SIMULATING A STORAGE AND RETRIEVAL SYSTEM
INTERFACED WITH AN AUTOMATED GUIDED
VEHICLE SYSTEM

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In Partial Fulfillment
of the Requirements for the Degree
Masters of Science

by
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CHAPTER 1

INTRODUCTION

Background

The purpose of this project is to design and simulate a high-rise pallet facility for XYZ company. The XYZ company is obviously a fictitious name to protect the company’s identity. The high-rise storage structure utilizes Storage and Retrieval (S/R) machines for performing picking and stowing operations. Automatic Guided Vehicles (AGVs) will be used for transporting loads to and from the storage structure.

A simulation model will be developed to mimic the dynamic elements of both the S/R and AGV systems. The simulation model will be used to evaluate:

1. the size and scope of the system.
2. how operating policies will perform.
3. trouble areas or possible bottlenecks.
4. the utilization of the equipment.

Problem and Objective

A high-rise pallet facility is considered the cornerstone project for the modernization efforts of a large
warehousing and distribution facility. The high-rise structure will allow faster moving palletized material from 515,235 square feet of heated and lighted conventional warehouse space to be consolidated in a smaller area. A projected annual savings of 45.8 Million British Thermal Units (BTUs) or $257,508.00, will be realized by eliminating the heating and lighting requirements of the four conventional warehouses. The new warehouse will also accommodate the projected twenty seven percent increase in Stock Keeping Units (SKU's) over the next five years.

The objectives are to:

1. develop a preliminary layout for the storage structure.

2. select the appropriate operating policies for the S / R machines and the AGV system.

3. develop a simulation model to check the system design.

The simulation model will allow the user to make some modifications in the design configuration, material handling equipment specifications, and operating policies. Major changes require the knowledge and assistance of a programmer who is familiar with SLAM.
CHAPTER 2

LITERATURE

Material Handling in Computer Integrated Manufacturing

The American economy has been changed by the evolution of global markets and foreign competition. The shift of our economy has been from manufacturing to service. These trends have resulted in the slowdown of growth of the Gross National Product (GNP) and the deterioration of several major industries. In order for the United States to regain some of these markets, Spencer (38), recommends that U.S. industries turn to automation and computer integrated manufacturing (CIM). Spencer believes these steps must be taken now to insure a future for U.S. industries in the international market.

Groover and Wiginton (15) indicate that there are two basic components to a computer integrated manufacturing system. They are:

1) factory information and communications
2) material handling.

Factory information and communications connect procurement, order entry, planning, scheduling, inventory
control, quality control, and shipping together by means of a communications network. The network makes use of a common data base shared by all the functions.

The second component, material handling, is concerned with the movement, storage and control of materials. The transportation system design must handle peak demands in order to prevent in process material delays and balance transportation and storage system throughputs with common interfaces, such as pickup/dropoff (P/D) stations. The material handling equipment must be capable of dealing with product size and weight variations and be flexible enough to accommodate alternate routing throughout the facility.

This investigation will concentrate on two types of material handling systems, the Automatic Storage and Retrieval System (AS/RS) interfaced to an Automatic Guided Vehicle System (AGVS).

**Automatic Storage and Retrieval Systems**

*Material Handling Engineering* (MHE) (23) describes the AS/RS as the technology that takes best advantage of the cube and height of a storage system while offering security and inventory control. MHE also states that the AS/RS is the most efficient and fastest manual batch picking operation, the best in-process buffer, the most precise and dependable controlled inventory system, and the system that
is most responsive to just-in-time (JIT) material delivery requirements.

According to the Handbook of Industrial Engineering (35), the AS/RS consists of storage racks, storage/retrieval (S/R) machines, Input/Output (I/O) or Pick-up/Deposit (P/D) stations, transportation devices, and controls.

There are three basic types of S/R systems described by Rygh (34). The first is the unit load system. This system handles inventories in unit loads which are usually palletized or placed on 'slave pallets'. The second is the order picking system, also known as the person-on-board system. This system is used for storing and retrieving materials of less than unit load quantities. The final S/R type is the work-in-process system. This system is used in CIM as a buffer storage between two production processes with different material throughput rates.

Rygh (34) provided the following list of benefits from using a AS/RS system.

1) better space utilization  
2) less direct and indirect labor  
3) reduced inventories  
4) less energy consumption  
5) reduced pilferage  
6) less product damage  
7) improved working conditions  
8) easier housekeeping
9) less equipment damage
10) improved customer service
11) better management control.

**Automatic Guided Vehicular System**

Groover and Wiginton (15) describe the AGVS as the arteries of an integrated material handling system. AGV's are independently operated, battery-powered vehicles that follow pathways defined in the warehouse floor. The pathways are defined by means of a guided wire imbedded in the floor or a chemical paint stripe marked on the surface of the floor. Sensors on-board the vehicles track the pathways and make deliveries between various stations on the track. AGV's are capable of variable routings, can carry a variety of loads by using standard pallets to hold the loads and can be operated under computer control.

According to Rygh (34), AGV's fall into one of five categories; each is designed to accommodate different applications.

1. Unit load vehicles. These vehicles are designed to transport one or more unit loads at a time and can be equipped with various material handling devices for automatic pick up and discharge of the load.

2. Tugger or tow vehicles. These vehicles are designed to pull a cart or a train of carts and can automatically hitch or release the trailers.

3. Pallet movers. These vehicles are low lift carriers resembling walkie pallet trucks. Loading and unloading may be accomplished manually or automatically.
4. Picking or stacking vehicles. These vehicles are equipped with forks to pick up loads from the floor and deposit the load at some elevated position.

5. Manufacturing vehicles. These vehicles are used for transporting unique loads in a work-in-process environment.

Some of the benefits of AGV Systems given by Norman (28) include:

1) automatic interfacing
2) flexible system capacity
3) tighter material control
4) increased productivity
4) efficient use of floor space
5) easily adapted to automation
6) ease of installation

Storage System and Policies

The storage facility for an AS/RS is generally one of two types: free standing structure or the rack supported structure. The free standing structure consist of racks which are installed inside of a building and is considered to be mobile. The rack supported structure is fixed since the racks are an integral part of the building structural support.

The rack supported structure is not only the cheapest to build, but it also offers other advantages. For example, the internal revenue service treats racks as equipment rather than as a building for depreciation purposes.
Equipment can be depreciated over a shorter life than buildings and it may also receive special Investment Tax Credits (ITC) and sales exemptions. Rygh (34) estimates that rack supported structures are twenty (20) percent less expensive than the buildings and equipment with free standing racks. Under the new tax laws, according to Schwind (36), the rack supported structure will not qualify for ITC.

Many factors in the storage matrix of an AS/RS can be varied to speed up the throughput and to maximize orderpicking productivity. The percentage and position of dedicated versus non-dedicated storage locations, the location of fast-moving versus slow-moving items, and the selection density of the items affect the throughput.

Graves, Hausman, and Schwarz (14) examined three storage assignment rules for unit load S/R system. The first is known as Random Storage Assignment (RAN). In this storage system all items have an equal chance of being stored in each of the storage locations. The second is called the Class Based storage system. This system separates the items and the locations of the storage racks into a small number (2 or 3) of classes. The most popular items are placed in storage class closest to the P/D station and the items are then stored randomly within a class. Less popular items are likewise stored at greater distances from the P/D station. The last storage assignment rule to be
examined is the Full turnover-based storage system (FULL). This rule results in a dedicated storage system which assigns a storage location to an item based on its turnover rate. The item with the highest turnover rate is assigned to the location closest to the P/D station.

Table 1 contains the results of study done by Graves, Hausman, and Schwarz (14). They simulated the operation of an AS/RS system using the above rules and reported the percentage improvements of the latter two types of storage assignments over random storage. The performance of the assignment rules depend on the characteristics of the inventory; a 20/60 ABC curve means that 20% of the inventory items account for 60% of the total demand.

<table>
<thead>
<tr>
<th>ABC Curve</th>
<th>% Improvement over Random Storage</th>
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<tbody>
<tr>
<td></td>
<td>Two Class</td>
</tr>
<tr>
<td>20 / 60</td>
<td>18.1</td>
</tr>
<tr>
<td>20 / 70</td>
<td>25.5</td>
</tr>
<tr>
<td>20 / 80</td>
<td>35.9</td>
</tr>
<tr>
<td>20 / 90</td>
<td>52.9</td>
</tr>
</tbody>
</table>

Their study indicated that a 2-class system requires a 2% to 3% increase in the number of storage rack openings compared to a random storage system. For a 3-class system requires a 4% to 5% increase in storage rack openings. Their calculations are based on the 95% confidence interval. That is, when an item is to be stored, a location in the proper class will not be available for about five percent of
the storage request.

Davies, Gabbard, and Reinholdt (7), evaluated four commonly used space assignment methods for order picking systems.

1. alphanumeric
2. fast and other
3. frequency
4. Selection Density Factor (SDF)

In the alphanumeric scheme, all items are assigned a storage location in their alphanumeric sequence. The second is placement of the items in two classes 'fast and other'. The most frequently selected items are placed closest to the P/D station. Items within each class are stored in a alphanumeric sequence. The third placement method is placement by frequency. The items are stored by frequency of demand or 'number of hits'. This is the same approach used in the FULL turnover-over based storage method for unit load S/R systems, except that multiple unit loads of an item may be stored rather than a single load for each item. The fourth type of placement is the Selection Density Factor. For this storage method, the number of selections made per year for an item is divided by the required storage volume. This value is referred to as the SDF value. Items with the highest SDF values are placed closest to the P/D station.

In the case study reported by Davies, et al. (7), the SDF placement method was the best of the four storage
strategies examined. The SDF placement method reduced labor requirements and storage requirements. The average travel distance between the P/D station and an item was also reduced by the largest factor. Other benefits of SDF assignment include a reduction in material handling effort for restocking purposes, improvement of supervision because the workers were confined to a smaller working area. Picking accuracy also improved because similar items, such as different types of safety glasses, resistors or fuses, were not grouped alphanumerically.

In another case study conducted by Hamada (16), the benefits of storing fractional unit loads of multi-packaged items on pallets were considered. If the order for a fractional load matches one of the stored loads a manual pick operation can be avoided. Fractional loads do not maximize storage space utilization. A 11% improvement in the throughput of the AS/RS was achieved with only a 0.8% sacrifice in storage capacity. Hamada noted that this improvement was only realized because the commodities had a comparatively small number of parts or containers per pallet.

In an article from Modern Material Handling (MMH) (29), another potential improvement for a AS/RS storage system is mentioned. For a product mix that varies in height, consideration should be given to varying the heights of openings within the storage rack. The author states that
this arrangement will provide better utilization of the storage cube if many items can be stored in each height category.

Finally, Heneveld (10) of the Ford Motor Company suggests that consideration must be given to the timeliness of accessing materials in a work-in-process environment. In the case of a S/R machine failure, or backlog on a particular aisle, he suggests storing identical commodities in different aisles. Shell Chemical of Belpre, Ohio also uses this concept to speed up the loading of trucks for shipping.

**S/R Machine and Operating Policies**

The S/R machine stores and retrieves loads from the storage structure. The typical S/R machine operates on a floor mounted rail and is guided at the top. The power supply is sometimes provided by the upper rail. Other S/R machines are battery powered and may move between aisles under their own power. If the S/R machine is not equipped with a battery pack, transfer mechanisms are available to make interaisle movements.

The S/R machine operates in three directions. In the horizontal direction, the S/R machine moves back and forth within the aisle. In the vertical direction, a hoist is used to raise and lower the carriage. In the lateral direction a shuttle drive transfers the loads from the S/R
machine to a storage location on either side of the aisle. Most S/R machines can operate both vertically and horizontally simultaneously. To take advantage of this capability, AS/RS systems are typically designed to be "square in time".

The S/R machine comes in a wide variety of sizes and configurations because it's design is a function of the loads it carries and the tasks it performs. Savendy (35) describes three sizes of S/R machines. The 'maxiload' machine is used for pallet load systems and handles loads of 1500 pounds or more. The 'miniload' machine is smaller and handles loads ranging up to 500 pounds. The 'microload machine' must be a 'driverless' system and is used for loads less than 80 pounds.

There are two types of S/R order picking systems. The first is 'in-aisle' orderpicking. The operator picks from pallets, shelves, bins, or drawers within the storage structure. The loads are then carried to the end of the aisle for dispatching. The second type is 'out-of-aisle' orderpicking. The unit loads, bins or totes are automatically retrieved from storage, and brought to the end of the aisle.

For the out-of-aisle order picking system two different scenarios are used for storing and retrieving unit loads. The first is referred to as the 'single address' system or the 'noninterleaving' (NIL) policy. In this case, the S/R
machine performs either a storage operation or a retrieval operation, but not both, before returning to the P/D station. The second, is referred to as the 'dual address' system, also known as a 'mandatory interleaving' (MIL) policy. In this case, the S/R machine stores one unit and then retrieves another, before returning to the P/D station. Throughput is increased by performing 'dual transactions'.

The throughput for dual transactions can be further increased by carefully selecting the retrieval request. On a first come first serve (MIL/FCFS) basis the retrieval waiting the longest amount of time is selected. Under the queue selection rule (MIL/Q=K), the next K retrieval locations are examined to see which is closest to the next storage transaction. The closest is selected to reduce intertransaction travel time. Nearly, all of the benefits of the queue selection rule can be obtained by considering only the first few request in the retrieval queue.

