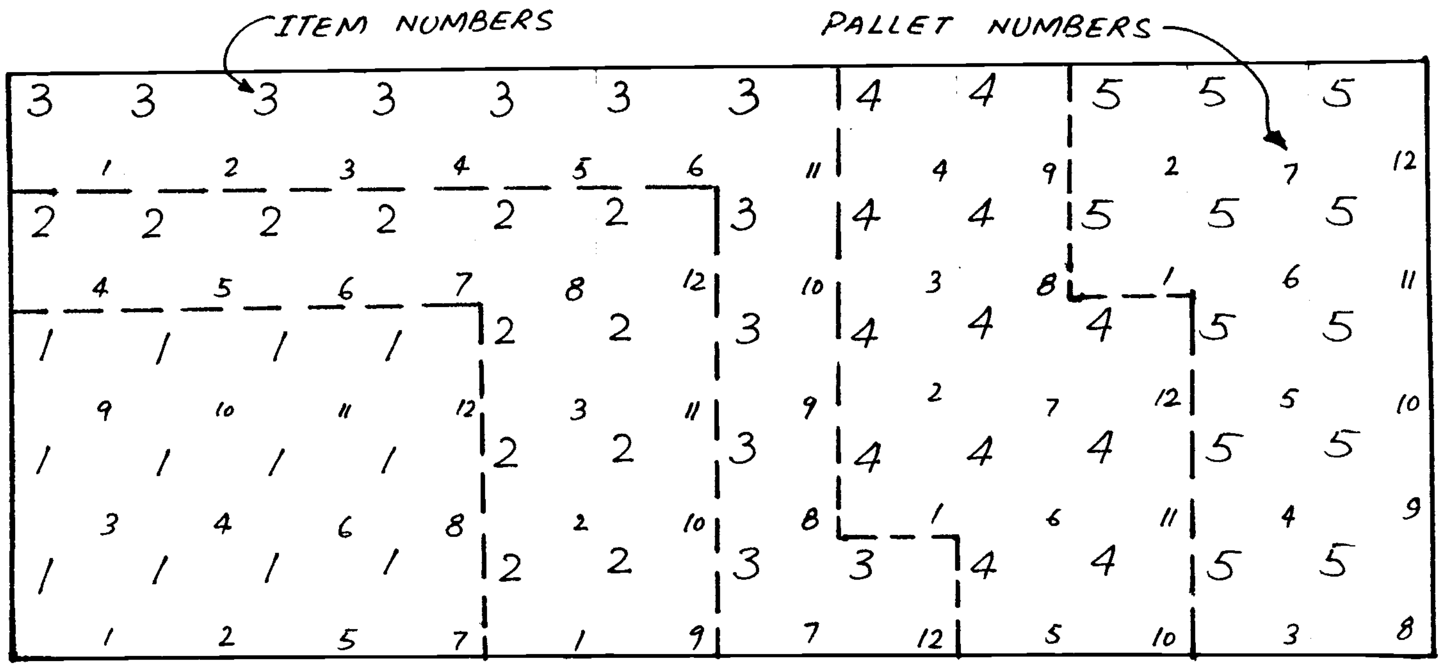
SUBROUTINE CLLCC FTN 5.1+538

```
      SUBROUTINE CLLCC
      COMMON/SCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,
     1NNAPC,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,
     2TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/AX,AY,VX,VY,DX,DY,XNEW,YNEW,XOLD,YOLD,PRT,CRT,T,
     1TUN,TNPAL,ORC,PAL1,PAL2,TRIP,FX(60),XVAL(60),J,K,L,RCT,M
C
      PAL=ATRIB(1)
      TYP=ATRIB(2)
      UTL=ATRIB(5)
      ATRIB(1)=ATRIB(1)+TNPAL
      ATRIB(5)=TUN
      CALL FILEM(J)
      IF(PAL.EQ.1.0)RETURN
      X=FLOAT(J)-2.0
      IF(NNQ(2).EQ.0.0)RETURN
      LOC=NFINC(X,5,2,2,0.)
      CALL COPY(LOC)
      ZX1=ATRIB(3)
      ZY1=ATRIB(4)
      TRIP=TRIP+1.0
      CALL TIMST(TRIP,TNOW,4)
      CALL RMOVE(MFE(J),J)
      ATRIB(1)=PAL
      ATRIB(2)=TYP
      ATRIB(3)=ZX1
      ATRIB(4)=ZY1
      ATRIB(5)=UTL
      CALL FILEM(J)
      RETURN
      END
```

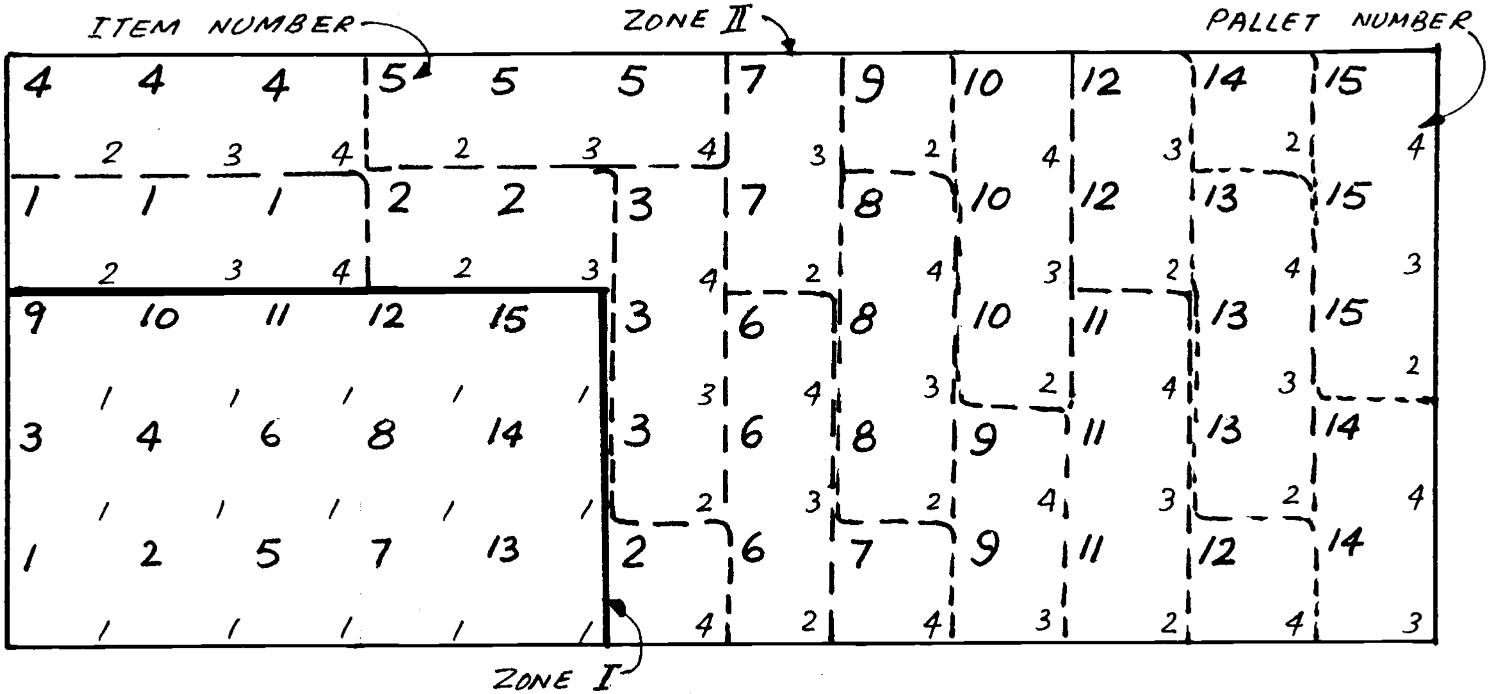
B-8. Listing of subroutine "CYCLTM" and subroutine "CLLOC".