Graves, Hausman, and Schwarz (14) computed the benefits made for several storage policies, S/R policies, and queue selection policies. The improvements for a 20/60 inventory over RAN/NIL/FCFS policy is presented in Table 2.

For in-aisle orderpicking, there are three methods listed in the MMH - 1986 Warehousing Guidebook (40). Sequential orderpicking is where a manaboard operator takes each order and moves through the warehouse making selections. After completing an order, the operator drops
it off at the closest P/D station for delivery to packing or shipping. For batch orderpicking, a manaboard operator

### TABLE 2

**BENEFITS OF VARIOUS STORAGE AND RETRIEVAL POLICIES**

<table>
<thead>
<tr>
<th>Policy Considered</th>
<th>% Improvement over RAN/NIL/FCFS</th>
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<tbody>
<tr>
<td>1) RAN/NIL/FCFS</td>
<td>0</td>
</tr>
<tr>
<td>2) FULL/NIL/FCFS</td>
<td>26.4</td>
</tr>
<tr>
<td>3) C2/NIL/FCFS</td>
<td>18.1</td>
</tr>
<tr>
<td>4) C3/NIL/FCFS</td>
<td>22.4</td>
</tr>
<tr>
<td>5) RAN/MIL/FCFS</td>
<td>32.5</td>
</tr>
<tr>
<td>6) FULL/MIL/FCFS</td>
<td>46.4</td>
</tr>
<tr>
<td>7) C2/MIL/FCFS</td>
<td>42.4</td>
</tr>
<tr>
<td>8) C3/MIL/FCFS</td>
<td>44.4</td>
</tr>
<tr>
<td>9) C2/MIL/Q=2</td>
<td>44.4</td>
</tr>
<tr>
<td>Q = 5</td>
<td>45.6</td>
</tr>
<tr>
<td>Q = infinity</td>
<td>46.5</td>
</tr>
<tr>
<td>10) C3/MIL/Q=2</td>
<td>46.1</td>
</tr>
<tr>
<td>Q = infinity</td>
<td>50.1</td>
</tr>
</tbody>
</table>

fills multiple orders at the same time. In zone picking the operator is assigned a specific portion of the storage area for filling orders. The manaboard operator then completes all orders within that zone. Both batch and zone picking reduce the travel time but a sorting operation must be done after picking operations.

Graphs of the interrelationships between the pick container size, travel time, the number of required replenishments, and the quantity stored at the pick location are given in Figure 1. An increase in the quantities stored results in increases in the picking area size and travel time to perform a picking cycle. The number of replenishments decrease as the quantity stored increases.
Figure 1: Analyzing Order-Picking Operations

- Travel time to perform a picking cycle
- Picking area size
- Number of required replenishments
- Quantity stored at picking location
Lotting of items can also have an effect on the number of unit loads that are required. Based on the assumptions that the cube of the item is known beforehand, and that the shape will not have an impact on the lotting of items, Barrett (3) presents four approaches for lotting items. In the first method items can be lotted by random assignment (RAN). In this case, each item is scanned on a first in first out (FIFO) basis to see if it will fit on the picking lot being formed. The second method, volume assignment (VOL), can reduce the number of lots by combining the smaller items into a single lot. The third approach uses a modified random (MRAN) assignment. In this case, if the next item being considered will not fit, it is skipped, and the remaining items in the queue are scanned in sequence to see if any will fit in the lot being formed. The fourth method (LOAD) is to sort the items in decreasing size, and then combined in the same manner as MRAN.

Barrett (3) discusses other ways to reduce order picking time. One of his recommendations is to pick in a double pass sweep, that is, the operator starts at the P/D station, works from left to right along the lower half of the rack, and then returns from right to left along the top half of the rack. This heuristic reduces the travel time and is much easier to implement than the shortest path algorithm which is used for transportation problems.
Transportation Devices

There are many types of transport devices which can be used with the AS/RS: forklifts, roller or chain conveyors, overhead power and free conveyors, in-floor towlines, shuttle trolleys, and guided vehicles. The choice again, depends on the system's throughput requirements, the type of load to be handled, and the degree of interaction with shipping, receiving, and other warehouse operations. Automatic guided vehicles (AGV) will be the transport system covered here.

AGV's are often referred to as the arteries of the material handling system. AGV's are independently operated, battery-powered vehicles that follow specific pathways. The pathways are defined by means of a guided wire imbedded in the floor or a chemical paint stripe marked on the surface of the floor. Sensors on-board the vehicles track the pathways and make deliveries between various stations on the track. AGV's are capable of variable routings; they can carry a variety of loads by using standard pallets to hold the loads; and they can be operated under computer control.

AGV's may operate under three levels of systems management control. Norman (28) discusses each.

1. On-board dispatching is performed by an operator who enters the appropriate codes on the vehicle to dispatch it to one or more stations.

2. Remote terminal dispatching is also performed by an operator who enters the appropriate codes from a remote terminal to send the vehicle to one or more
stations.

3. Central computer dispatching is performed by a dedicated computer or by a computer which supports other components of production (e.g. AS/RS).

Norman (28) also discusses other operating strategies, such as which AGV should be selected if more than one AGV is available to transport a request. Norman lists five possible rules:

1) Select the vehicle randomly from the set of available vehicles.

2) Select the vehicle which has the shortest travel time to the pickup station.

3) Select the vehicle which has the longest travel time to the pickup station.

4) Select the vehicle that has been idle the longest since its last task.

5) Select the least utilized vehicle.

Norman (28) discusses another issue that deals with selecting a task. If more than one task is waiting when a vehicle becomes available, Norman lists six different rules that can be used:

1) Select the task randomly.

2) Select the task that is waiting in the station that has the maximum on-hand outgoing queue size.

3) Select the task that is waiting in the station which is the closest to the vehicle.

4) Select the task that is waiting in the station which is the farthest from the vehicle.

5) Select the task that is waiting in the station that has the smallest remaining outgoing queue capacity.
6) Select the task that has been waiting the longest from a subset of waiting tasks. This subset allows only one task from each station to be waiting.

AGV’s are often called the 'backbone of the material handling system' because they offer the flexibility to move variable products over different routes. In Burlington Industries MMH (1) new automated textile plant, AGVS and an advanced computer control system have linked handling and manufacturing in what must be the most automated textile plant in the world. More than 2,000 I/O stations forms the interface between processing machines, two AS/RS and a nine- dock shipping area. Four types of trailers are used with the guided vehicles; most loading and unloading operations are automatic.

Mechanical Interfacing of the Various Systems

The term 'mechanical interfacing' refers to the capability to transfer loads back and forth between various systems in the warehouse. The most promising scheme for achieving load transfers between the various systems in the warehouse makes use of standard-sized containers and/or pallets. Some requirements of the transfer mechanism must be accurate, reliable and sufficiently fast acting so that it does not cause a bottleneck in a smooth flowing system. The accuracy is required for aligning the transfer mechanism between the two systems to prevent jamming. This level of accuracy may be achieved by using tapered pins or other
alignment devices to locate the material handling carrier (e.g. the AGV and AS/RS) at the transfer station.

Groover and Wiginton (15) have listed some common transfer mechanisms that are designed for loading and unloading between material handling systems. They are:

1) lift-and-carry devices
2) push-pull devices
3) AGV's with powered rollers or powered belts.
4) AGV's with lift-and-lower platforms
5) deflectors

The AGVs may operate at end-of-aisle interfaced with P&D stations or enter the first level of AS/RS rack and be unloaded directly by the S/R machine. Other techniques for feeding an AS/RS are discussed in MHE (23). They include the use of self-powered monorails and overhead cranes.

The AS/RS can be designed for specific operations and orderpicking requirements by varying the location of both the input (I) station and the output (O) station. Bozer and White (4) conducted an analytical study that showed the effects of locating the I & O stations at different positions. The comparisons are made with respect to the conventional method of locating both the I & O station at the lower left hand corner of the storage matrix. The results of their study are shown in Table 3.
TABLE 3

EFFECTS OF LOCATING THE I&O STATIONS AT DIFFERENT POSITIONS

<table>
<thead>
<tr>
<th>I&amp;O Locations</th>
<th>% Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) opposite ends of the aisle</td>
<td>10.5</td>
</tr>
<tr>
<td>2) the same end of the aisle but at different elevations</td>
<td>18.3</td>
</tr>
<tr>
<td>3) the same elevation, but at the midpoint in the aisle</td>
<td>39.7</td>
</tr>
<tr>
<td>4) elevated at the end of the aisle</td>
<td>16.2</td>
</tr>
</tbody>
</table>

The Controls

The control techniques used in a AS/RS determine how the system will operate. For high volume light variety conditions, White (45) suggest using 'hard or rigid automation', and for low volume and high variety conditions, he recommends using 'soft or flexible automation'.

In AS/RS the unit load system is a excellent candidate for 'hard or rigid automation'. As an illustration, each S/R machine has its own on-board microprocessor which controls the individual machine. The I/O stations and the transport devices are controlled by one or more microprocessors. All of these processors communicate with one or more equipment controllers which in turn direct the movement of the equipment and provide system information. The equipment controller in turn, communicates with a the larger minicomputer which provides the overall AS/RS
control. This computer may also perform tasks like inventory control, data collection, and networking control. In a CIM system this minicomputer is frequently linked to a larger computer which provides corporate information.

The order picking S/R system is less conducive to 'hard or rigid automation. Instead, 'soft or flexible automation' is often used. MMH - 1986 Warehousing Guidebook (29) presents two examples of 'soft or flexible' automation in in-aisle S/R order picking systems. In the first example, the operator may use picking labels or a bar-code reader. The picking labels are affixed to the product as it is picked and the operator turns in the unuseable labels to indicate out-of-stock items. If a bar-code reader is used, a list of the picked items can be generated as the selection is made.

In the second example, all paperwork is eliminated. A lamp, counter-display, and a button are mounted at each picking location. The lamp lights up next to the items to be picked, and the display indicates the quantity required. The picker hits the button to inform the computer the pick has been made and the light is turned off.

SIMULATION

Today's advanced materials handling systems must interact with a variety of complex operations in ways that are not always intuitively obvious. The more complex a
materials handling system is, the harder it is to predict how it will perform. One way to minimize the risk is to simulate the proposed system with a computer model that attempts to mimic the way a system will actually work. Ultimately the simulation model must answer the broad question of whether the system will operate as planned, and detailed questions about equipment utilization, and the effectiveness of component choices and operating strategies.

According to Modern Material Handling (MMH) (11), a computer simulation models can be used to:

1) establish the scope and size of a system
2) evaluate different hardware configurations and operating policies during the design stage
3) test and debug components during development
4) perform analyses of the system in operation
5) examine alternate operating strategies.

Unfortunately not all companies use simulation techniques. In a survey conducted by MMH (41), 700 companies responded to the question:

'Does your company use simulation analysis to check the feasibility of a proposed material handling system design? Only 14% of the respondents answered positively. About 30% of the companies with annual sales between 125 million and 1 billion use simulation, and almost 50% of companies with more than 1 billion in sales used these modeling techniques.

Glenney and MacKulak (13) recommend that an automated
A warehouse simulation model should include the following components:

1) the human-factored work environment
2) the automation/computer controls
3) the islands of automation
4) the material handling systems.

Many simulation models have been prepared for the AS/RS system. Dangelmaier (8) used the computer simulation language SIMULAP to model the "front court area of a high-bay warehouse". Perry, Hoover, and Reeman (31) used the general purpose language Fortran because of its modelling flexibility and transferability to other systems. Bailey (2) used the Basic language and then interfaced the program with a Computer Aided Design (CAD) system. Grant and Wilson (12) used the Slam II simulation language because of its direct applications to material handling systems. The marketer of SLAM II, Pritsker and Associates, have just recently released two new modelling functions for material handling equipment. Both functions have direct applications to AGV and S/R systems. Norman (28) used SIMAN to simulate AGV Systems. SIMAN offers a modeling framework for materializing equipment, routing and scheduling.
CHAPTER 3

SYSTEM DESIGN

General Considerations

The simulation model was developed to answer the following questions:

1) What is the scope and size of the system?
2) Will the system operate as planned?
3) Are there bottlenecks in the system?
4) What percent of the time is the equipment utilized?

Programming Languages

According to Pritsker, A. B. and Pegden, C. D. (32), the following features should be considered when selecting a simulation language:

1) the ease of learning the language.
2) the ease of coding; including random sampling and numerical integration.
3) transferability of the language onto other computers.
4) the flexibility of the language in supporting other modeling concepts.
5) the ease of gathering statistics, allocating core memory, producing standard and user-tailored reports.
6) the ease of debugging and the reliability of the support systems, and the documentation.

7) the compilation and execution speed.

Only two simulation languages were available to the author: SIMSCRIPT and SLAM II. SLAM is the ancestor to the SIMAN simulation language. The author had been exposed to SIMAN simulation, and therefore SLAM II was chosen on its availability and the author's knowledge of a similar language.

SLAM II was developed by Pegden, C. D., and Pritsker, A. A., and is presently supported by Pritsker and Associates, Inc. of West Lafayette, Indiana. The source language was written in FORTRAN and is available for mainframes and microcomputers. SLAM II has been specifically designed for simulating manufacturing problems and recently extensions for material handling (MH) equipment have been added. The MH extensions are in a network form and represent S/R machines and AGVs.