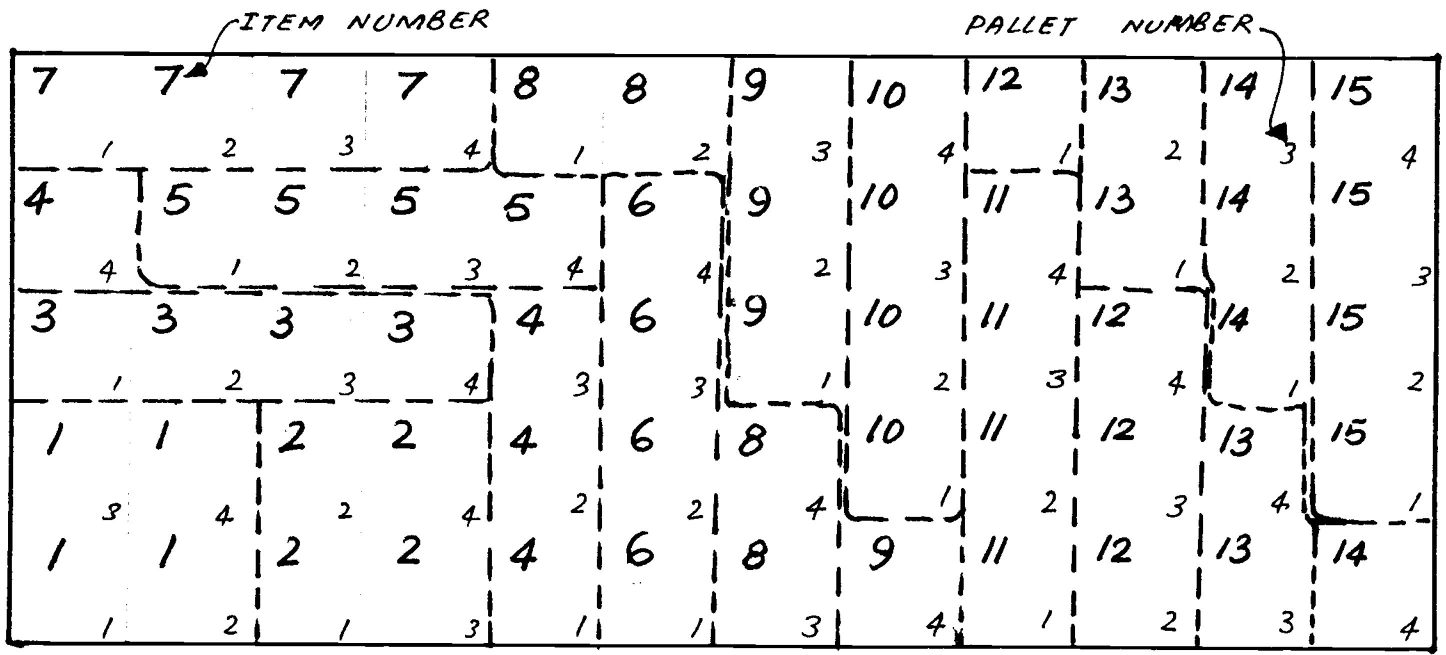
B-9. Layout of D-Zone aisle with 5 items.



B-10. Layout of S-Zone aisle with 5 items.



B-11. Layout of D-Zone aisle with 15 items.



B-12. Layout of S-Zone aisle with 15 items.

APPENDIX C

INPUT DATA AND FILE STORAGE

```
.4051.000 .6222.000 .7853.000 .9074.0001.0005.000
```

INPUT FOR 'ALBL' TREATMENT

```
.2001.000 .4002.000 .6003.000 .8004.0001.0005.000
```

INPUT FOR 'ALBH' TREATMENT

```
.067 1.000  .133 2.000  .200 3.000  .267 4.000  .333 5.000  .400 6.000
.467 7.000  .533 8.000  .600 9.000  .66710.000  .73311.000  .80012.000
.86713.000  .93314.000 1.00015.000
```

INPUT FOR 'AHBH' TREATMENT

```
.255 1.000  .396 2.000  .496 3.000  .574 4.000  .638 5.000  .693 6.000
.741 7.000  .784 8.000  .823 9.000  .85810.000  .89111.000  .92112.000
.94913.000  .97514.000 1.00015.000
```

INPUT FOR 'AHBL' TREATMENT

```
GEN,KHAN,1,12,3,1981,2,7,Y,Y, ,Y*
STA,3,4,3*
LIM,0,2,100,5,8,4000*
COL,1,U-RECD,2,ITM-TYP,3,ACCES-TM*
COL,4,RETUN-TM,5,CR-WT-TM,6,REP-TM*
COL,7,CYCLE-TM,8,OP-WT-TM,9,AVE-CYT*
TIM,1,ORDERS,0.,2,LEVIN-PAL,0.,3,SECON-PAL,0.*
TIM,4,TRIPZON2,0.*
HIS,1,U-RECRD,20,0,1.,2,ITM-TYP,20,1,1,3,CYCLE-TM,20,0,5*
PRI,1,LVF,1,2,LVF,2,3,LVF,1,4,LVF,1,5,LVF,1,6,LVF,1,7,LVF,1*
PAR,1,4,1,20.*
INI,1,Y,Y,0.,40000.,Y*
SEE,75831,83135*
```

GENERAL INPUT FOR ALL 'AL' TREATMENTS

```
GEN,KHAN,1,12,3,1981,2,7,Y,Y, ,Y*
STA,9,4,3*
LIM,1,2,150,5,18,4000*
COL,1,U-RECD,2,ITM-TYP,3,ACCES-TM*
COL,4,RETUN-TM,5,CR-WT-TM,6,REP-TM*
COL,7,CYCLE-TM,8,OP-WT-TM,9,AVE-CYT*
TIM,1,CRDERS,0.,2,LEVIN-PAL,0.,3,SECON-PAL,0.*
TIM,4,TRIPZON2,0.*
HIS,1,U-RECRD,20,0,1.,2,ITM-TYP,20,1,1,3,CYCLE-TM,20,0,5*
PRI,1,LVF,1,2,LVF,2,3,LVF,1,4,LVF,1,5,LVF,1,6,LVF,1,7,LVF,1,8,LVF,1*
PRI,9,LVF,1,10,LVF,1,11,LVF,1,12,LVF,1,13,LVF,1,14,LVF,1,15,LVF,1*
PRI,16,LVF,1,17,LVF,1*
PAR,1,9,1,20.*
INI,1,Y,Y,0.,40000.,Y*
SEE,75831,83135*
```

GENERAL INPUT FOR ALL 'AH' TREATMENTS

C-1. Common inputs for all runs.

```
ENT,3,1,1,4.5,0.0,20.,3,2,1,13.5,4.5,20.,3,3,1,18.0,0.0,20.*
ENT,3,4,1,18.0,4.5,20.,3,5,1,4.5,9.0,20.,3,6,1,9.0,9.0,20.*
ENT,3,7,1,13.5,9.0,20.,3,8,1,18.0,9.0,20.,3,9,1,22.5,0.0,20.*
ENT,3,10,1,22.5,4.5,20.,3,11,1,22.5,9.0,20.,3,12,1,4.5,13.5,20.*
ENT,4,1,2,9.0,0.0,20.,4,2,2,9.0,13.5,20.,4,3,2,13.5,13.5,20.*
ENT,4,4,2,18.0,13.5,20.,4,5,2,22.5,13.5,20.,4,6,2,27.0,0.0,20.*
ENT,4,7,2,27.0,4.5,20.,4,8,2,27.0,9.0,20.,4,9,2,27.0,13.5,20.*
ENT,4,10,2,4.5,18.0,20.,4,11,2,9.0,18.0,20.,4,12,2,13.5,18.0,20.*
ENT,5,1,3,4.5,4.5,20.,5,2,3,18.0,18.0,20.,5,3,3,22.5,18.0,20.*
ENT,5,4,3,27.0,18.,20.,5,5,3,31.5,0.0,20.,5,6,3,31.5,4.5,20.*
ENT,5,7,3,31.5,9.0,20.,5,8,3,31.5,13.5,20.,5,9,3,31.5,18.0,20.*
ENT,5,10,3,36.0,0.0,20.,5,11,3,36.0,4.5,20.,5,12,3,36.0,9.0,20.*
ENT,6,1,4,9.0,4.5,20.,6,2,4,36.0,13.5,20.,6,3,4,36.0,18.0,20.*
ENT,6,4,4,40.5,0.0,20.,6,5,4,40.5,4.5,20.,6,6,4,40.5,9.0,20.*
ENT,6,7,4,40.5,13.5,20.,6,8,4,40.5,18.0,20.,5,9,4,45.0,0.0,20.*
ENT,6,10,4,45.0,4.5,20.,6,11,4,45.,9.0,20.,6,12,4,45.0,13.5,20.
ENT,7,1,5,13.50,0.0,20.,7,2,5,45.0,18.0,20.,7,3,5,49.5,0.0,20.*
ENT,7,4,5,49.5,4.5,20.,7,5,5,49.5,9.0,20.,7,6,5,49.5,13.5,20.*
ENT,7,7,5,49.5,18.0,20.,7,8,5,54.0,0.0,20.,7,9,5,54.0,4.5,20.*
ENT,7,10,5,54.0,9.0,20.,7,11,5,54.0,13.5,20.,7,12,5,54.0,18.0,20.*
ENT,1,10000.,-2.*
SIP*
```

LOCATION ENTRIES FOR ALL 'AL' D-ZONES

```
ENT,3,1,1,4.5,0.0,20.,3,2,1,9.0,0.0,20.,3,3,1,4.5,4.5,20.*
ENT,3,4,1,9.0,4.5,20.,3,5,1,13.5,0.0,20.,3,6,1,13.5,4.5,20.*
ENT,3,7,1,18.0,0.0,20.,3,8,1,18.0,4.5,20.,3,9,1,4.5,9.0,20.*
ENT,3,10,1,9.0,9.0,20.,3,11,1,13.5,9.0,20.,3,12,1,18.0,9.0,20.*
ENT,4,1,2,22.5,0.0,20.,4,2,2,22.5,4.5,20.,4,3,2,22.5,9.0,20.*
ENT,4,4,2,4.5,13.5,20.,4,5,2,9.0,13.5,20.,4,6,2,13.5,13.5,20.*
ENT,4,7,2,18.0,13.5,20.,4,8,2,22.5,13.5,20.,4,9,2,27.0,0.0,20.*
ENT,4,10,2,27.0,4.5,20.,4,11,2,27.0,9.0,20.,4,12,2,27.0,13.5,20.*
ENT,5,1,3,4.5,18.0,20.,5,2,3,9.0,18.0,20.,5,3,3,13.5,18.0,20.*
ENT,5,4,3,18.0,18.0,20.,5,5,3,22.5,18.0,20.,5,6,3,27.0,18.0,20.*
ENT,5,7,3,31.5,0.0,20.,5,8,3,31.5,4.5,20.,5,9,3,31.5,9.0,20.*
ENT,5,10,3,31.5,13.5,20.,5,11,3,31.5,18.0,20.,5,12,3,36.0,0.0,20.*
ENT,6,1,4,36.0,4.5,20.,6,2,4,36.0,9.0,20.,6,3,4,36.0,13.5,20.*
ENT,6,4,4,36.0,18.0,20.,6,5,4,40.5,0.0,20,6,6,4,40.5,4.5,20.*
ENT,6,7,4,40.5,9.0,20.,6,8,4,40.5,13.5,20.,6,9,4,40.5,18.0,20.*
ENT,6,10,4,45.0,0.0,20.,6,11,4,45.0,4.5,20.,6,12,4,45.0,9.0,20.*
ENT,7,1,5,45.0,13.5,20.,7,2,5,45.0,18.0,20.,7,3,5,49.5,0.0,20.*
ENT,7,4,5,49.5,4.5,20.,7,5,5,49.5,9.0,20.,7,6,5,49.5,13.5,20.*
ENT,7,7,5,49.5,18.0,20.,7,8,5,54.0,0.0,20.,7,9,5,54.0,4.5,20.*
ENT,7,10,5,54.0,9.0,20.,7,11,5,54.0,13.5,20.,7,12,5,54.0,18.0,20.*
ENT,1,10000.,-2.*
FIN*
```

LOCATION ENTRIES FOR ALL 'AL' S-ZONES

C-2. Location entries for all "AL" D-Zones and S-Zones.

**GASP FILE STORAGE AREA DUMP AT TIME 0. **

S-ZONE (AL)

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 62

PRINTOUT OF FILE NUMBER 1
TNOW = 0.
QQTIM= 0.

FILE CONTENTS

ENTRY	1	=	0.	.3000E+01	.2000E+01	0.	0.
ENTRY	2	=	.1000E+05	-.2000E+01	0.	0.	0.

PRINTOUT OF FILE NUMBER 2
TNOW = 0.
QQTIM= 0.

THE FILE IS EMPTY

PRINTOUT OF FILE NUMBER 3
TNOW = 0.
QQTIM= 0.

FILE CONTENTS

ENTRY	1	=	.1000E+01	.1000E+01	.4500E+01	0.	.2000E+02
ENTRY	2	=	.2000E+01	.1000E+01	.9000E+01	0.	.2000E+02
ENTRY	3	=	.3000E+01	.1000E+01	.4500E+01	.4500E+01	.2000E+02
ENTRY	4	=	.4000E+01	.1000E+01	.9000E+01	.4500E+01	.2000E+02
ENTRY	5	=	.5000E+01	.1000E+01	.1350E+02	0.	.2000E+02
ENTRY	6	=	.6000E+01	.1000E+01	.1350E+02	.4500E+01	.2000E+02
ENTRY	7	=	.7000E+01	.1000E+01	.1800E+02	0.	.2000E+02
ENTRY	8	=	.8000E+01	.1000E+01	.1800E+02	.4500E+01	.2000E+02
ENTRY	9	=	.9000E+01	.1000E+01	.4500E+01	.9000E+01	.2000E+02
ENTRY	10	=	.1000E+02	.1000E+01	.9000E+01	.9000E+01	.2000E+02
ENTRY	11	=	.1100E+02	.1000E+01	.1350E+02	.9000E+01	.2000E+02
ENTRY	12	=	.1200E+02	.1000E+01	.1800E+02	.9000E+01	.2000E+02

C-3. Typical file storage area for an "AL" S-Zone at time zero.

PRINTOUT OF FILE NUMBER 4
TNOW = 0.
QQTIM= 0.

FILE CONTENTS

ENTRY 1	=	.1000E+01	.2000E+01	.2250E+02	0.	.2000E+02
ENTRY 2	=	.2000E+01	.2000E+01	.2250E+02	.4500E+01	.2000E+02
ENTRY 3	=	.3000E+01	.2000E+01	.2250E+02	.9000E+01	.2000E+02
ENTRY 4	=	.4000E+01	.2000E+01	.4500E+01	.1350E+02	.2000E+02
ENTRY 5	=	.5000E+01	.2000E+01	.9000E+01	.1350E+02	.2000E+02
ENTRY 6	=	.6000E+01	.2000E+01	.1350E+02	.1350E+02	.2000E+02
ENTRY 7	=	.7000E+01	.2000E+01	.1800E+02	.1350E+02	.2000E+02
ENTRY 8	=	.8000E+01	.2000E+01	.2250E+02	.1350E+02	.2000E+02
ENTRY 9	=	.9000E+01	.2000E+01	.2700E+02	0.	.2000E+02
ENTRY 10	=	.1000E+02	.2000E+01	.2700E+02	.4500E+01	.2000E+02
ENTRY 11	=	.1100E+02	.2000E+01	.2700E+02	.9000E+01	.2000E+02
ENTRY 12	=	.1200E+02	.2000E+01	.2700E+02	.1350E+02	.2000E+02

PRINTOUT OF FILE NUMBER 5
TNOW = 0.
QQTIM= 0.

FILE CONTENTS

ENTRY 1	=	.1000E+01	.3000E+01	.4500E+01	.1800E+02	.2000E+02
ENTRY 2	=	.2000E+01	.3000E+01	.9000E+01	.1800E+02	.2000E+02
ENTRY 3	=	.3000E+01	.3000E+01	.1350E+02	.1800E+02	.2000E+02
ENTRY 4	=	.4000E+01	.3000E+01	.1800E+02	.1800E+02	.2000E+02
ENTRY 5	=	.5000E+01	.3000E+01	.2250E+02	.1800E+02	.2000E+02
ENTRY 6	=	.6000E+01	.3000E+01	.2700E+02	.1800E+02	.2000E+02
ENTRY 7	=	.7000E+01	.3000E+01	.3150E+02	0.	.2000E+02
ENTRY 8	=	.8000E+01	.3000E+01	.3150E+02	.4500E+01	.2000E+02
ENTRY 9	=	.9000E+01	.3000E+01	.3150E+02	.9000E+01	.2000E+02
ENTRY 10	=	.1000E+02	.3000E+01	.3150E+02	.1350E+02	.2000E+02
ENTRY 11	=	.1100E+02	.3000E+01	.3150E+02	.1800E+02	.2000E+02
ENTRY 12	=	.1200E+02	.3000E+01	.3600E+02	0.	.2000E+02

C-3--(continued)

PRINTOUT OF FILE NUMBER 6
TNOW = 0.
QQTIM= 0.

FILE CONTENTS

ENTRY 1	=	.1000E+01	.4000E+01	.3600E+02	.4500E+01	.2000E+02
ENTRY 2	=	.2000E+01	.4000E+01	.3600E+02	.9000E+01	.2000E+02
ENTRY 3	=	.3000E+01	.4000E+01	.3600E+02	.1350E+02	.2000E+02
ENTRY 4	=	.4000E+01	.4000E+01	.3600E+02	.1800E+02	.2000E+02
ENTRY 5	=	.5000E+01	.4000E+01	.4050E+02	0.	.2000E+02
ENTRY 6	=	.6000E+01	.4000E+01	.4050E+02	.4500E+01	.2000E+02
ENTRY 7	=	.7000E+01	.4000E+01	.4050E+02	.9000E+01	.2000E+02
ENTRY 8	=	.8000E+01	.4000E+01	.4050E+02	.1350E+02	.2000E+02
ENTRY 9	=	.9000E+01	.4000E+01	.4050E+02	.1800E+02	.2000E+02
ENTRY 10	=	.1000E+02	.4000E+01	.4500E+02	0.	.2000E+02
ENTRY 11	=	.1100E+02	.4000E+01	.4500E+02	.4500E+01	.2000E+02
ENTRY 12	=	.1200E+02	.4000E+01	.4500E+02	.9000E+01	.2000E+02

PRINTOUT OF FILE NUMBER 7
TNOW = 0.
QQTIM= 0.

FILE CONTENTS

ENTRY 1	=	.1000E+01	.5000E+01	.4500E+02	.1350E+02	.2000E+02
ENTRY 2	=	.2000E+01	.5000E+01	.4500E+02	.1800E+02	.2000E+02
ENTRY 3	=	.3000E+01	.5000E+01	.4950E+02	0.	.2000E+02
ENTRY 4	=	.4000E+01	.5000E+01	.4950E+02	.4500E+01	.2000E+02
ENTRY 5	=	.5000E+01	.5000E+01	.4950E+02	.9000E+01	.2000E+02
ENTRY 6	=	.6000E+01	.5000E+01	.4950E+02	.1350E+02	.2000E+02
ENTRY 7	=	.7000E+01	.5000E+01	.4950E+02	.1800E+02	.2000E+02
ENTRY 8	=	.8000E+01	.5000E+01	.5400E+02	0.	.2000E+02
ENTRY 9	=	.9000E+01	.5000E+01	.5400E+02	.4500E+01	.2000E+02
ENTRY 10	=	.1000E+02	.5000E+01	.5400E+02	.9000E+01	.2000E+02
ENTRY 11	=	.1100E+02	.5000E+01	.5400E+02	.1350E+02	.2000E+02
ENTRY 12	=	.1200E+02	.5000E+01	.5400E+02	.1800E+02	.2000E+02

PRINTOUT OF FILE NUMBER 8
TNOW = 0.
QQTIM= 0.