SLAM was the first simulation language to provide all three modeling viewpoints in a single integrated framework. The three modeling viewpoints are network, discrete event, and continuous modeling and/or any combination of the three.

The network model consists of a set of interconnected symbols that depict the operation of the system. The node and branch symbols are used to represent the model and its routing and processing functions.
The flow of entities through a network is defined by the sequencing of the network input statements. If a node statement is followed by another node statement, an arrival to the first node is followed by an arrival to the second. Nonsequential routing of an entity is specified by referencing the label of the node to which a transfer is made. For example, balking an entity from a QUEUE node to a COLCT node is accomplished by including the label of the COLCT node in the QUEUE node statement. This feature is equivalent to a GOTO statement in FORTRAN.

In a discrete event orientation, the modeler defines the events and the potential changes to the system. The mathematical-logic associated with each event is coded in FORTRAN. SLAM provides a set of subroutines and functions that are commonly used to describe discrete events. These subprograms include: scheduling events, manipulating files, collecting statistics, and generating random samples. The random sample generator for SLAM II contains the exponential, uniform, Weibull, triangular, normal, lognormal, Erlang, gamma, beta, and Poisson distributions and the user can add routines for other distributions.

SLAM II controls the simulation in the executive control program by advancing time and initiating calls to the appropriate event subroutines. If any user written subprograms are included in a SLAM model, the dummy versions are replaced by linking the compiled user-written FORTRAN...
version with the compiled SLAM library. Thus, the modeler is relieved of the responsibility of sequencing the events in chronological order.

In the author's program, the network file is used to represent the physical configuration: storage structure, S/R machine, input and output stations, AGVs and track layout. The FORTRAN files are used to represent the operating policies: sequencing of orders, lotting, scheduling of S/R machines and AGVs, etc. The continuous orientation was not used in the author's model.

Some problems were encountered with the SLAM language as the model was being developed. First, the user written SELECT function NQS would not always return to the FORTRAN subroutine. In the case when entities were held in only one QUEUE node, the executive control program would default to the first available server. Thus, the user-written selection rule could not be used to schedule parallel servers. An error was detected if an attempt was made to override the system. When entities were held in two or more QUEUE nodes, control would be passed to user-written SELECT function. The SELECT function in turn, would pass back the activity number associated with the server selected. If no server could be selected, then a zero was returned.
Description of the S/R System

The material to be stored in the high-rise warehouse complex is classified as pallet rack type merchandise and is packed in single units weighing up to 1500 pounds, or manhandle packages weighing 70 pounds or less. The product mix includes general and industrial supplies as well as construction materials.

Standard-size pallets are to be used for making load transfers between the various systems. The standard pallet is 40 inches deep by 48 inches wide, with a maximum storage height of 60 inches. A maximum of three pallet loads of any one line item is stored in the racks. Any line item with a quantity in excess of three pallets is stored in the bulk warehouse which is outside the system.

In the pallet handling system, a stow transaction is defined as the movement of a palletized load from the receiving area into storage. A pick transaction is defined as the movement of a palletized load from a storage area to the shipping area. A transshipment, also referred to as a 'walk-through' transaction, is the movement of a palletized load from the receiving area to the shipping area.

Material Release Orders (MROs) are authorizations to pick, release and ship material from storage. There are three types of MROs, each is color coded to indicate its priority. A "red" MRO has a priority of one; the material is to be picked, packed and shipped within one day to the
customer. A "green" MRO has a priority of two and must be completed within two days. A "white" MRO has the lowest priority (a three), and warehouse workers have three days to pick the material.

The return of merchandise, the receipt of new material or the replenishment of a stock keeping unit (s.k.u) generates a stow transaction. A transshipment is a combination of both a pick and a stow transaction. A transshipment results when there is a backorder on the merchandise. To reduce the time delays to the customer, when an adequate quantity arrives, the item is taken directly to the shipping area.

The merchandise handled is rackable material with a fairly large cube. These items are either manhandle packages or single unit loads. Manhandle packages are carton items weighing seventy pounds or less. The average number of manhandle packages per pallet is nine. A single unit load is defined as an item weighing more than seventy pounds with only one package or container on a pallet. The maximum capacity of either the multipackage load or a single unit load is 1500 pounds. The S/R system is therefore both a orderpicking system and unit load system.

The standard transaction times for rackable order picking operations have been developed by the accounting office and are outlined in the work measurement standards. The standard pick transaction consists of a single order
document issue. Each issue consists of one line item per
document. The number of pieces picked per line item varies.
The number of orders (customers) and line item issues
(documents) processed during an order picking cycle have
been sampled. See Figure 2A for an example.

A standard stow transaction consist of one line item
per receipt document. The number of containers to be stored
per line item varies. The number of line items processed
during a stowing cycle has also been sampled. Refer to
Figure 2B.

Time elements for the picking and stowing operations
are grouped into segments corresponding to issue
preparation, document processing, maneuvering, lift/lower,
and other miscellaneous operations. The times have been
computed and a 13.9% Personal, Fatigue, and Delays (PF&D)
allowance has been provided. These segments were further
consolidated into two components: fixed (or base) time and
travel time. See Table 4. The fixed time component is
determined by the human performance standard and is
independent of system size. The travel time component is
variable and is directly related to system layout, item
density, and inventory size.

The base component generally accounts for 67% of the
picking time. The remainder of the time is represented by
the travel component for conventional forklift equipment.
This time element has been removed for the study so that the
FIGURE 2A  SAMPLE OF LINES PICKED PER PALLET

FIGURE 2B  SAMPLE OF LINES STOWED PER PALLET
operating specifications for the S/R machine could be included.

**TABLE 4**

**BASIC COMPONENTS OF THE HUMAN PERFORMANCE TIME STANDARDS**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Base (min.)</th>
<th>Travel (min.)</th>
<th>Total (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picking</td>
<td>7.70</td>
<td>3.77</td>
<td>11.47</td>
</tr>
<tr>
<td>Stowing</td>
<td>11.74</td>
<td>2.83</td>
<td>14.57</td>
</tr>
</tbody>
</table>

The number of transactions per day for each function has been estimated from historical data and listed in the following table. The tabulated values do not include the projected increase in workloads over the next five years.

**TABLE 5**

**DAILY NUMBER OF TRANSACTIONS**

**(LINE ITEMS)**

<table>
<thead>
<tr>
<th>Average</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MRO 'red'</td>
<td>99</td>
</tr>
<tr>
<td>MRO 'green'</td>
<td>165</td>
</tr>
<tr>
<td>MRO 'white'</td>
<td>396</td>
</tr>
<tr>
<td>Total Picks</td>
<td>660</td>
</tr>
<tr>
<td>Stows</td>
<td>150</td>
</tr>
<tr>
<td>Transshipments</td>
<td>---</td>
</tr>
</tbody>
</table>

The warehouse policy is to 'get the right item, in the right amount, to the right place, in the right condition, on time, all the time.' Therefore, the following priorities have been established in Table 6, for the various systems. The S/R machine is not involved in transshipments.
<table>
<thead>
<tr>
<th>Transaction</th>
<th>AGV</th>
<th>S/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transshipments</td>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>MRO 'red'</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>MRO 'green'</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>MRO 'white'</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Stows</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Both the AGVS and S/R system are involved in picking and stowing operations. The AGVS is responsible for the movement of receipt items from the receiving area to the storage area, and for the removal of the pick items from the storage area to the shipping area. The S/R system is responsible for movement of pick and stow items between the Input and Output (I&O) stations and the storage system.

The Hardware

The Warehouse Modernization and Layout Planning Guide (42) was utilized as a self-help guide for the development of the proposed Computer Aided Pallet Storage (CAPS) system. Construction specifications and building dimensions outlined in this guide were altered to design a storage structure that met the specific needs of the CAPS system.

A free standing storage structure is to be constructed. This type of structure is supported by steel framing and insulated metal siding. Tubular internal columns are often used to support the inner weight of the roof. The roof is generally constructed of a single layered membrane covered
with tar, felt, or a gravel buildup.

The conventional beam type pallet rack is to be used. The storage rack is assembled with structural uprights joined by pallet beams. The rack depth for a standard pallet rack is 40 inches which is the same depth as the pallets themselves. To avoid loads from falling between the beams 'pallet support members' are installed between the beams as shown in Figure 3.

The typical pallet rack elevation and storage level heights for standard 40' deep, 48' wide, and 36' high pallets and stored ten levels high are shown in Figure 4. The 40 feet stacking height (SH) is the maximum permitted by management at XYZ company. The 40 feet indicates allowances for the 12' from the floor to the top of the first level, the horizontal structural 4 inch beams across the face of each pallet rack, and the clearance required between the top of the pallet and the rack beam. Allowances are provided for approximately four inches of over-travel and at least eight inches of clearance above the pallet. The pallet rack has a uniform beam spacing of 4 feet which accommodates pallets that are 3 feet high or less.

A 100% sample of the pallets to be stored in the warehouse complex was collected to determine the distribution of pallet load heights. This information is shown in Table 7 (heights include the pallet skid). The data indicates that the pallet loads vary considerably in
FIGURE 3  RACK COMPONENTS
Lowermost point of sprinkler heads, joist, rafters, beams, or roof trusses.

10 PALLETS
40'-0" TOP OF LOAD (SH)

9 PALLETS
36'-0" TOP OF LOAD (SH)

8 PALLETS
32'-0" TOP OF LOAD (SH)

7 PALLETS
28'-0" TOP OF LOAD (SH)

6 PALLETS
24'-0" TOP OF LOAD (SH)

5 PALLETS
20'-0" TOP OF LOAD (SH)

4 PALLETS
16'-0" TOP OF LOAD (SH)

3 PALLETS
12'-0" TOP OF LOAD (SH)

2 PALLETS
8'-0" TOP OF LOAD (SH)

4'-0"

12" shown for bottom beam elevation. See specific system for rack elevation details.

All Loads 1 Measurement Ton

108" FRONT VIEW

FIGURE 4 TYPICAL PALLET RACK ELEVATION
height and that only 71 percent of the pallets would fit in the rack illustrated in Figure 4. Also the mean height of all the pallets was 32 inches or 2.67 feet which is less than the standard 36 inch high pallet shown in Figure 4. By varying the beam spacing to fit the pallet heights, better cube utilization could be achieved.

**TABLE 7**

**PALLET LOADS BY HEIGHT**

<table>
<thead>
<tr>
<th>Height (feet)</th>
<th>Number (pallets)</th>
<th>Accumulative Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1606</td>
<td>6.0</td>
</tr>
<tr>
<td>1.5</td>
<td>4332</td>
<td>21.0</td>
</tr>
<tr>
<td>2.0</td>
<td>4633</td>
<td>38.0</td>
</tr>
<tr>
<td>2.5</td>
<td>4748</td>
<td>55.0</td>
</tr>
<tr>
<td>3.0</td>
<td>4405</td>
<td>71.0</td>
</tr>
<tr>
<td>3.5</td>
<td>3860</td>
<td>85.0</td>
</tr>
<tr>
<td>4.0</td>
<td>2238</td>
<td>93.0</td>
</tr>
<tr>
<td>4.5</td>
<td>1277</td>
<td>98.0</td>
</tr>
<tr>
<td>5.0</td>
<td>688</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>27787</td>
<td></td>
</tr>
</tbody>
</table>

The maximum pallet height of each level was established by ordering the pallets in increasing height and finding the height that corresponded to the pallet at each of the 10 percentiles (10, 20, ..., 100). Since the racks are to have 10 levels, 10% of the products have to be at each level.

To fit the S/R machine (Raymond Transstacker SSR 89), the lowest support beam in the pallet rack must be elevated two feet above the floor level. The elevation of the second support beam is determined by adding the elevation of the first beam (2 feet), the maximum pallet height for the first
level, the clearance allowance between the top of the pallet and the rack beam (8 inches or 0.66 feet), and the width of the supporting beam (4 inches or 0.33 feet). Ten percent of the pallet loads have a vertical dimension of 1.5 feet or less. Therefore the elevation of the second beam is

\[ 2.0 + 1.5 + 0.66 + 0.33 = 4.5 \text{ feet}. \]

Subsequent storage elevations are computed in a similar manner. The resulting beam spacings, vertical load openings, and stack heights (SH) are shown in Table 8.

<table>
<thead>
<tr>
<th>Level</th>
<th>Support Beam Elevation (feet)</th>
<th>Pallet Height (feet)</th>
<th>Stack Height (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>2.0</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>7.5</td>
<td>2.0</td>
<td>9.5</td>
</tr>
<tr>
<td>4</td>
<td>10.5</td>
<td>2.5</td>
<td>13.0</td>
</tr>
<tr>
<td>5</td>
<td>14.0</td>
<td>2.5</td>
<td>16.5</td>
</tr>
<tr>
<td>6</td>
<td>17.5</td>
<td>3.0</td>
<td>20.5</td>
</tr>
<tr>
<td>7</td>
<td>21.5</td>
<td>3.0</td>
<td>24.5</td>
</tr>
<tr>
<td>8</td>
<td>25.5</td>
<td>3.5</td>
<td>29.0</td>
</tr>
<tr>
<td>9</td>
<td>30.0</td>
<td>4.0</td>
<td>34.0</td>
</tr>
<tr>
<td>10</td>
<td>35.0</td>
<td>5.0</td>
<td>40.0</td>
</tr>
</tbody>
</table>

The rack with the shortest vertical dimension is placed at the bottom and each level is progressively larger until the tallest pallets are placed on the top level. Variable height spacing will generate better cube utilization of the rack structure, but some variations from the ideal may be necessary. For example, if all the proper size spaces for a particular size pallet are occupied, a pallet may need to be
stored at a higher level than necessary or split into 2 pallets of smaller size.