THE FILE IS EMPTY

C-3--(continued)

GASP FILE STORAGE AREA DUMP AT TIME .2000E+05

S-ZONE (AL)

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 74

PRINTOUT OF FILE NUMBER 1
TNOW = .2000E+05
QQTIM= .2000E+05

TIME PERIOD FOR STATISTICS	.1000E+05
AVERAGE NUMBER IN FILE	2.0000
STANDARD DEVIATION	.0000
MAXIMUM NUMBER IN FILE	2

FILE CONTENTS

ENTRY	1	=	.2000E+05	.1000E+01	.3000E+01	0.	0.
ENTRY	2	=	.3000E+05	-.5000E+01	.1000E+05	0.	0.

PRINTOUT OF FILE NUMBER 2
TNOW = .2000E+05
QQTIM= .1000E+05

TIME PERIOD FOR STATISTICS	.1000E+05
AVERAGE NUMBER IN FILE	5.0000
STANDARD DEVIATION	0.0000
MAXIMUM NUMBER IN FILE	5

FILE CONTENTS

ENTRY	1	=	.1000E+01	.1000E+01	.4500E+01	0.	.2000E+02
ENTRY	2	=	.1000E+01	.2000E+01	.2250E+02	0.	.2000E+02
ENTRY	3	=	.1000E+01	.3000E+01	.4500E+01	.1800E+02	.2000E+02
ENTRY	4	=	.1000E+01	.4000E+01	.3600E+02	.4500E+01	.2000E+02
ENTRY	5	=	.1000E+01	.5000E+01	.4500E+02	.1350E+02	.2000E+02

C-4. Typical file storage area for an "AL" S-Zone at time 20,000.

PRINTOUT OF FILE NUMBER 3

TNOW = .2000E+05
QQTIM= .1979E+05

TIME PERIOD FOR STATISTICS .1000E+05
AVERAGE NUMBER IN FILE 12.9261
STANDARD DEVIATION .2616
MAXIMUM NUMBER IN FILE 13

FILE CONTENTS

ENTRY	1	=	.2000E+02	.1000E+01	.4500E+01	0.	.1600E+02
ENTRY	2	=	.2100E+02	.1000E+01	.4500E+01	.9000E+01	.2000E+02
ENTRY	3	=	.2200E+02	.1000E+01	.9000E+01	.9000E+01	.2000E+02
ENTRY	4	=	.2300E+02	.1000E+01	.1350E+02	.9000E+01	.2000E+02
ENTRY	5	=	.2400E+02	.1000E+01	.1800E+02	.9000E+01	.2000E+02
ENTRY	6	=	.2500E+02	.1000E+01	.4500E+01	0.	.2000E+02
ENTRY	7	=	.2600E+02	.1000E+01	.9000E+01	0.	.2000E+02
ENTRY	8	=	.2700E+02	.1000E+01	.4500E+01	.4500E+01	.2000E+02
ENTRY	9	=	.2800E+02	.1000E+01	.9000E+01	.4500E+01	.2000E+02
ENTRY	10	=	.2900E+02	.1000E+01	.1350E+02	0.	.2000E+02
ENTRY	11	=	.3000E+02	.1000E+01	.1350E+02	.4500E+01	.2000E+02
ENTRY	12	=	.3100E+02	.1000E+01	.1800E+02	0.	.2000E+02
ENTRY	13	=	.3200E+02	.1000E+01	.1800E+02	.4500E+01	.2000E+02

PRINTOUT OF FILE NUMBER 4

TNOW = .2000E+05
QQTIM= .1975E+05

TIME PERIOD FOR STATISTICS .1000E+05
AVERAGE NUMBER IN FILE 12.9641
STANDARD DEVIATION .1861
MAXIMUM NUMBER IN FILE 13

FILE CONTENTS

ENTRY	1	=	.1100E+02	.2000E+01	.2250E+02	0.	.9000E+01
ENTRY	2	=	.1200E+02	.2000E+01	.2700E+02	.1350E+02	.2000E+02
ENTRY	3	=	.1300E+02	.2000E+01	.2250E+02	0.	.2000E+02
ENTRY	4	=	.1400E+02	.2000E+01	.2250E+02	.4500E+01	.2000E+02
ENTRY	5	=	.1500E+02	.2000E+01	.2250E+02	.9000E+01	.2000E+02
ENTRY	6	=	.1600E+02	.2000E+01	.4500E+01	.1350E+02	.2000E+02
ENTRY	7	=	.1700E+02	.2000E+01	.9000E+01	.1350E+02	.2000E+02
ENTRY	8	=	.1800E+02	.2000E+01	.1350E+02	.1350E+02	.2000E+02
ENTRY	9	=	.1900E+02	.2000E+01	.1800E+02	.1350E+02	.2000E+02
ENTRY	10	=	.2000E+02	.2000E+01	.2250E+02	.1350E+02	.2000E+02
ENTRY	11	=	.2100E+02	.2000E+01	.2700E+02	0.	.2000E+02
ENTRY	12	=	.2200E+02	.2000E+01	.2700E+02	.4500E+01	.2000E+02
ENTRY	13	=	.2300E+02	.2000E+01	.2700E+02	.9000E+01	.2000E+02

C-4--(continued)

PRINTOUT OF FILE NUMBER 5

TNOW = .2000E+05

QQTIM= .1994E+05

TIME PERIOD FOR STATISTICS .1000E+05
AVERAGE NUMBER IN FILE 13.0000
STANDARD DEVIATION -.0000
MAXIMUM NUMBER IN FILE 13

FILE CONTENTS

ENTRY	1	=	.8000E+01	.3000E+01	.4500E+01	.1800E+02	.1000E+02
ENTRY	2	=	.9000E+01	.3000E+01	.3150E+02	.9000E+01	.2000E+02
ENTRY	3	=	.1000E+02	.3000E+01	.3150E+02	.1350E+02	.2000E+02
ENTRY	4	=	.1100E+02	.3000E+01	.3150E+02	.1800E+02	.2000E+02
ENTRY	5	=	.1200E+02	.3000E+01	.3600E+02	0.	.2000E+02
ENTRY	6	=	.1300E+02	.3000E+01	.4500E+01	.1800E+02	.2000E+02
ENTRY	7	=	.1400E+02	.3000E+01	.9000E+01	.1800E+02	.2000E+02
ENTRY	8	=	.1500E+02	.3000E+01	.1350E+02	.1800E+02	.2000E+02
ENTRY	9	=	.1600E+02	.3000E+01	.1600E+02	.1800E+02	.2000E+02
ENTRY	10	=	.1700E+02	.3000E+01	.2250E+02	.1800E+02	.2000E+02
ENTRY	11	=	.1800E+02	.3000E+01	.2700E+02	.1800E+02	.2000E+02
ENTRY	12	=	.1900E+02	.3000E+01	.3150E+02	0.	.2000E+02
ENTRY	13	=	.2000E+02	.3000E+01	.3150E+02	.4500E+01	.2000E+02

PRINTOUT OF FILE NUMBER 6

TNOW = .2000E+05

QQTIM= .1961E+05

TIME PERIOD FOR STATISTICS .1000E+05
AVERAGE NUMBER IN FILE 12.9251
STANDARD DEVIATION .2632
MAXIMUM NUMBER IN FILE 13

FILE CONTENTS

ENTRY	1	=	.8000E+01	.4000E+01	.3600E+02	.4500E+01	.1600E+02
ENTRY	2	=	.9000E+01	.4000E+01	.4050E+02	.1800E+02	.2000E+02
ENTRY	3	=	.1000E+02	.4000E+01	.4500E+02	0.	.2000E+02
ENTRY	4	=	.1100E+02	.4000E+01	.4500E+02	.4500E+01	.2000E+02
ENTRY	5	=	.1200E+02	.4000E+01	.4500E+02	.9000E+01	.2000E+02
ENTRY	6	=	.1300E+02	.4000E+01	.3600E+02	.4500E+01	.2000E+02
ENTRY	7	=	.1400E+02	.4000E+01	.3600E+02	.9000E+01	.2000E+02
ENTRY	8	=	.1500E+02	.4000E+01	.3600E+02	.1350E+02	.2000E+02
ENTRY	9	=	.1600E+02	.4000E+01	.3600E+02	.1800E+02	.2000E+02
ENTRY	10	=	.1700E+02	.4000E+01	.4050E+02	0.	.2000E+02
ENTRY	11	=	.1800E+02	.4000E+01	.4050E+02	.4500E+01	.2000E+02
ENTRY	12	=	.1900E+02	.4000E+01	.4050E+02	.9000E+01	.2000E+02
ENTRY	13	=	.2000E+02	.4000E+01	.4050E+02	.1350E+02	.2000E+02

C-4--(continued)

PRINTOUT OF FILE NUMBER 7
TNOW = .2000E+05
QQTIM= .1982E+05

TIME PERIOD FOR STATISTICS .1000E+05
AVERAGE NUMBER IN FILE 12.9536
STANDARD DEVIATION .1991
MAXIMUM NUMBER IN FILE 13

FILE CONTENTS

ENTRY	1	=	.7000E+01	.5000E+01	.4500E+02	.1350E+02	.1900E+02
ENTRY	2	=	.8000E+01	.5000E+01	.5400E+02	0.	.2000E+02
ENTRY	3	=	.9000E+01	.5000E+01	.5400E+02	.4500E+01	.2000E+02
ENTRY	4	=	.1000E+02	.5000E+01	.5400E+02	.9000E+01	.2000E+02
ENTRY	5	=	.1100E+02	.5000E+01	.5400E+02	.1350E+02	.2000E+02
ENTRY	6	=	.1200E+02	.5000E+01	.5400E+02	.1800E+02	.2000E+02
ENTRY	7	=	.1300E+02	.5000E+01	.4500E+02	.1350E+02	.2000E+02
ENTRY	8	=	.1400E+02	.5000E+01	.4500E+02	.1800E+02	.2000E+02
ENTRY	9	=	.1500E+02	.5000E+01	.4950E+02	0.	.2000E+02
ENTRY	10	=	.1600E+02	.5000E+01	.4950E+02	.4500E+01	.2000E+02
ENTRY	11	=	.1700E+02	.5000E+01	.4950E+02	.9000E+01	.2000E+02
ENTRY	12	=	.1800E+02	.5000E+01	.4950E+02	.1350E+02	.2000E+02
ENTRY	13	=	.1900E+02	.5000E+01	.4950E+02	.1800E+02	.2000E+02

PRINTOUT OF FILE NUMBER 8
TNOW = .2000E+05
QQTIM= .1994E+05

TIME PERIOD FOR STATISTICS .1000E+05
AVERAGE NUMBER IN FILE 1.0000
STANDARD DEVIATION .0000
MAXIMUM NUMBER IN FILE 2

FILE CONTENTS

ENTRY	1	=	.8000E+01	.1500E+01	.4500E+01	.1800E+02	.1000E+02

C-4--(continued)

```
ENT,3,1,1,4.5,0.,20.,3,2,1,4.5,13.5,20.,3,3,1,9.,13.5,20.*
ENT,3,4,1,13.5,13.5,20.,4,1,2,9.,0.,20.,4,2,2,18.,13.5,20.*
ENT,4,3,2,22.5,13.5,20.,4,4,2,27.,0.,20.,5,1,3,4.5,4.5,20.*
ENT,5,2,3,27.,4.5,20.,5,3,3,27.,9.,20.,5,4,3,27.,13.5,20.*
ENT,6,1,4,9.,4.5,20.,6,2,4,4.5,18.,20.,6,3,4,9.,18.,20.*
ENT,6,4,4,13.5,18.,20.,7,1,5,13.5,0.,20.,7,2,5,18.,18.,20.*
ENT,7,3,5,22.5,18.,20.,7,4,5,27.,18.,20.,8,1,6,13.5,4.5,20.*
ENT,8,2,6,31.5,0.,20.,8,3,6,31.5,4.5,20.,8,4,6,31.5,9.,20.*
ENT,9,1,7,18.,0.,20.,9,2,7,31.5,13.5,20.,9,3,7,31.5,18.,20.*
ENT,9,4,7,36.,0.,20.,10,1,8,18.,4.5,20.,10,2,8,36.,4.5,20.*
ENT,10,3,8,36.,9.,20.,10,4,8,36.,13.5,20.,11,1,9,4.5,9.,20.*
ENT,11,2,9,36.,18.,20.,11,3,9,40.5,0.,20.,11,4,9,40.5,4.5,20.*
ENT,12,1,10,9.,9.,20.,12,2,10,40.5,9.,20.,12,3,10,40.5,13.5,20.*
ENT,12,4,10,40.5,18.,20.,13,1,11,13.5,9.,20.,13,2,11,45.,0.,20.*
ENT,13,3,11,45.,4.5,20.,13,4,11,45.,9.,20.,14,1,12,18.,9.,20.*
ENT,14,2,12,45.,13.5,20.,14,3,12,45.,18.,20.,14,4,12,49.5,0.,20.*
ENT,15,1,13,22.5,0.,20.,15,2,13,49.5,4.5,20.,15,3,13,49.5,9.,20.*
ENT,15,4,13,49.5,13.5,20.,16,1,14,22.5,4.5,20.,16,2,14,49.5,18.,20.*
ENT,16,3,14,54.,0.,20.,16,4,14,54.,4.5,20.,17,1,15,22.5,9.,20.*
ENT,17,2,15,54.,9.,20.,17,3,15,54.,13.5,20.,17,4,15,54.,18.,20.*
ENT,1,10000.,-2.*
SIM*
```

LOCATION ENTERIES FOR ALL 'AH' D-ZONES

```
ENT,3,1,1,4.5,0.0,20.,3,2,1,9.0,0.0,20.,3,3,1,4.5,4.5,20.*
ENT,3,4,1,9.,4.5,20.,4,1,2,13.5,0.,20.,4,2,2,13.5,4.5,20.*
ENT,4,3,2,18.,0.,20.,4,4,2,18.,4.5,20.,5,1,3,4.5,9.,20.*
ENT,5,2,3,9.,9.,20.,5,3,3,13.5,9.,20.,5,4,3,18.,9.,20.*
ENT,6,1,4,22.5,0.,20.,6,2,4,22.5,4.5,20.,6,3,4,22.5,9.,20.*
ENT,6,4,4,4.5,13.5,20.,7,1,5,9.,13.5,20.,7,2,5,13.5,13.5,20.*
ENT,7,3,5,18.,13.5,20.,7,4,5,22.5,13.5,20.,8,1,6,27.,0.,20.*
ENT,8,2,6,27.,4.5,20.,8,3,6,27.,9.,20.,8,4,6,27.,13.5,20.*
ENT,9,1,7,4.5,18.,20.,9,2,7,9.,18.,20.,9,3,7,13.5,18.,20.*
ENT,9,4,7,18.,18.,20.,10,1,8,22.5,18.,20.,10,2,8,27.,18.,20.*
ENT,10,3,8,31.5,0.,20.,10,4,8,31.5,4.5,20.,11,1,9,31.5,9.,20.*
ENT,11,2,9,31.5,13.5,20.,11,3,9,31.5,18.,20.,11,4,9,36.,0.,20.*
ENT,12,1,10,36.,4.5,20.,12,2,10,36.,9.,20.,12,3,10,36.,13.5,20.*
ENT,12,4,10,36.,18.,20.,13,1,11,40.5,0.,20.,13,2,11,40.5,4.5,20.*
ENT,13,3,11,40.5,9.,20.,13,4,11,40.5,13.5,20.,14,1,12,40.5,18.,20.*
ENT,14,2,12,45.,0.,20.,14,3,12,45.,4.5,20.,14,4,12,45.,9.,20.*
ENT,15,1,13,45.,13.5,20.,15,2,13,45.,18.,20.,15,3,13,49.5,0.,20.*
ENT,15,4,13,49.5,4.5,20.,16,1,14,49.5,9.,20.,16,2,14,49.5,13.5,20.*
ENT,16,3,14,49.5,18.,20.,16,4,14,54.,0.,20.,17,1,15,54.,4.5,20.*
ENT,17,2,15,54.,9.,20.,17,3,15,54.,13.5,20.,17,4,15,54.,18.,20.*
ENT,1,10000.,-2.*
FIN*
```

LOCATION ENTERIES FOR ALL 'AH' S-ZONES

C-5. Location entries for all "AH" D-Zones and S-Zones.

GASP FILE STORAGE AREA DUMP AT TIME .1000E+05

D-ZONE (AH)

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 79

PRINTOUT OF FILE NUMBER 1
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.1004E+05	.7000E+01	.2000E+01	0.	0.
ENTRY	2	=	.2000E+05	-.5000E+01	.1000E+05	0.	0.