An additional 3 feet of clearance is required between the top of the uppermost pallet and the lowermost point of sprinkler heads, hoist, rafters, beams, or roof trusses. This clearance helps prevent damage to the structure, sprinkler system, and electric lines. The inner height of the structure must be a minimum of 43 feet. A pictoral representation of the information presented in Table 8 can be found in Figure 5.

To achieve maximum operating efficiency for the S/R machine the pallet rack is designed to be 'square in time'. In other words, it takes the S/R machine an equal amount of time to reach the highest level as it does to reach the most distant column. Since the S/R machine can travel horizontally and vertically simultaneously, it can reach the most distant point (the top row at the most distant column) in the same amount of time it takes to reach either the top row or the most distant column. The rackface was designed specifically for the Raymond Transtacker 89. Other S/R machines could be considered but the dimensions of the storage racks might vary.

The specifications for the S/R machine are:

- horizontal speed of 5 miles per hour (440 feet/min.)

- vertical speed of 1 mile per hour (60 feet/min.)
FIGURE 5 CAPS PALLET RACK ELEVATION
Therefore, the time to reach the highest level is:

\[
\frac{40 \text{ ft.}}{60 \text{ ft./min.}} = \frac{2}{3} \text{ min. or 40 secs.}
\]

The horizontal distance that can be travelled in \(2/3\) min. is:

\[
\frac{440 \text{ ft}}{\text{min.}} \times \frac{2}{3} \text{ min.} = 293 \text{ ft.}
\]

From Figure 4, a double rack (holding two pallets) is 112 inches or 9.33 feet wide. The number of pallet locations per level is:

\[
\frac{293 \text{ ft.}}{9.33 \text{ ft./2 pallet locations}} = 64 \text{ pallets}
\]

The number of pallets per rack face is:

\[
64 \text{ pallets/level} \times 10 \text{ levels} = 640 \text{ pallets}
\]

The number of pallets per aisle is \(2 \times 640 = 1280 \text{ pallets}\)

Computing the Number of Aisles

The five year workload projection suggests that 40,000 pallets locations will be required. Therefore, the number of aisles required are:

\[
\frac{40,000 \text{ pallets}}{1280 \text{ pallets/aisle}} = 31 \text{ aisles.}
\]

Computing Floor Area

The standard layout module for person-on-board S/R machines is shown in Figure 6. The aisle specifications assume that the pallets have zero inches of overhang into the aisle. To compensate for aisle overhang the aisle width has been increased to 60 inches. Also, for interaisle movement of the Raymond Transtacker 89, a 25 foot rear court bay is required. As shown in Figure 7, the front court bay
FIGURE 6 MODULAR LAYOUT FOR A PERSON-ON-BOARD S/R MACHINE
GUIDE BAR AND POWER SUPPLY FOR S/R MACHINE

CLEARANCE FOR SPRINKLER SYSTEM

RACKS AND I/O STATIONS ELEVATED

FLOOR LEVEL

I/O STATIONS

AGV PATH PATH

FRONT BAY AREA

FIGURE 7 CAPS FRONT COURT BAY AREA
must also be extended to 25 feet to accommodate 15 feet of input and output stations and 10 feet for the AGV pathways. Therefore, the total length of the storage structure is roughly \((300+25+25)\) 350 feet.

One storage aisle, including rack depths, and flue space is 12.58 feet wide: therefore, the total width of the storage structure is \((12.58\times31)\) 390 feet wide. The free standing structure would occupy \((350\times390)\) 136500 square feet of storage space.

The *Warehouse Modernization and Layout Planning Guide* (42) recommends that support columns be placed between every other aisle (or every \((2\times12.58) = 25.2\) feet) and on 35.9 foot centers. To maintain consistency within the proposed 350 foot long structure, 35 foot centers are recommended. As shown in Figure 8, the total number of internal support columns required is 135. The total number of external support columns required is 50. A summary of the storage specifications is found in Table 9.
TABLE 9

STORAGE STRUCTURE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of a pallet location</td>
<td>4.67 ft</td>
</tr>
<tr>
<td>Number of pallet locations / level</td>
<td>64</td>
</tr>
<tr>
<td>Number of locations / rack</td>
<td>640</td>
</tr>
<tr>
<td>Number of locations / aisle</td>
<td>1280</td>
</tr>
<tr>
<td>Number of aisles</td>
<td></td>
</tr>
<tr>
<td>Initially</td>
<td>24</td>
</tr>
<tr>
<td>Future</td>
<td>31</td>
</tr>
<tr>
<td>Length of pallet rack</td>
<td>300 ft</td>
</tr>
<tr>
<td>Length of Front Court Bay</td>
<td>25 ft</td>
</tr>
<tr>
<td>Length of Rear Court Bay</td>
<td>25 ft</td>
</tr>
<tr>
<td>Overall Length</td>
<td>350 ft</td>
</tr>
<tr>
<td>Width of two pallet rack</td>
<td>6.67 ft</td>
</tr>
<tr>
<td>Width between racks</td>
<td>0.92 ft</td>
</tr>
<tr>
<td>Width of aisle</td>
<td>5.00 ft</td>
</tr>
<tr>
<td>Width per storage aisle</td>
<td>12.59 ft</td>
</tr>
<tr>
<td>Overall Width</td>
<td>390 ft</td>
</tr>
<tr>
<td>Overall square footage</td>
<td>1365000 ft²</td>
</tr>
<tr>
<td>Spacing between columns</td>
<td></td>
</tr>
<tr>
<td>Lengthwise</td>
<td>35.0 ft</td>
</tr>
<tr>
<td>Widthwise</td>
<td>25.17 ft</td>
</tr>
</tbody>
</table>

S/R Machine

An Automated Storage and Retrieval System (AS/RS) is typically an unmanned operation. Such systems are more susceptible to logistic failures due to mechanical malfunctions and power outage. A person-on-board system is considered more fail-safe and can be expanded or altered rapidly by the addition of basic automation. For the in-aisle orderpicking system the person-on-board S/R machine has been recommended. The S/R operator goes to the storage location and places the picked item on the pallet. The pallet is then carried to the front of the aisle for dispatching.
The person-on-board S/R machine offers the benefits of a narrow aisle orderpicking vehicle and unit load S/R machine. The S/R machine is equipped with a tall rigid mast which is anchored to a upper guidance system. The mast is equipped with a shuttle table that is capable of handling the pallet loads. The pallet handling mechanisms are similar to those used on conventional forklift trucks.

The base of the vehicle consists of a battery powered wheeled platform which permits the person-on-board machine to drive between aisles in a manner similar to a conventional orderpicking vehicle. Outside the storage aisle, the S/R machine runs on batteries. When the S/R machine is operating in the storage aisle, the power is supplied by an overhead collector bar.

The use of upper and lower guide rails provides added stability which reduces the 'flag pole' effect common in most high lift fork trucks and eliminates the need for load derating. Therefore, the full lift capacity is available over the entire lift range. Specifications for the S/R machine are based on the Raymond Transtacker SSR 89 (19) and are given in Table 10.

The S/R machine works within the storage system, and interfaces with Input (I) and an Output (O) stations located at one end of each aisle. The I/O stations act as an intermediate storage buffer and transfer devise between the S/R system and the Automatic Guided Vehicle System (AGVS).
TABLE 10
S/R SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal acceleration</td>
<td>3 feet/second</td>
</tr>
<tr>
<td>Horizontal speed</td>
<td>440 feet/minute</td>
</tr>
<tr>
<td>Vertical acceleration</td>
<td>1 foot/second</td>
</tr>
<tr>
<td>Vertical speed</td>
<td>60 feet/minute</td>
</tr>
<tr>
<td>Load/Unload time</td>
<td>.33 minutes</td>
</tr>
<tr>
<td>Interaisle travel time</td>
<td>5.0 minutes</td>
</tr>
</tbody>
</table>

The input station is in front of the output station so that a AGV can make a Dropoff (D) and a Pickup (P) in the same aisle. The I & O stations are elevated to the same height as the AGV and no special equipment is needed for raising or lowering the pallet load.

The I & O stations are active or powered roller conveyors. The input conveyor transfers the pallet load from the AGV to the S/R machine. The loads are moved forward to fill the last available position. No pressure or contact is permitted between the pallet loads for easy removal by the S/R operator. The pallets are obviously handled on a First Come First Serve (FCFS) basis. When the input station reaches capacity the conveyor is blocked and no more dropoffs are permitted.

The output conveyor transfers the pallet load from the S/R machine onto the AGV. The powered roller conveyor must therefore have the versatility to perform accumulation, switching, timing, and scheduling of materials. The pallets are again advanced on a FCFS basis. When the output station reaches capacity the conveyor is blocked and no more
deliveries are permitted by the S/R machine. The specifications for the I/O stations were obtained from existing equipment measurements and are given in Table 11.

**TABLE 11**

<table>
<thead>
<tr>
<th>I/O STATION SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length / pallet position</strong></td>
</tr>
<tr>
<td><strong>Width of station</strong></td>
</tr>
<tr>
<td><strong>Height of stations</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of Input Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storage Area</strong></td>
</tr>
<tr>
<td>Present</td>
</tr>
<tr>
<td>Future</td>
</tr>
<tr>
<td><strong>Shipping Area</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of Output Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receiving Area</strong></td>
</tr>
<tr>
<td>Stow Trans.</td>
</tr>
<tr>
<td>Transshipments</td>
</tr>
<tr>
<td><strong>Storage Area</strong></td>
</tr>
<tr>
<td>Present</td>
</tr>
<tr>
<td>Future</td>
</tr>
</tbody>
</table>

To prevent jamming, tapered pins would be used to align the AGVs to the I & O stations. The AGVS is responsible for moving palletized loads from the receiving area to the storage area, and for the removing palletized loads from the storage area to the shipping area. For transshipments, the AGVS moves palletized loads directly from the receiving area to the shipping area.

The track layout for the AGVS is shown in Figure 9. The lengths of each segment is given below in Table 12. The track segment between Control Points (CP) 80 and 90 is used for a parking zone for any AGV that does not have a pickup or dropoff assignment.
FIGURE 9  CAPS WAREHOUSE LAYOUT
TABLE 12
AGV TRACK LAYOUT

<table>
<thead>
<tr>
<th>Track Segment</th>
<th>Length (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1 - CP2</td>
<td>960</td>
</tr>
<tr>
<td>CP7 - CP8</td>
<td>920</td>
</tr>
<tr>
<td>CP8 - CP9</td>
<td>15</td>
</tr>
<tr>
<td>CP9 - CP70</td>
<td>390</td>
</tr>
<tr>
<td>CP70 - CP71</td>
<td>15</td>
</tr>
<tr>
<td>CP71 - CP72</td>
<td>250</td>
</tr>
<tr>
<td>CP77 - CP78</td>
<td>250</td>
</tr>
<tr>
<td>CP78 - CP1</td>
<td>390</td>
</tr>
<tr>
<td>CP78 - CP99</td>
<td>407</td>
</tr>
</tbody>
</table>

Sensors on-board the AGVs are used to follow the pathways. Communications between the vehicle and the I & O stations are conducted through the guidance wire. Decisions for selecting a task and selecting and routing a AGV are made by the computerized controller system or by warehouse workers who use remote input terminals. Remote terminals are located in the receiving area to dispatch stow and transhipment transactions.

The AGVs are independently powered by batteries. The internal storage batteries must last up to 14 hours on a single charge. The Raymond Corporation (9) provided the speed and time specifications shown in Table 13.

TABLE 13
AGV SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loaded speed</td>
<td>80 feet/minute</td>
</tr>
<tr>
<td>Unloaded speed</td>
<td>100 feet/minute</td>
</tr>
<tr>
<td>Load time</td>
<td>0.33 minutes</td>
</tr>
<tr>
<td>Unload time</td>
<td>0.33 minutes</td>
</tr>
</tbody>
</table>
A major component of the S/R system is the document processing time. This function generally accounts for 20% - 32% of the base time. A computer assisted orderpicking system can reduce this time, eliminate paper work, correct or compensate for errors in inventory location and quantity, and provide a real time response to the order picker. This capability could increase the system throughput or enable fewer stackers and AGV's to meet the required service level.

Operating Policies

The sequencing of pick orders before sending them to the order pickers is an important element in the overall efficiency of the order picking operation. The pick order consists of the customer's name or code number, storage address, requested item, product description, and quantity. The above information is available from the Material Receipt Order (MRO). The pick orders are then sequenced by priority (as discussed previously), aisle, column, and row.

The items are stored in a class based storage system. The classes are based on the pallet loads height. There are seven classes: 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, and 5.0 feet. Pallet loads greater than five feet can not be handled by the S/R machine and are therefore kept in another storage area. Items are stored randomly; each item has an equal chance of being stored in any of the storage locations.
within its class.