PRINTOUT OF FILE NUMBER 2
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.1000E+01	.1000E+01	.4500E+01	0.	.2000E+02
ENTRY	2	=	.1000E+01	.2000E+01	.9000E+01	0.	.2000E+02
ENTRY	3	=	.1000E+01	.3000E+01	.4500E+01	.4500E+01	.2000E+02
ENTRY	4	=	.1000E+01	.4000E+01	.9000E+01	.4500E+01	.2000E+02
ENTRY	5	=	.1000E+01	.5000E+01	.1350E+02	0.	.2000E+02
ENTRY	6	=	.1000E+01	.6000E+01	.1350E+02	.4500E+01	.2000E+02
ENTRY	7	=	.1000E+01	.7000E+01	.1800E+02	0.	.2000E+02
ENTRY	8	=	.1000E+01	.8000E+01	.1800E+02	.4500E+01	.2000E+02
ENTRY	9	=	.1000E+01	.9000E+01	.4500E+01	.9000E+01	.2000E+02
ENTRY	10	=	.1000E+01	.1000E+02	.9000E+01	.9000E+01	.2000E+02
ENTRY	11	=	.1000E+01	.1100E+02	.1350E+02	.9000E+01	.2000E+02
ENTRY	12	=	.1000E+01	.1200E+02	.1800E+02	.9000E+01	.2000E+02
ENTRY	13	=	.1000E+01	.1300E+02	.2250E+02	0.	.2000E+02
ENTRY	14	=	.1000E+01	.1400E+02	.2250E+02	.4500E+01	.2000E+02
ENTRY	15	=	.1000E+01	.1500E+02	.2250E+02	.9000E+01	.2000E+02

PRINTOUT OF FILE NUMBER 3
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.1000E+01	.4500E+01	0.	.6000E+01
ENTRY	2	=	.3000E+01	.1000E+01	.9000E+01	.1350E+02	.2000E+02
ENTRY	3	=	.4000E+01	.1000E+01	.1350E+02	.1350E+02	.2000E+02
ENTRY	4	=	.6000E+01	.1000E+01	.4500E+01	.1350E+02	.2000E+02

C-6. Typical file storage area for an "AH" D-Zone at time 10,000.

PRINTOUT OF FILE NUMBER 4
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.2000E+01	.9000E+01	0.	.9000E+01
ENTRY	2	=	.3000E+01	.2000E+01	.2250E+02	.1350E+02	.2000E+02
ENTRY	3	=	.4000E+01	.2000E+01	.2700E+02	0.	.2000E+02
ENTRY	4	=	.6000E+01	.2000E+01	.1800E+02	.1350E+02	.2000E+02

PRINTOUT OF FILE NUMBER 5
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.3000E+01	.4500E+01	.4500E+01	.1100E+02
ENTRY	2	=	.3000E+01	.3000E+01	.2700E+02	.9000E+01	.2000E+02
ENTRY	3	=	.4000E+01	.3000E+01	.2700E+02	.1350E+02	.2000E+02
ENTRY	4	=	.6000E+01	.3000E+01	.2700E+02	.4500E+01	.2000E+02

PRINTOUT OF FILE NUMBER 6
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.4000E+01	.9000E+01	.4500E+01	.4000E+01
ENTRY	2	=	.3000E+01	.4000E+01	.9000E+01	.1800E+02	.2000E+02
ENTRY	3	=	.4000E+01	.4000E+01	.1350E+02	.1800E+02	.2000E+02
ENTRY	4	=	.6000E+01	.4000E+01	.4500E+01	.1800E+02	.2000E+02

PRINTOUT OF FILE NUMBER 7
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.5000E+01	.1350E+02	0.	.6000E+01
ENTRY	2	=	.3000E+01	.5000E+01	.2250E+02	.1300E+02	.2000E+02
ENTRY	3	=	.4000E+01	.5000E+01	.2700E+02	.1800E+02	.2000E+02
ENTRY	4	=	.6000E+01	.5000E+01	.1800E+02	.1800E+02	.2000E+02

C-6--(continued)

PRINTOUT OF FILE NUMBER 8

TNOW = .1000E+05

QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.6000E+01	.1350E+02	.4500E+01	.1500E+02
ENTRY	2	=	.3000E+01	.6000E+01	.3150E+02	.4500E+01	.2000E+02
ENTRY	3	=	.4000E+01	.6000E+01	.3150E+02	.9000E+01	.2000E+02
ENTRY	4	=	.6000E+01	.6000E+01	.3150E+02	0.	.2000E+02

PRINTOUT OF FILE NUMBER 9

TNOW = .1000E+05

QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.7000E+01	.1800E+02	0.	.1900E+02
ENTRY	2	=	.3000E+01	.7000E+01	.3150E+02	.1800E+02	.2000E+02
ENTRY	3	=	.4000E+01	.7000E+01	.3600E+02	0.	.2000E+02
ENTRY	4	=	.6000E+01	.7000E+01	.3150E+02	.1350E+02	.2000E+02

PRINTOUT OF FILE NUMBER 10

TNOW = .1000E+05

QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.8000E+01	.1800E+02	.4500E+01	.1500E+02
ENTRY	2	=	.3000E+01	.8000E+01	.3600E+02	.9000E+01	.2000E+02
ENTRY	3	=	.4000E+01	.8000E+01	.3600E+02	.1350E+02	.2000E+02
ENTRY	4	=	.6000E+01	.8000E+01	.3600E+02	.4500E+01	.2000E+02

PRINTOUT OF FILE NUMBER 11

TNOW = .1000E+05

QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.9000E+01	.4500E+01	.9000E+01	.1200E+02
ENTRY	2	=	.3000E+01	.9000E+01	.4050E+02	0.	.2000E+02
ENTRY	3	=	.4000E+01	.9000E+01	.4050E+02	.4500E+01	.2000E+02
ENTRY	4	=	.6000E+01	.9000E+01	.3600E+02	.1800E+02	.2000E+02

C-6--(continued)

PRINTOUT OF FILE NUMBER 12
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.1000E+02	.9000E+01	.9000E+01	.8000E+01
ENTRY	2	=	.3000E+01	.1000E+02	.4050E+02	.1350E+02	.2000E+02
ENTRY	3	=	.4000E+01	.1000E+02	.4050E+02	.1800E+02	.2000E+02
ENTRY	4	=	.6000E+01	.1000E+02	.4050E+02	.9000E+01	.2000E+02

PRINTOUT OF FILE NUMBER 13
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.1000E+01	.1100E+02	.1350E+02	.9000E+01	.1000E+01
ENTRY	2	=	.2000E+01	.1100E+02	.4500E+02	0.	.2000E+02
ENTRY	3	=	.3000E+01	.1100E+02	.4500E+02	.4500E+01	.2000E+02
ENTRY	4	=	.4000E+01	.1100E+02	.4500E+02	.9000E+01	.2000E+02

PRINTOUT OF FILE NUMBER 14
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.1200E+02	.1800E+02	.9000E+01	.1800E+02
ENTRY	2	=	.3000E+01	.1200E+02	.4500E+02	.1800E+02	.2000E+02
ENTRY	3	=	.4000E+01	.1200E+02	.4950E+02	0.	.2000E+02
ENTRY	4	=	.6000E+01	.1200E+02	.4500E+02	.1350E+02	.2000E+02

PRINTOUT OF FILE NUMBER 15
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.1300E+02	.2250E+02	0.	.1000E+02
ENTRY	2	=	.3000E+01	.1300E+02	.4950E+02	.9000E+01	.2000E+02
ENTRY	3	=	.4000E+01	.1300E+02	.4950E+02	.1350E+02	.2000E+02
ENTRY	4	=	.6000E+01	.1300E+02	.4950E+02	.4500E+01	.2000E+02

C-6--(continued)

PRINTOUT OF FILE NUMBER 16
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

ENTRY	1	=	.2000E+01	.1400E+02	.2250E+02	.4500E+01	.1100E+02
ENTRY	2	=	.3000E+01	.1400E+02	.5400E+02	0.	.2000E+02
ENTRY	3	=	.4000E+01	.1400E+02	.5400E+02	.4500E+01	.2000E+02
ENTRY	4	=	.6000E+01	.1400E+02	.4950E+02	.1800E+02	.2000E+02

PRINTOUT OF FILE NUMBER 17
TNOW = .1000E+05
QQTIM= .1000E+05

FILE CONTENTS

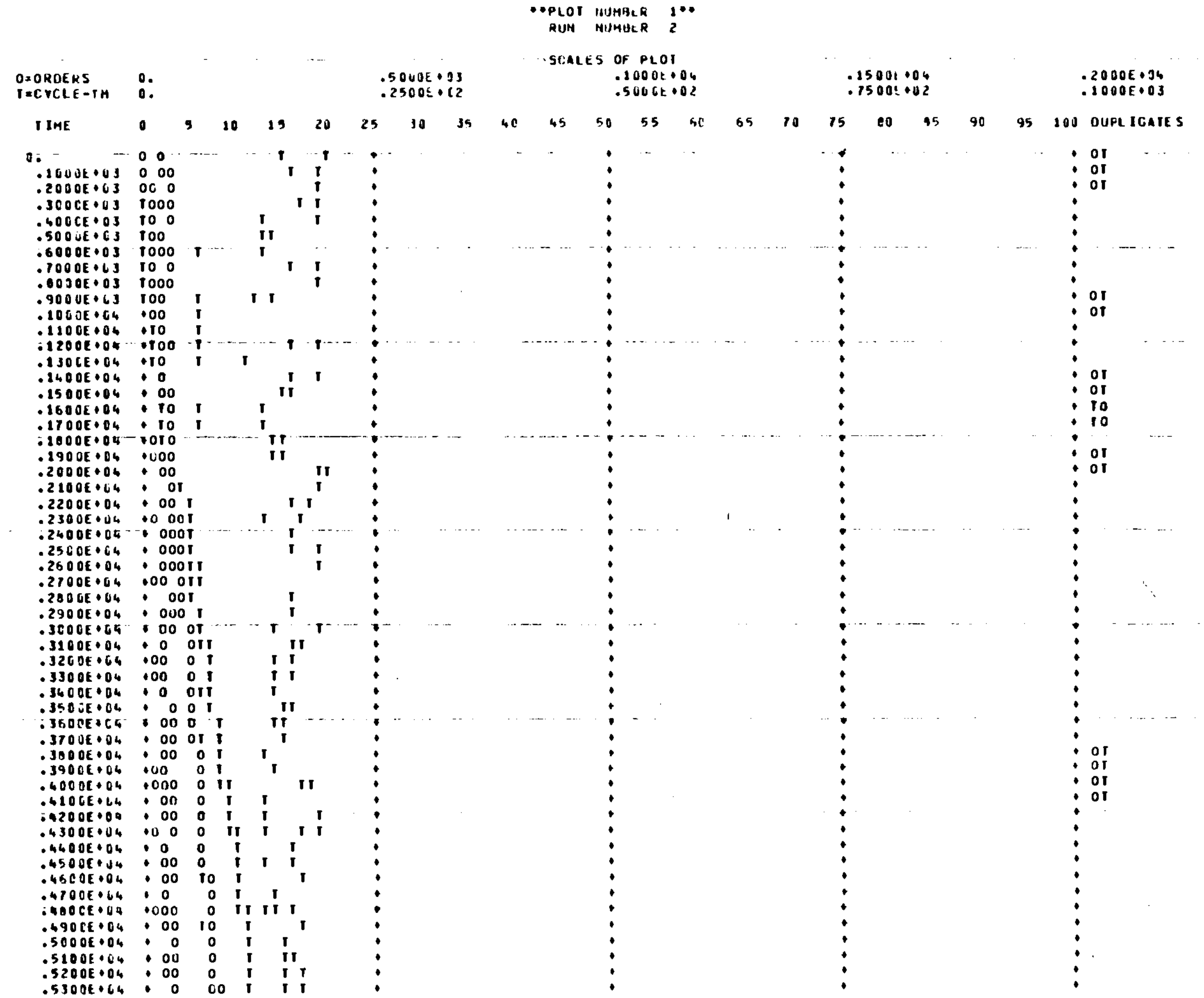
ENTRY	1	=	.2000E+01	.1500E+02	.2250E+02	.9000E+01	.3000E+01
ENTRY	2	=	.3000E+01	.1500E+02	.5400E+02	.1350E+02	.2000E+02
ENTRY	3	=	.4000E+01	.1500E+02	.5400E+02	.1800E+02	.2000E+02
ENTRY	4	=	.6000E+01	.1500E+02	.5400E+02	.9000E+01	.2000E+02

PRINTOUT OF FILE NUMBER 18
TNOW = .1000E+05
QQTIM= .1000E+05

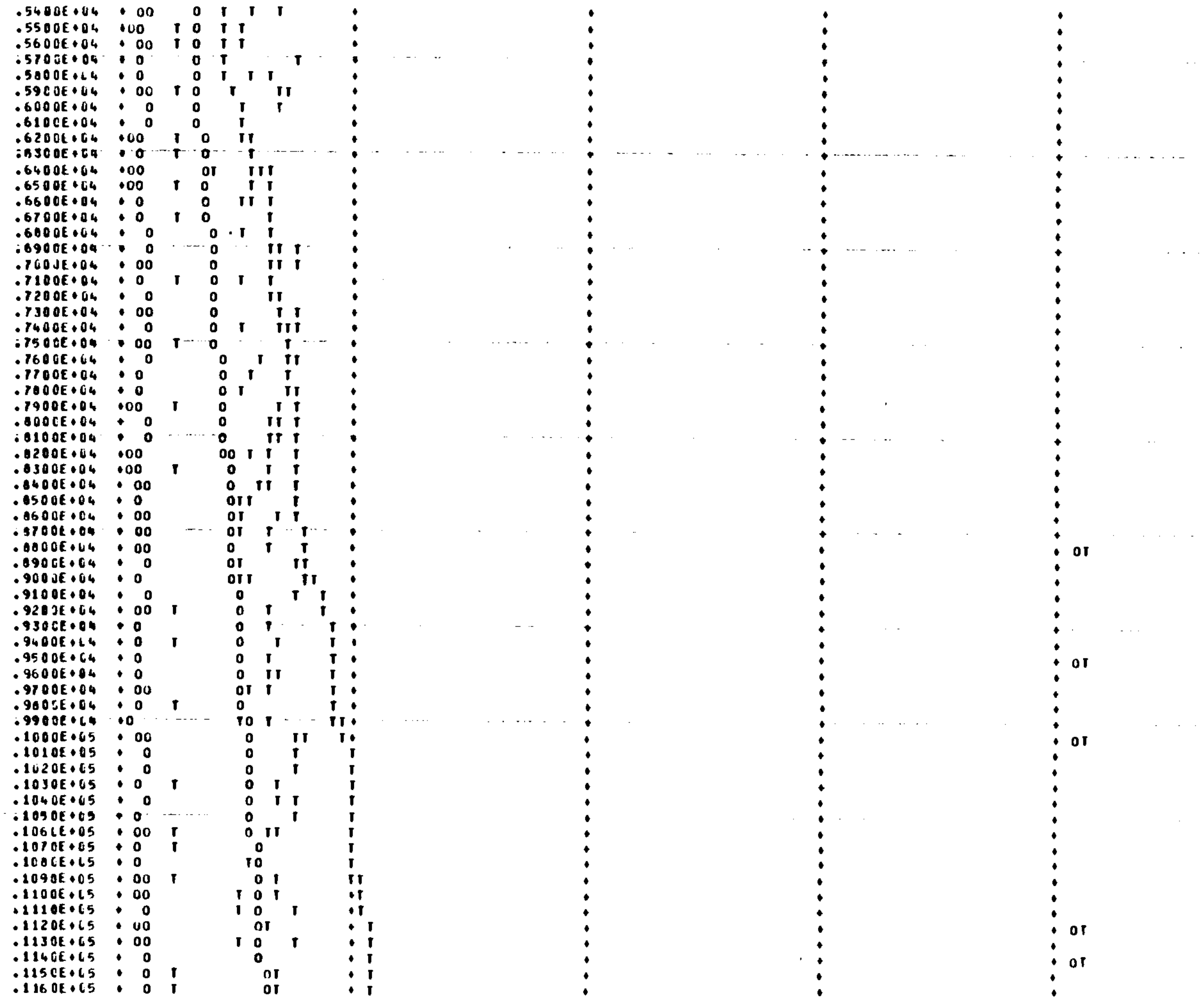
FILE CONTENTS

ENTRY	1	=	.2000E+01	.5000E+00	.1800E+02	.9000E+01	.1800E+02

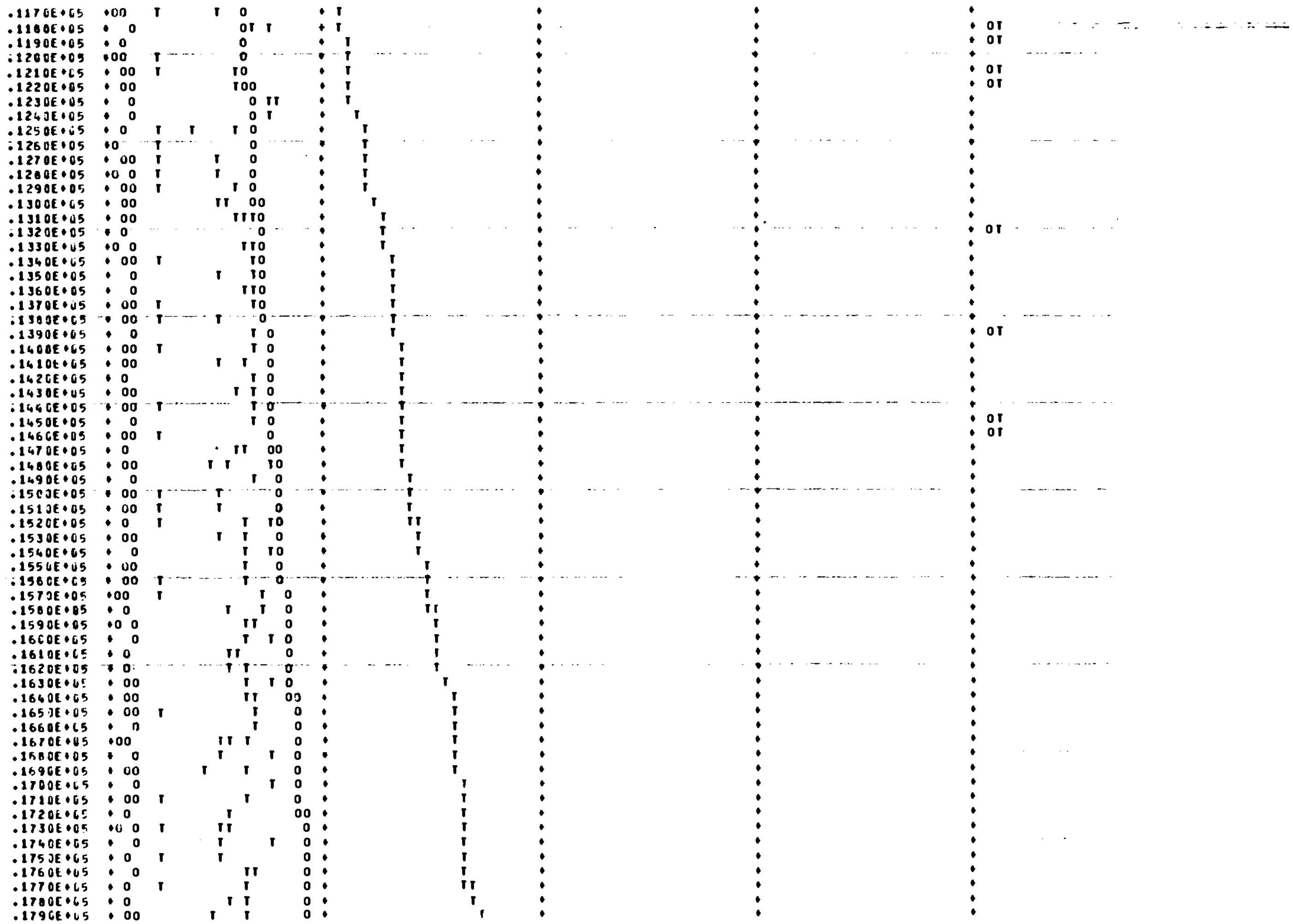
C-6--(continued)