Since emphasis is placed on completing all MROs '.... on time, all of the time', a noninterleaving policy has been adopted. In this situation, the operator of the S/R machine performs all retrieval (pick) operations before performing storage (stow) operations. No storage operation and retrieval operation will be performed in the same cycle.

Since, there is one S/R machine per storage aisle, the S/R system is considered to be 'aisle captive' except for mechanical failures. Thus, a zone picking method has been adopted for the orderpicking policy. In this case, the MROs of each aisle are assigned to the S/R machine operator of that aisle. If the S/R operator completes all orders in that aisle he/she then proceeds to stow items for that aisle. Only one S/R machine is permitted in a aisle at a time.

For manhandle packages the items are batched or lotted by random assignment. In this situation, the next item is scanned by order sequence to see if the item will fit on the picking lot being formed. The number of line items to be lotted per pallet has been sampled and is depicted in Figure 2A. If the next item has a different priority, the lot being formed is carried to the end of the aisle for dispatching. Only one item is lotted per unit load. Stows are also treated as unit loads since lotting would require additional sorting in the receiving area.
AGVs are dispatched on a First Come First Serve (FCFS) bases. If additional vehicles are needed in a particular area the computer will direct idle AGVs to that area. Otherwise, the AGV will remain at the parking zone. AGVs are directed by the controller to take the shortest path to the next destination. If more than one pallet is waiting when a AGV becomes available, the pallet with the highest MRO priority is selected. Ties in MRO priority are broken by selecting the pallet that has been waiting the longest.

**Assumptions for the Simulation Model**

The model assumes that all S/R machines and AGVs have the resources available (i.e. battery charge) to operate for a second shift. The model also assumes that similar vehicles have identical capabilities and travelling speeds.
CHAPTER 4

MODEL PERFORMANCE

Model Testing

As the simulation model was being developed, a detailed trace of the simulation was periodically printed to verify that the model was performing correctly. SLAM and its AGV extension provide trace facilities which automatically output the result of each model statement, as well as any variables requested by the user and the time of each event. Below is narrative version of two pick transactions and one stow transaction run through the system. The trace was developed to verify the performance of the model. The time of each event and a brief description of each are provided. Hand calculations have also been prepared for comparison.

SLAM and MH Extension Trace

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Description of the Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAM 00:00.0 a.m. Cal. 00:00.0 a.m.</td>
<td>A customer order is received, requesting 1 line item (referred to as item # 1). The item is located in aisle 13, column 26, level 2. A &quot;red&quot; Material Release Order (MRO) is prepared and held until day shift (6:30 a.m.).</td>
</tr>
<tr>
<td>SLAM 00:02:0 a.m. Cal. 00:02:0 a.m.</td>
<td>A second customer order is received, requesting 1 line item (referred to as item # 2). The item is located in aisle</td>
</tr>
</tbody>
</table>
A "red" MRO is prepared and held until day shift.

The computer sorts the MROs by priority, aisle, column, level, ascending, and descending order. MRO # 2 is placed first, and MRO # 1 is placed second.

The orders are released for picking at the beginning of day shift.

S/R machine unit 4 is available for operation in aisle 7. The S/R machine is initially located at the I/O station and travels to the storage location: column 29, level 4.

The S/R operating time for MRO # 2 is calculated:

The travel time of the S/R machine accounts for the acceleration, maximum speed, and deceleration of the S/R unit. The horizontal distance traveled =

\[ 29 \text{ columns} \times 4.67 \text{ ft/column} = 135.43 \text{ ft} \]

The travel time during acceleration or deceleration =

\[ \frac{440 \text{ ft/min}}{7200 \text{ ft/min}^2} = 0.06 \text{ min} \]

The distance traveled during acceleration or deceleration =

\[ \frac{7200 \text{ ft/min}^2 \times (0.06 \text{ min})^2}{2} = 12.96 \text{ ft} \]

The travel time at maximum velocity =

\[ \frac{(135.43 \text{ ft} - 2 \times 12.96 \text{ ft})}{440 \text{ ft/min}} = 0.25 \text{ min} \]

The total horizontal traveling time to storage column 29 =

\[ 0.06 \text{ min} + 0.25 \text{ min} + 0.06 \text{ min} = 0.37 \text{ min} \]

The vertical distance traveled =

\[ 3.0 \text{ ft} + 3.5 \text{ ft} + 3.5 \text{ ft} = 10 \text{ ft} \]
The travel time during acceleration or deceleration =

\[ \frac{60 \text{ ft/min}}{3600 \text{ ft/min}^2} = 0.017 \text{ min} \]

The distance traveled during acceleration or deceleration =

\[ 3600 \text{ ft/min}^2 \times (0.017 \text{ min})^2 / 2 = 0.52 \text{ ft} \]

The travel time at maximum velocity =

\[ \frac{(10.0 \text{ ft} - 2 \times 0.52 \text{ ft})}{60 \text{ ft/min}} = 0.15 \text{ min} \]

The total vertical traveling time to storage level 4 =

\[ 0.017 \text{ min} + 0.15 \text{ min} + 0.017 \text{ min} = 0.184 \text{ min} \]

The travel time to the storage location: column 29, level 4 =

Max (0.37 sec, 0.184 sec) = 0.37 ft

The human time element for order picking = 6.16 min

S/R machine unit 4 attempts to lot additional orders. No other orders with a 'red' priority are located in aisle 7. The S/R unit returns to output station 7.

The total time of order picking cycle =

\[ 0.37 \text{ min} + 6.16 \text{ min.} + 0.37 \text{ min} = 6.90 \text{ min} \]

There is no S/R machine in aisle 13, therefore the closest aisle is checked for an available unit. S/R unit 7 is available in aisle 12, and an operator moves the unit to aisle 13.

The S/R operating time for MRO 1 is calculated:

The travel time between aisles =

\[ \frac{12.59 \text{ ft}}{88 \text{ ft/min}} = 0.143 \text{ min} \]
The base time for movement between aisles including maneuver between aisles, the lining up of guiderails, and the travel time to and from I/O stations = 5.0 min

The total interaisle travel time = 0.143 min + 5.0 min = 5.143 min

S/R unit 7 begins traveling to the storage location of item # 1. The intra-aisle travel time to and from the I/O station is computed in the same manner as item # 2. The total travel time =

Max (0.34 min, 0.067 min) * 2 = 0.68 min

The human time element for order picking = 6.16 min

S/R machine unit 7 attempts to lot additional orders. No other orders with a 'red' priority are located in aisle 13. The S/R unit returns to output station 13.

The total time of order picking cycle =

5.143 min + + 0.68 min + 6.16 min = 11.983 min

SLAM 06:36.9 a.m. S/R unit 4 begins unloading the pallet containing item # 2, onto output station 7. The unloading time = 0.33 min.

Cal. 06:36.9 a.m.

SLAM 06:37.2 a.m. The unloading of S/R unit 4 at output station 7 is complete. The unit becomes idle.

Cal. 06:37.2 a.m.

Output station 7 advances the pallet containing item # 2 toward the AGV pickup station. The time in transit = 0.33 min

SLAM 06:37.6 a.m. The pallet is available for pickup by an AGV. An electronic signal is sent to the controller to dispatch a unit. AGV unit 1 is assigned to the pallet
containing item # 2 at output station 7.

The AGV operating time for MRO # 2 is calculated:
The travel time for the AGV is computed at maximum speed. AGV unit 1 is initially located at control point 99. The unit must travel track segments:

99, 80, 8, 9 - 21

The total distance traveled =

\[6.3 \text{ ft} + 15 \text{ ft} + 15 \text{ ft} + 13 \times 6.3 \text{ ft} = 118.2 \text{ ft}\]

The travel time to output station 7 =

\[118.2 \text{ ft} / 120 \text{ ft/min} = 0.985 \text{ min}\]

SLAM 06:38.7 a.m. Cal. 06:38.5 a.m. AGV unit 1 arrives at output station 7 and begins loading the pallet containing item # 2. The time to load a pallet = 0.5 min

SLAM 06:39.2 a.m. Cal. 06:39.0 a.m. AGV unit 1 is loaded and begins traveling to the shipping station. The unit must travel track segments:

22 - 69, 70, 71, 72 - 73

The total distance traveled =

\[48 \times 6.3 \text{ ft} + 15 \text{ ft} + 250 \text{ ft} + 2 \times 6.3 \text{ ft} = 580 \text{ ft}\]

The travel time to shipping station =

\[580 \text{ ft} / 80 \text{ ft/min} = 7.25 \text{ min}\]

SLAM 06:42.0 a.m. Cal. 06:42.0 a.m. S/R unit 7 begins unloading the pallet containing item # 1 onto output station 13. The unloading time = 0.33 min.

SLAM 06:42.3 a.m. Cal. 06:42.3 a.m. The unloading of S/R unit 7 is complete. The unit becomes idle.

Output station 13 advances the pallet containing item # 1 toward the AGV pickup station. The time in transit = 0.33 min
The pallet is available for pickup by an AGV. An electronic signal sent to the controller to dispatch a unit. AGV unit 2 is assigned to the pallet containing item #1 at output station 13.

**The AGV operating time for MRO #1 is calculated.**

AGV unit 2 is initially located at control point 98. The unit must travel track segments:

98 - 99, 80, 8, 9 - 33

The total distance traveled =

\[2 \times 6.3 \text{ ft} + 15 \text{ ft} + 15 \text{ ft} + 25 \times 6.3 \text{ ft} = 200.1 \text{ ft}\]

The travel time to output station 13 =

\[\frac{200.1 \text{ ft}}{120 \text{ ft/min}} = 1.67 \text{ min}\]

AGV unit 2 arrives at output station 13 and begins loading the pallet containing item #1. The time to load the pallet = 0.5 min

AGV unit 2 is loaded and begins traveling to the shipping station. The unit must travel track segments:

34 - 69, 70, 71, 72-73

The total distance traveled =

\[36 \times 6.3 \text{ ft} + 15 \text{ ft} + 250 \text{ ft} + 2 \times 6.3 \text{ ft} = 504.4 \text{ ft}\]

The travel time to the shipping station =

\[\frac{504.4 \text{ ft}}{80 \text{ ft/min}} = 6.30 \text{ min}\]

AGV unit 1 arrives at the shipping station and begins unloading the pallet containing item #2. The time to unload the pallet = 0.5 min

The unloading of AGV unit 1 is complete. The unit travels "idle" with no other
assignments to perform, to the parking zone.

Statistics on item # 2 are collected.
SLAM time in the system =

06:47.4 a.m. - 06:30.0 a.m. = 17.4 min

Calculated time in the system =

06:46.8 a.m. - 06:30.0 a.m. = 16.8 min

Customer order # 2 is complete.

SLAM 06:51.6 a.m. AGV unit 2 arrives at the shipping station and begins unloading the pallet containing item # 1. The time to unload the pallet = 0.5 min
Cal. 06:51.1 a.m.

SLAM 06:52.1 a.m. The unloading of AGV unit 2 is complete. The unit travels 'idle' with no other assignments to perform, to the parking zone.
Cal. 06:51.6 a.m.

Statistics on item # 1 are collected.
SLAM time in system =

06:52.1 a.m. - 06:30.0 a.m. = 22.1 min
Calculated time in system =

06:51.6 a.m. - 06:30.0 a.m. = 21.6 min

Customer order # 1 is complete.

SLAM 11:00.0 a.m. A line item has arrived in the receiving area. The item (referred to as 'stow' item) is to be stored in aisle 9, column 24, level 2. A receipt is prepared and the stow item is placed on a pallet made available for pick up by an AGV. An electronic signal is sent to the controller to dispatch a unit. AGV unit 3 is assigned to the pallet containing the stow item.
Cal. 11:00.0 a.m.

The AGV operating time for the stow item is calculated.
AGV unit 3 is initially located at
control point 97. The unit must travel track segments:

97 - 99, 1

The total distance traveled =

\[3 \times 6.3 \text{ ft} + 960 \text{ ft} = 978.9 \text{ ft}\]

The travel time to the receiving station

= 978.9 / 120 \text{ ft/min} = 8.16 \text{ min}

AGV unit 3 arrives at the receiving station and begins loading the pallet containing stow item. The time to load the pallet = 0.5 min

AGV unit 3 is loaded and begins traveling to input station 9. The unit must travel track segments:

\[2 - 6, 7, 8, 9 - 25\]

The total distance traveled =

\[5 \times 6.3 \text{ ft} + 928.5 \text{ ft} + 15 \text{ ft} + 17 \times 6.3 \text{ ft} = 1082.1\]

The travel time to input station 9 =

\[1082.1 / 80 \text{ ft/min} = 13.53 \text{ min}\]

AGV unit 3 arrives at output station 9 and begins unloading the pallet containing stow item. The time to unload the pallet = 0.5 min

The unloading of AGV unit 3 is complete. The unit travels "idle" with no other assignments to perform, to the parking zone.

Input station 9 advances the pallet containing stow item toward the S/R input station. The time in transit = 0.3 min

The pallet containing the stow item becomes available for pickup. S/R unit 5 is in aisle number 9 and begins
loading the pallet. The loading time = 0.3 min

SLAM 11:23.4 a.m. S/R unit 5 is loaded and begins traveling to storage column 24, level 2.
Cal. 11:23.3 a.m.

The S/R operating time for the stow item is calculated:
The intra-aisle travel time =
Max (0.32 min, 0.13 min) * 2 = 0.64 min

The human time element for stowing =
9.78 min

The total time of the stowing cycle =
0.648 min + 9.78 min = 10.42 min

SLAM 11:33.9 a.m. S/R unit 5 stops at I/O station 9 and becomes idle.
Cal. 11:33.7 a.m.

Statistics are collected on stow item.

SLAM time in the system =
11:33.9 a.m. - 11:00.0 a.m. = 33.9 min
Calculated time in the system =
11:33.7 a.m. - 11:00.0 a.m. = 33.7 min

Stow item is complete.

Table 14 is a comparison of the SLAM time values and the hand calculated time values. The agreement of the SLAM II time values and the calculated time values for the S/R system and the I/O station appears to be within reason. The difference for MRO # 1 in the I/O system is attributed to round off error.

A comparison of the SLAM II time values and the calculated time values for the AGVS reveals a difference
that was consistently higher for SLAM. A technical representative of Pritsker and Associates attributed the differences to the discrete time increments of continuous modeling. In this model the minimum (DTMIN = 0.0125 min) and maximum (DTMAX = 1.0 min) time increments were established in the VCONTROL statement.

SLAM II treats each control point (or node) of the AGV network as a special event. Within a minimum of one time increment (DTMIN = 0.0125) after passing a control point, SLAM II makes contention and routing decisions. SLAM reinitializes the starting point of the AGV at the control point but does not reduce the clock value by the fraction of
DTMIN by which the AGV passed the node. This difference (averaging DTMIN / 2 or 0.00625 min) is insignificant, except when the AGV passes through several nodes between the start and destination nodes. In this model:

1. AGV unit 2 passed through 68 nodes in traveling to output station 7 and delivering MRO #1 to the shipping station. On average this would result in a error of (68 * 0.00625 min) = 0.425 min.

2. For MRO #2 AGV unit 1 passed through 67 nodes, roughly accounting for (67 * 0.00625 min) = 0.419 min of the difference.

3. AGV unit 3 passed through 25 nodes in transporting the stow item to input station 9. This accounting for a difference of (25 * 0.00625 min) = 0.156 min in the SLAM II time values and the calculated time values. The remaining variation is attributed to round off error.

Simulation Runs

Following the development of the simulation model, a series of 6 test runs was performed to determine performance and assess the need for changes. A description of each of these 6 cases follows. Summary reports and graphs of the equipment utilization are included.

Case 1

For the first case, the model was tested as described in Chapter 3. A list of all the input variables and the operating policies for the AGVS and S/R system are provided in Appendix A.

The results of the SLAM Summary Report, abbreviated in Table 15, show that only thirty three percent of all the
customer orders were processed and delivered to shipping for packing during the 8 hour shift. Zero percent of the stow items were stored.

The utilization of equipment was also poor, as shown in Figures 10A and 10B. The S/R machines were blocked fifty nine percent of the time whereas the AGVs were blocked sixty percent of the time.

A review of the SLAM Summary Report shows that the last transaction was delivered to shipping at 160.1 minutes (or 09:10.1 a.m.). A SLAM trace of the model showed that at 09:05.6a.m., AGV unit 14 attempted to unload a pallet at input station 9. Under the initial conditions, when the input station reached capacity, the conveyor was blocked and the AGV was not permitted to unload. Meanwhile, the S/R machines continued to retrieve and deliver customer orders to the output stations. When the output stations reach capacity, the S/R machines were blocked. In essence both the AGV and S/R systems experience blockage and became totally "locked up".

<table>
<thead>
<tr>
<th>TABLE 15</th>
<th>SLAM Summary Report: Case 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Red Orders</td>
<td>54.7</td>
</tr>
<tr>
<td>Green Orders</td>
<td>118.4</td>
</tr>
<tr>
<td>White Orders</td>
<td></td>
</tr>
<tr>
<td>All Orders</td>
<td>82.0</td>
</tr>
<tr>
<td>Stows</td>
<td>No Values Recorded</td>
</tr>
</tbody>
</table>
Figure 10A AGV Utilization Chart: Case 1

Figure 10B S/R Utilization Chart: Case 1
Case 2

In the second case, the operating policy for unloading the AGVs was relaxed. If the input stations reach capacity the vehicle was directed around the 'loop' in the storage area. Refer to Figure 9.

The material flow was again sluggish. The throughput, for the pick transactions improved by twenty two percent, to a total of fifty five percent of the picks completed. Only four percent of the stow transactions were completed.

The AGVs filled the input stations early in the eight hour shift. The AGVs then traveled loaded with stow pallets, two hundred and sixty one times around the loop. The travel time around the loop accounted for thirty three percent of AGVs total time (Refer to Figure 11A). In the mean time the S/R machines continued to pick orders until the output stations reached capacity. The S/R machines remained blocked for thirty nine percent of the total time, as shown in Figure 11B. The system responded poorly because the AGVs were unable to unload stow pallets.

The Case 2 Summary Report follows.

<table>
<thead>
<tr>
<th>TABLE 16</th>
<th>SLAM Summary Report: Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Red orders</td>
<td>54.7</td>
</tr>
<tr>
<td>Green orders</td>
<td>162.0</td>
</tr>
<tr>
<td>White orders</td>
<td>302.6</td>
</tr>
<tr>
<td>All orders</td>
<td>154.5</td>
</tr>
<tr>
<td>Stows</td>
<td>434.1</td>
</tr>
</tbody>
</table>
**FIGURE 11A AGV UTILIZATION CHART: CASE 2**

**FIGURE 11B S/R UTILIZATION CHART: CASE 2**
Case 3

In this case, the stow pallets were delayed in the receiving area until 11:00.0 a.m. As a result, the material flowed more smoothly through the system. As listed in Table 17, ninety four percent of all the pick transactions were completed and forty seven percent of the stow transactions were completed.

The AGVs traveled loaded only twelve times around the 'loop' accounting for less than two percent of their total time. As shown in Figure 12B, the S/R machines were blocked less than three percent of the time.

A breakdown of the utilization of the S/R machines shows that:

1) five percent of the time, the units were in travel storing or retrieving items.

2) six percent of the time, the units were traveling between aisles.

3) one percent of the time the units were either loading or unloading pallets.

4) seventy one percent of the total time, the operators of the units were physically picking/storing items, or completing the proper documentation. The S/R machines remained stationary during this period of time.

<table>
<thead>
<tr>
<th>TABLE 17</th>
<th>SLAM Summary Report: Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Red orders</td>
<td>53.4</td>
</tr>
<tr>
<td>Green orders</td>
<td>128.0</td>
</tr>
<tr>
<td>White orders</td>
<td>271.3</td>
</tr>
<tr>
<td>All orders</td>
<td>188.5</td>
</tr>
<tr>
<td>Stows</td>
<td>403.5</td>
</tr>
</tbody>
</table>
FIGURE 12A AGV UTILIZATION CHART: CASE 3

FIGURE 12B S/R UTILIZATION CHART: CASE 3
Case 4

In this case the AGV and S/R systems were tested for sensitivity when the human time standards were reduced by twenty percent. The resulting values for the human time elements were as follows:

- Storing \( [XX (42)] = 9.78 \text{ min/line item} \)
- Retrieving \( [XX (43)] = 6.16 \text{ min/line item} \)

The material continued to flow smoothly. As shown in Figure 13A, the AGVs remained blocked about seven percent of the total time. Ironically, the time the S/R machines were blocked dropped to one percent of the total time as Figure 13B illustrates. The reduction in the human time was offset by a thirteen percent increase in the S/R idle time. The twenty seven percent total idle time could be reduced, by reducing the number of S/R machines. Table 18 contains the Case 4 Summary Report.

<table>
<thead>
<tr>
<th>SLAM Summary Report: Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Red orders</td>
</tr>
<tr>
<td>Green orders</td>
</tr>
<tr>
<td>White orders</td>
</tr>
<tr>
<td>All orders</td>
</tr>
<tr>
<td>Stows</td>
</tr>
</tbody>
</table>

Case 5

In this case, the effect of increasing the number of AGVs by four, was determined. A statistical test was conducted to compare the results of the previous case (case 4) with the present one. The hypotheses state:
FIGURE 13A AGV UTILIZATION CHART: CASE 4

FIGURE 13B S/R UTILIZATION CHART: CASE 4
HO: There is no significant difference in the mean transaction times of cases 4 and 5.

H1: There is a significant difference in the mean transaction times of the two cases.

The comparison was based on a ninety five percent confidence interval.

**TABLE 19**

**Test Comparison of the Transaction Times**

<table>
<thead>
<tr>
<th>Transaction Type</th>
<th>Table Value</th>
<th>Calculated Value</th>
<th>Hypothesis 0 Accept / Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red order</td>
<td>1.67</td>
<td>0.53</td>
<td>Accept</td>
</tr>
<tr>
<td>Green order</td>
<td>1.67</td>
<td>0.73</td>
<td>Accept</td>
</tr>
<tr>
<td>White order</td>
<td>1.66</td>
<td>0.35</td>
<td>Accept</td>
</tr>
<tr>
<td>All order</td>
<td>1.65</td>
<td>0.29</td>
<td>Accept</td>
</tr>
<tr>
<td>Stow</td>
<td>1.66</td>
<td>0.51</td>
<td>Accept</td>
</tr>
</tbody>
</table>

The results of the test summarized in Table 19, indicate that the H0 hypothesis should be accepted, that is, there was no significant difference when the number of AGVs was increased by four.

A review of the AGV utilization chart (Figure 14A), shows that the increase in the number of AGVs was offset by a fifteen percent increase in the travel 'idle' time. The S/R utilization chart (Figure 14B) shows little change in how they were utilized.

**TABLE 20**

**SLAM Summary Report: Case 5**

<table>
<thead>
<tr>
<th>Type</th>
<th>Mean Value</th>
<th>Standard Deviation Value</th>
<th>Min. Value</th>
<th>Maxi. Value</th>
<th>Percent Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red orders</td>
<td>47.2</td>
<td>17.4</td>
<td>16.9</td>
<td>91.4</td>
<td>100</td>
</tr>
<tr>
<td>Green</td>
<td>108.8</td>
<td>29.1</td>
<td>55.2</td>
<td>200.3</td>
<td>100</td>
</tr>
<tr>
<td>White</td>
<td>230.8</td>
<td>71.2</td>
<td>119.6</td>
<td>475.0</td>
<td>99</td>
</tr>
<tr>
<td>All</td>
<td>165.0</td>
<td>94.5</td>
<td>16.9</td>
<td>475.0</td>
<td>99</td>
</tr>
<tr>
<td>Stows</td>
<td>401.2</td>
<td>49.9</td>
<td>307.5</td>
<td>478.7</td>
<td>67</td>
</tr>
</tbody>
</table>
FIGURE 14A AGV UTILIZATION CHART: CASE 5

FIGURE 14B S/R UTILIZATION CHART: CASE 5
Case 6

In the final case, the human time standards were reduced significantly. The manual method of completing pick/stow documents was replaced by a computer assisted system. CRT, keyboards, bar code readers, and printers were installed on the S/R machines. A work measurement study indicated that the human time standards:

\[ \text{storing} \quad (XX (42)) = 2.74 \text{ min/line item} \]
\[ \text{retrieving} \quad (XX (43)) = 2.16 \text{ min/line item} \]

As a result of the new standards, the material flowed through the system at a much faster rate. The AGV utilization (Figure 15A) increased to eighty percent of their total time. The S/R (Figure 15B) machines however experienced some difficulties. Even though the S/R machine were idle fifty two percent of the time, the units were blocked nearly twelve percent of the time. The problem may be attributed to bottlenecks downstream. In other words, the AGVs were unable to take away the pallets fast enough or the output stations were insufficient in capacity. The problem may be corrected by reducing the number of S/R machines. Additional computer runs would be required, to determine if this change would be a suitable solution to the problem.
FIGURE 15A AGV UTILIZATION CHART: CASE 6

FIGURE 15B S/R UTILIZATION CHART: CASE 6
The results of the six cases presented above are summarized in Table 22. The AGV utilization has been categorized as productive or nonproductive time. The productive time for the AGV may be defined as including the travel time to load, the travel time to unload (less the travel time in loop), the loading time, and the unloading time. The nonproductive time includes the travel time in the loop while loaded, the idle travel time, the time the unit is blocked, and the time it is parked.

The S/R machine utilization has been categorized as productive time, nonproductive time, and human factor time. The productive time for the S/R machine encompasses the travel time within the aisle (intra-aisle), the travel time between aisles, the loading time, and the unloading time. The nonproductive time includes the time the S/R machines are either stopped or blocked. A third category entitled the human factor time has been developed to indicate the amount of time the S/R machine is stationary while the operator is performing a manual pick/stow operation or
completing the proper documentation.