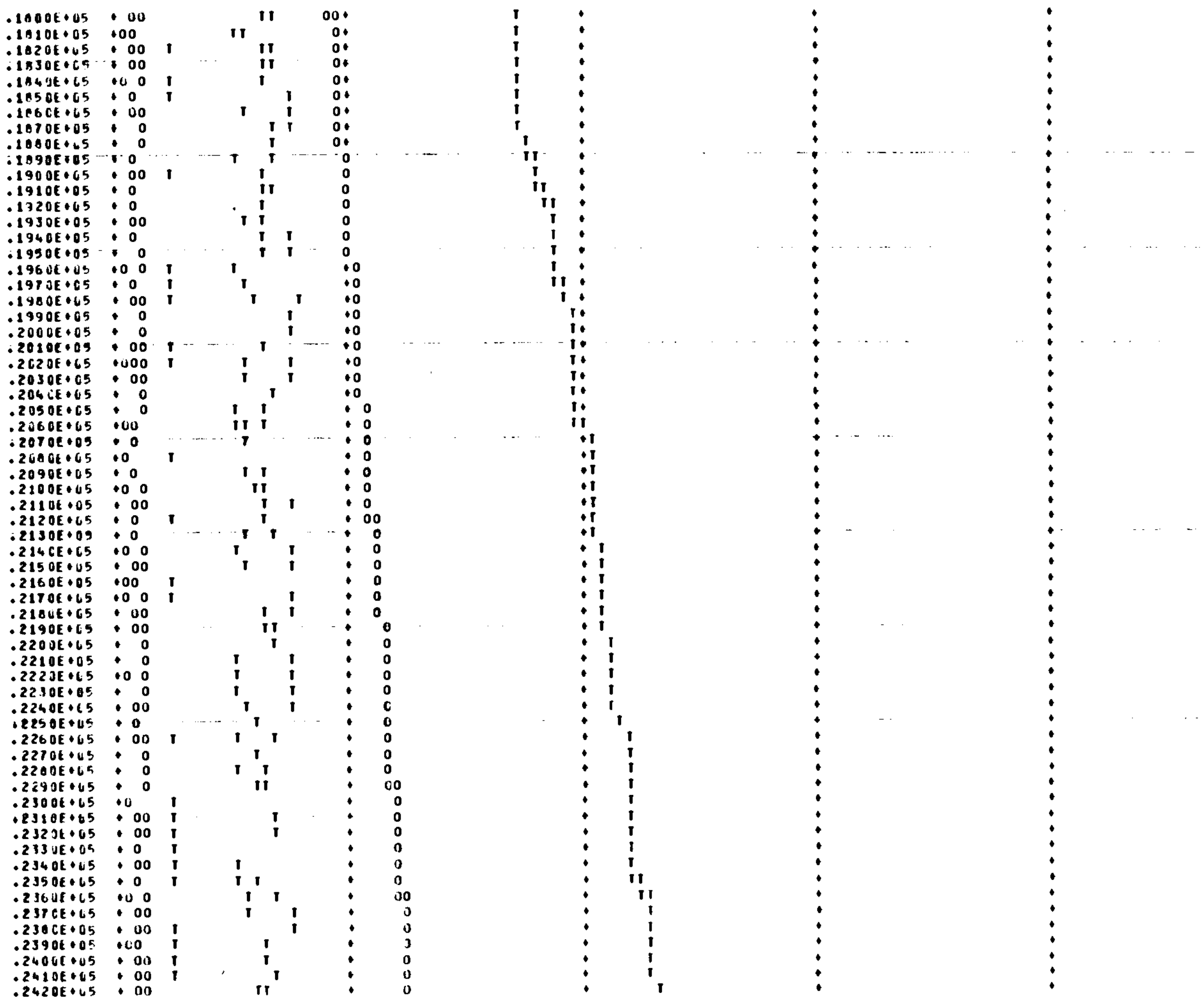
C-7. Typical plot of CYCLE-TM and number of orders against time.



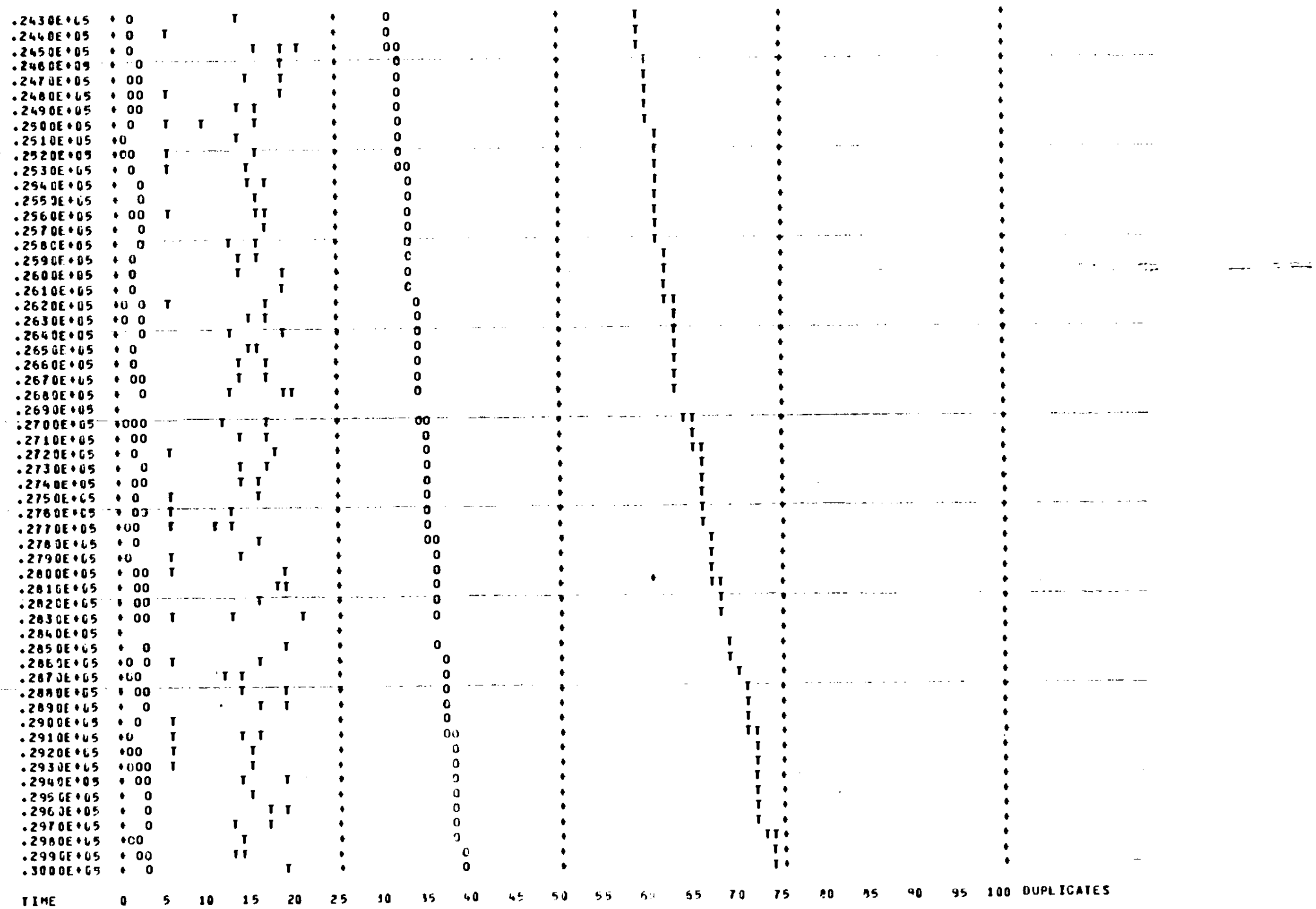
C-7--(continued)



C-7--(continued)



C-7--(continued)



C-7--(continued)