The material flow is a representation of the number of transactions completed (pallets * lot size), divided by the total number of transactions created. The number of transactions did not change in the six cases. These values are provided in Appendix A.
<table>
<thead>
<tr>
<th>SUMMARY OF RESULTS</th>
<th>CASE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>AGVs</strong></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL % PRODUCTIVE TIME</strong></td>
<td>33</td>
</tr>
<tr>
<td><strong>TOTAL % NONPRODUCTIVE TIME</strong></td>
<td>68</td>
</tr>
<tr>
<td><strong>S/R MACHINES</strong></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL % PRODUCTIVE TIME</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>TOTAL % NONPRODUCTIVE TIME</strong></td>
<td>59</td>
</tr>
<tr>
<td><strong>TOTAL % HUMAN FACTOR TIME</strong></td>
<td>35</td>
</tr>
<tr>
<td><strong>MATERIAL FLOW (% Orders Completed)</strong></td>
<td></td>
</tr>
<tr>
<td>Red Orders</td>
<td>100</td>
</tr>
<tr>
<td>Green Orders</td>
<td>55</td>
</tr>
<tr>
<td>White Orders</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>33</td>
</tr>
<tr>
<td><strong>(% Stows Completed)</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>NUMBER OF TIMES BYPASS LOOP</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CASE NUMBER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NO LOOP</td>
</tr>
<tr>
<td>2</td>
<td>LOOP</td>
</tr>
<tr>
<td>3</td>
<td>+ STOWING OPERATIONS BEING AT 11:00 AM</td>
</tr>
<tr>
<td>4</td>
<td>+ HUMAN STANDARDS REDUCED BY 20 PERCENT</td>
</tr>
<tr>
<td>5</td>
<td>+ NUMBER OF AGVs INCREASED BY 20 PERCENT</td>
</tr>
<tr>
<td>6</td>
<td>+ HUMAN TIME STANDARDS FOR A PAPERLESS ENVIRONMENT</td>
</tr>
</tbody>
</table>
Conclusions

The warehouse simulation model was developed to assist the client in designing one component of a five year modernization plan. The task required that separate models for a storage and retrieval system and a transport system be written and integrated. The model for the storage and retrieval system was written in FORTRAN and simulates an orderpicking (not a unit load) operation. Several unique features were incorporated, including sequencing and batching of orders, variation in the stacking height for each storage level, and movement of S/R machines between aisles.

An AGV transport system model was generated using both FORTRAN functions and SLAM network statements provided in the Material Handling (MH) extension package. The integration of the AGV transport system model and the S/R system model required the use of SLAM II.

The client's overriding concern was to provide customer service. Currently, this concern translates into an operating policy in which the S/R system fills all picking
orders before performing any stows. Meanwhile, the AGV system can pick up material for storage whenever it arrives at the receiving terminal of the warehouse. The simulation of this policy, described in Case 1, indicated that both systems would experience total 'lockup' and fail as all input and output queues became saturated and movement was impossible.

A suggested change to the model was the addition of a loop onto which loaded and blocked AGVs were diverted (Case 2). Although the system operated more smoothly, the S/R system still experienced excessive blockage and the AGVs spent a large percentage of their operating time travelling the loop. By preventing the AGVs from picking up material to be stowed until four and one half hours after the start of the shift (Case 3), the effective utilization of the S/R equipment was increased to more than seventy five percent.

Other scenarios tested included the improvement of human performance standards by 20% (Case 4) and the use of standards for a paperless environment (Case 6). In both of these situations, the AGVs were productive more than seventy-five percent of the time but the S/R machines began to experience excessive blockage in case 6. In Case 5, four more AGVs were added to the transport system. Although the S/R equipment was more fully utilized in this case, AGV productivity suffered.

One hundred percent utilization of the S/R equipment
can never be achieved because of the transient nature of the system. If higher utilization is desired, the client may want to examine the possibility of scheduling multiple or split shifts.

The simulation model and the results of just a few of the hundreds of possible scenarios were presented to the client. It was pointed out that the model would prove useful in several different ways, including but not limited to the following:

1. comparing different equipment proposals
2. testing and debugging of components during construction of the actual warehouse system
3. performing analysis of the system in operation
4. examining other operating strategies.

However, before the model can be fully utilized, accurate estimates on the daily number of transactions must be provided. Also, a detailed study of the appropriate time standards for the proposed person-on-board S/R system should be conducted. This study is especially important since the simulated operation used standards that were developed in 1979 for a fork truck. If the time to perform the manual part of the pick / stow operation remained high, consideration ought to be given to a part-to-man orderpicking system. Currently, the S/R machines are in actual operation (intra-aisle travel, interaisle travel, loading, and unloading) less than fifteen percent of the
time. A part-to-man system would increase machine productivity but not necessarily system productivity, since part-to-man usually requires 2 pick transactions. In this case, consideration must be given to an interleaving policy. Major changes such as the one described, would require modifications to the model.

Use of Model

The development and use of the CAPS simulation model can assess the performance of the system before it is actually constructed. The measure of performance most often selected is for optimization of cost. Perry, Hoover, and Freeman (31) have developed a design aid process for selecting a cost effective system.

The problem is described in a linear programming framework. The goal or objective function is:

Minimize: Dollar Cost

Other selected performance measures are used as constraints for the model as described below:

Subject to: Throughput \( \geq C_1 \)
Hours worked / day \( \geq C_2 \)
Hours worked / day \( \leq C_3 \)
Human idle time \( \leq C_4 \)
S/R utilization \( \geq C_5 \)
AGV utilization time \( \geq C_6 \)
Number of AGVs recycled around the LOOP \( \leq C_7 \)

where: \( C_1 - C_7 \) are upper or lower bounds established by the client.
Since the model is descriptive in nature, there is no algorithmic way to optimize the above formulation. Perry, et.al, have developed the following heuristic procedure to solve the problem.

First, list the design variables that describe the physical configuration of the system and govern the dynamic movement of the components. Many of these variables are constrained by the available equipment options. The system performance is also more sensitive to some design variables than others. It is the latter point which is the key to cost effective system design.

Second, select the operating policies which are used to control the actions of the system for efficient and effective performance. The operating policies have a significant impact on the overall system performance. Both the design variables and operating policies for the initial simulation run are listed in Appendix A.

Third, estimate the initial number of S/R machines, I/O stations and AGVs required for the design of the CAPS system. Perry, et.al. (31), recommend a simple expected value model that uses the 'time in system' values obtained from the trace model in Chapter 4.

The expected value model yields a design balance for the S/R machines and AGVs. The model does not include I&O stations because one of each is specified per aisle; nor does the simple expected model take into consideration the
effects of lotting orders. The model assumes all S/R machines and AGVs are utilized 100% of the time. Obviously, these assumptions are not valid for a real system; However, the initial values do provide a starting point for a detailed simulation. The results of the Perry model for the client problem are listed in Table 23.

TABLE 23
Simple Expected Value Model

<table>
<thead>
<tr>
<th>System</th>
<th>Time</th>
<th>Transactions</th>
<th>Equipment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picks</td>
<td>9.75</td>
<td>660</td>
<td>13.4</td>
</tr>
<tr>
<td>Stows</td>
<td>10.8</td>
<td>150</td>
<td>3.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>810</td>
<td>16.8</td>
</tr>
<tr>
<td>AGVS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picks</td>
<td>9.65</td>
<td>660</td>
<td>13.3</td>
</tr>
<tr>
<td>Stows</td>
<td>22.8</td>
<td>150</td>
<td>7.1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>810</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Fourth, use the expected number of S/R machines, AGVs, the original design variables and operating policies as inputs to the detailed stochastic simulation. If the results of the simulation model meet the constraints listed above, the cost of the system is computed.

Fifth, select the design and operating policy variables to be manipulated. The variables are arranged in order of preference by the client. To simplify the problem a limit on the number of design and operating policy variables should be considered.
Sixth, the second iteration requires the manipulation of the next highest client preference design or operating policy variable. A sensitivity analysis is performed on the variable. If the iteration reduces the system cost the variable is manipulated again (if possible) until a minimum system cost is reached. If the manipulated variable does not reduce system cost the variable is not altered. The iterative process is continued until all the selected design and operating policies have been tested. If the constraints listed above can not be satisfied, attention should be focussed on only the more critical ones.

Seventh, additional iterations require knowledge about the system performance-cost ratios for the components and their interaction before definitive statements can be made about the 'best' system. To design a cost effective system a detailed comprehension of design variables, operating policy variables, and their interaction on system performance is required. This approach could be used with the CAPS system.

Discussion on Programming Language

The Material Handling (MH) extension to SLAM II was extremely useful in modeling the AGVS. The control points, segments of the guidepaths, and the AGV specifications were all input as resource blocks. Logic rules were available to handle contentions at intersections, routing of vehicles,
directional characteristics of the track segments, job requests, vehicle requests, and idle vehicle disposition.

As noted in Chapter 4, the division of time increments (DTMIN = 0.0125 min.) resulted in an average error of 
\[
\frac{(0.5 + 0.5 + 0.1)}{(9.0 + 9.3 + 22.7)} = 0.025 \text{ or } 2.5\%.
\]
The consistently higher SLAM values, in comparison to the calculated time values, were proportionally related to the number of control points crossed. No adjustments were made to correct the error. However, the bias of the error is used to offset the affects of acceleration and deceleration of the time values.

The MH extension is not suitable for modeling storage and retrieval systems and was not used for that portion of the simulation. The MH extension requires at least one crane to be assigned to each aisle and allows only one unit to be transported at a time. Also, each pickup, dropoff, and storage location must be identified by X and Y coordinates in a resource block. Since the MH extension has a limited number of resource blocks, the number of possible locations would be restricted. Because of these constraints, user written FORTRAN routines provide a better model of the storage and retrieval system.

Another drawback to SLAM II involves two of the more commonly utilized user-written functions in the software: USERF and UMONT. SLAM II will not allow routine changes in the filing operation to take place when either of these
functions is used. This limitation made it difficult to take advantage of sorting utilities written in FORTRAN.

SLAM II is inferior in some ways to its offshoot language, SIMAN. Whereas SLAM II requires that all values be entered directly into the network file, SIMAN offers the user the capability to store capacities of resources, distribution parameters, random number seeds and run times in an experimental file for rapid changes in variables. These features allow SIMAN to be more interactive and 'user friendly'.

Recommendations

The current simulation model should be improved in two ways. First, enhancement of the client's understanding of the results of the model executions is needed. An interface or output processor which would automatically produce histograms, bar charts, and trend graphs, and which would store the data in some type of database management system would benefit the client. Animation packages for graphically displaying the model in execution, or which would save the animation file for replay later would assist the client in 'seeing' potential bottlenecks or hangups in the current design.

Another improvement to the model should be to expand the scope of the operating policies under consideration.
Areas that could be explored include:

1. storage assignment policies (2 and 3 based class, and SDF)
2. sequential and batch orderpicking systems
3. interleaving S/R procedures
4. job selection for the S/R machine (FCFS and queue selection)
5. vehicle selection scheme for AGVs (random, longest idle time, longest travel time, and least utilized)
6. contention at AGV intersections (FIFO, closest to point, and priority of load)
7. disposition of idle vehicles
8. location and structure of I/O stations

The client may also wish to consider studying the impact of seasonal changes in demands and the impact machine breakdowns would have on the system. More complex changes would involve incorporating other projects from the 5 Year Modernization Plan, providing other options for interfacing the AGV and S/R systems (a circular conveyor connecting all input stations and another connecting all output stations), allowing a larger queue buildup, or reducing the number of pickup and dropoff points for the AGVs.

Finally, for future models, a better computer file system might be examined. Such a system may reduce the amount of computer storage required and could lead to increased execution time.
Bibliography


37. Sims, R. E. Jr., Planning and Managing Materials Flow, Industrial Education Institute, Boston, Massachusetts, 1968.


APPENDIX A

Input Variables
Input Variables to FORTRAN Subroutine
INTLC, INTLC2 and INTLC3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Location of Each S / R Machine</td>
<td>XX (1 - 31) - aisle location of N S/R machine (refer to array IAISLE (I, J))</td>
<td>---</td>
</tr>
<tr>
<td>Priority of Transactions</td>
<td>XX (32) - priority of a transhipment transaction</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>XX (33) - * red order</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>XX (34) - * green order</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>XX (35) - * white order</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>XX (36) - * stow transaction</td>
<td>5</td>
</tr>
<tr>
<td>Interface Times</td>
<td>XX (37) - unload time for AGVs</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>XX (38) - conveyor time for I / O station</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>XX (39) - load time for AGV</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>XX (40) - unload time for S / R machine</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>XX (41) - load</td>
<td>0.33</td>
</tr>
<tr>
<td>Special Purpose Data</td>
<td>XX (42) - Special Purpose Data (SPD) for bulk stowage operations: Standard 3251 (min / line item)</td>
<td>11.74</td>
</tr>
<tr>
<td></td>
<td>XX (43) - Special Purpose Data for bulk issues Standard 3320 (min / line item)</td>
<td>7.70</td>
</tr>
<tr>
<td>S / R Machine Numbers per Bay (Cumulative)</td>
<td>XX (45) - initialize variable for resources</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>XX (46) - S / R machine numbers in bay 1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>XX (47) - *</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>XX (48) - *</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>XX (49) - *</td>
<td>17</td>
</tr>
<tr>
<td>Aisle Numbers per Bay (Cumulative)</td>
<td>XX (50) - initialize variable for aisles</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>XX (51) - aisle numbers in bay 1</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>XX (52) - *</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>XX (53) - *</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>XX (54) - *</td>
<td>31</td>
</tr>
</tbody>
</table>
S / R Machine Specifications

XX (55) - number of S / R machines 17
XX (56) - horizontal speed of S / R machine 440
XX (57) - vertical acceleration of S / R mach. 60
XX (58) - horizontal acceleration of S / R machine 2
(units - ft/sec)
XX (59) - vertical acceleration of S / R machine 1
(units - ft/sec)
XX (60) - interaisle travel speed fo S / R mach. 88
XX (61) - standard performance time for inter- 5
aisle travel time (units - min.)

Storage Structure Specifications

XX (68) - width per pallet position 4.67
XX (69) - width per aisle 12.59
XX (70) - column location of the P / D station 0
XX (71) - row 1
XX (72) - number of columns per rack 64
XX (73) - levels 10
XX (74) - number of aisles 31

Other Variables

XX (75) - minimum distribution value 1
XX (76) - simulation time to begin filling 390
customer orders

FORTRAN Variables

FLEVEL - height per storage level
/ 2.5, 3.0, 3.0, 3.5, 3.5, 4.0, 4.0, 4.5, 5.0, 5.0 /

IAISLE(I, J) - storage aisle occupied by an
S/R machine
1, 3, 5, 7, 9, 11, 12, 14, 16, 18, 20, 22, 23, 25, 27, 29, 31

PVAL(I) - number of picks per pallet
1, 2, 3, 4, 5, 6, 7, 8

RFX - cumulative probability for each
PVAL (I)
/ 0.42, 0.61, 0.75, 0.83, 0.89, 0.93, 0.95, 1.0 /

Random Seed Value
1 - 358741533
### INPUT VARIABLES FOR SLAM PROGRAM

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Value or Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input / Output Specifications</strong> (RESOURCE statement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAP</td>
<td>number of stations per aisle</td>
<td>3</td>
</tr>
<tr>
<td><strong>AGV Track Layout</strong> (VCPOINT statement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNTNTN</td>
<td>contention rule at intersections</td>
<td>PRIORITY</td>
</tr>
<tr>
<td></td>
<td>(FIRST COME FIRST SERVE, PRIORITY, or USER defined)</td>
<td></td>
</tr>
<tr>
<td>ROUTING</td>
<td>path to be taken by the vehicle</td>
<td>SHORTEST</td>
</tr>
<tr>
<td></td>
<td>(SHORTEST, or USER defined)</td>
<td></td>
</tr>
<tr>
<td><strong>(VSGMENT statement)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEN</td>
<td>length of each track segment between</td>
<td>960</td>
</tr>
<tr>
<td></td>
<td>Parking - Receiving</td>
<td>928</td>
</tr>
<tr>
<td></td>
<td>Receiving - CAPS</td>
<td>390</td>
</tr>
<tr>
<td></td>
<td>CAPS - CAPS</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>CAPS - Shipping</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Shipping - Parking</td>
<td>390</td>
</tr>
<tr>
<td></td>
<td>Parking - Parking</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>CAPS - Parking</td>
<td>15</td>
</tr>
<tr>
<td>TYPE</td>
<td>type of track (UNI or BI directional)</td>
<td>UNI</td>
</tr>
<tr>
<td><strong>AGV Specifications</strong> (VFLEET statement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NVEH</td>
<td>number of vehicles</td>
<td>17</td>
</tr>
<tr>
<td>ESPED</td>
<td>empty speed of vehicles (ft. / min)</td>
<td>120</td>
</tr>
<tr>
<td>LSPD</td>
<td>loaded</td>
<td>80</td>
</tr>
<tr>
<td>ACC</td>
<td>acceleration</td>
<td>--</td>
</tr>
<tr>
<td>DEC</td>
<td>deceleration</td>
<td>--</td>
</tr>
<tr>
<td>BUF</td>
<td>buffer space between vehicles</td>
<td>0</td>
</tr>
<tr>
<td>RJREQ</td>
<td>rule for job request (CLOSEST, PRIORITY, or USER specified)</td>
<td>0</td>
</tr>
<tr>
<td>RIDL</td>
<td>rule for idle vehicles (STOP at last dropoff station, go to PARKING area, travel a predetermined path, or a USER specified rule)</td>
<td>PARKING</td>
</tr>
<tr>
<td><strong>(VWAIT NODE)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVREQ</td>
<td>rule for vehicle request (CLOSEST, PRIORITY, or USER specified)</td>
<td>CLOSEST</td>
</tr>
<tr>
<td>REREL</td>
<td>rule for release of transaction (MATCH, TOP, or USER specified)</td>
<td>TOP</td>
</tr>
</tbody>
</table>
### Transaction Information

**CREATE node**

<table>
<thead>
<tr>
<th>TBC - time between creations</th>
<th>TRANSSHIPMENTS</th>
<th>RED Orders</th>
<th>0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GREEN</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WHITE</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STOWS</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T - time of first creation</th>
<th>TRANSSHIPMENTS</th>
<th>RED Orders</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GREEN</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WHITE</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STOWS</td>
<td>450.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MC - maximum number of creations</th>
<th>TRANSSHIPMENTS</th>
<th>RED Orders</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GREEN</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WHITE</td>
<td>396</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STOWS</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

**ASSIGN NODE**

<table>
<thead>
<tr>
<th>ATRIB (3) - assigned aisle number</th>
<th>DISTRIBUTION</th>
<th>UNIFORM (1,31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATRIB (5) - size of lot</td>
<td></td>
<td>DPROB(PX,PVAL)</td>
</tr>
<tr>
<td>ATRIB (6) - column location of item</td>
<td></td>
<td>UNIFORM (1,64)</td>
</tr>
<tr>
<td>ATRIB (8) - level location of item</td>
<td></td>
<td>UNIFORM (1,10)</td>
</tr>
<tr>
<td>ATRIB (9) - control point or</td>
<td></td>
<td>USER Specified</td>
</tr>
<tr>
<td>destination of AGV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Random Seeds**

| 2     | 527371189 |
| 3     | 52980039  |
| 4     | 87504891  |
| 5     | 933757703 |
| 6     | 1438965723|
| 7     | 1510412679|

**Units**

- all times in minutes
- distances in feet

Unless otherwise indicated
USER WRITTEN OPERATING POLICIES

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORT</td>
<td>The customer orders are sequenced by priority, aisle, column, and row. If the column is odd the column is sorted in ascending order, and if the column is even the row is sorted in descending order.</td>
</tr>
<tr>
<td>LOT</td>
<td>The customer orders are lotted by a user defined distribution. The operating times of the S / R machine are computed and the Standard Performance Data is added to each lot.</td>
</tr>
<tr>
<td>ALLOC</td>
<td>When a transaction arrives or when an S / R machine becomes available, this subroutine allocates an S / R machine if possible. A transaction is selected by priority. An S / R machine is allocated by a closest rule. Only one S / R machine is permitted in a aisle at a time.</td>
</tr>
</tbody>
</table>
APPENDIX B

Flow Charts
Main Program

* Dimension the *
* SLAM storage *
* arrays *
* *******************
 *
* V *
* *******************
 *
* Specify SLAM *
* variables *
* *
* *******************
 *
* V *
* *******************
 *
* Call SLAM exec-* *
* utive control *
* program *
* *******************
 *
* V *
* ************
 *
* Stop *
* *
* ************
Subroutine INTLC

*************************************************************************
* Input User distribution: no. of picks/pallet *
*************************************************************************

V
*************************************************************************
* Initialize the user distribution array *
*************************************************************************

V
*************************************************************************
* Prioritize the various transactions *
*************************************************************************

V
*************************************************************************
* Input the standard performance data *
*************************************************************************

V
*************************************************************************
* Specify the beginning of day shift *
*************************************************************************

V
*************************************************************************
* Call Subroutine INTLC2 *
*************************************************************************

V
Call Subroutine INTLC3

***************
V
***************
* Return *
***************

***************
Subroutine INTLC2

************************
* Input User distribution: stack heights/level *
************************

V
************************
* Initialize the user distribution array *
************************

V
************************
* Input aisle number per bay *
************************

V
************************
* Input storage structure specifications *
************************

V
************************
* Initialize minimum distribution value *
************************

V
************************
* Initialize maximum distribution values *
************************

V
************************
* Return *
************************
Subroutine INTLC3

*******************
* Initialize *
* array *
* IAISLE (I, J) *
*******************

V

*******************
* Input S / R *
* Machine *
* Specifications *
*******************

V

*******************
* Input S / R *
* machine numbers *
* per bay *
*******************

V

*******************
* Calculate the *
* accelerations *
* for S/R machine *
*******************

V

*******************
* Input *
* AGV *
* specifications *
*******************

V

*******************
* Call *
* Subroutine *
* SCHEDI *
*******************

V

*******************
* Return *
*******************
Subroutine SCHEDI

*******************
* Initialize *
* variables *
*
*******************

.....................

V

*******************
* Initialize the *
* location of *
* S / R machines *

V

* If *
* all S / R * NO *
* machines been *
* scheduled? *

* YES

V

*************
* *
* Return *
* *
*************
Subroutine EVENT

* * * *******************
* * I equals 1 **********>
* * then * 
* * * 
* * NO 
* *
* * *******************
* * If * YES *
* I equals 2 **********>
* * then * 
* * * 
* * NO 
* *
* * *******************
* * Else Print *
* Error in Sub-
* routine EVENT *
* *******************
* 
* *
* Return *
* *
* *******************
Subroutine SORT

* * If * file 1 * YES * YES *
* * is empty * then * Return *
* * * * *
* * NO *
* * *

*************
* Call SLAM *
* subroutine *
* COPY *
*************

*************>

*************
* Copy 1st (MMFE) *
* entity into *
* buffer array *
*************

*************>

*************
* CALL SLAM *
* function *
* NSUCR *
*************

*************>

*************
* Read *
* attributes of *
* next entity *
*************

*************>

*************
* Sequence *
* customer orders *
* by priority *
*************

*************>
* ******************************
* Sequence *
* by *
* aisle *
* ******************************
* ~
* V
* ******************************
* Sequence *
* by *
* column *
* ******************************
* ~
* V
* *
* * If *
* column * YES * Sequence level *
* no. is even ************> * by descending *
* then ** *
* *
* * NO *
* ~
* V
* *
* Sequence level *
* by ascending *
* order *
* *
* Call SLAM *
* Subroutine *
* ULINK *
* *
* ~
* V
* *
* Unlink *
* entity from *
* file 1 *
* *
* ~
* V
* Call SLAM subroutine LINK
* V
* Link entity to file 3
* V
* CALL SLAM subroutine COPY
* V
* Copy next entity into buffer array
* V
* If no more entities in file 1 then
* NO

**************
YES
**************

**********

**********
Subroutine LOT

* If file 3 is empty then
  * Return
  *
************>

************>

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************>
Compute pick time

Read next order in file 3

If order has different priority then

If order has different lot aisle no. then

NO

If picking lot complete? then

YES

Write lot size in ATRIB (5)
* ********************
*  Write pick       *
*  time for lot     *
*  in ATRIB (4)     *
*  ********************
* ^
* V
* *
*   NO      * If all *
* ******(****  orders been  *
*        * filled?  *
*        *   *
*     * Yes
* V
*  **********
*   *
*  Return *
*   *
*  **********
Subroutine PICK

*****************************
* Initialize *
* time *
* variable *
*****************************

V

*****************************
* Pick up pallet *
* at Input *
* station *
*****************************

********>********

V

*****************************
* Travel to *
* next storage *
* location *
*****************************

V

*****************************
* Call subroutine *
* SRMACH *
*****************************

V

*****************************
* Add Standard *
* Performance *
* Data *
*****************************

V

V

NO  Is the *
***<**** picking lot *
* complete? *
*   *
* YES
************
* Return to *
* Input *
* station *
************

V

************
* *
* Call subroutine *
* SRMACH *
************

V

************
* *
* Return *
* *
************
Function USERF

* If I equals 1 then
  YES
  Initialize time variable
  Pick up item at Input station
  Travel to storage location
  Call subroutine SRMACH
  Add Standard Performance Data

*
* Return to *
  * Input *
  * station *
* ***************

* V *
* ***************
  * *
  * Return *
  * *
* ***************
Subroutine SRMACH

***************
* Initialize *
* time *
* variable *
***************

V

***************
* Calculate the *
* horizontal *
* travel time *
***************

V

***************
* Calculate the *
* vertical *
* travel time *
***************

V

***************
* Select the *
* maximum *
* time value *
***************

V

***************
* Return *
***************
Subroutine ALLOC

* Initialize the aisle numbers per Bay

* Initialize the S/R machine numbers per Bay

* Allocation is for what Bay number?

* If Bay number is exceeded then
  * NO

* If a S/R machine is available then
  * YES

* If a trans- action is waiting then
  * YES
*** Allocation is for what Aisle number? ***

V

* If *

NO * no trans- *

******<***** action is *

* waiting *

* then *

* YES

V

V

* If *

* no S / R *

YES * Print Error *

* machine is available *

* then *

* NO

V

V

* If *

* S / R *

YES * Print Error *

* machine is busy *

* then *

* NO

V

V

* Call *

* Subroutine *MNILL*

* *

***************

V

V
* If no S/R YES Call Subroutine TRANS *
* machine is available then *
  * v NO *
  *
* If S/R YES machine is busy then *
  * * *
  *
* NO *

Call Subroutine STRANS *

Set IFLAG equal to IFLAG *

Return
Subroutine MNILL

***************************************************************************
* Initialize the *
* S / R machine *
* number *
***************************************************************************
* V
***************************************************************************
* Initialize the *
* aisle numbers *
* per Bay *
***************************************************************************
* V

* If *
* Bay * YES * Print Error *
* number *********** in Subroutine *
* exceeded * * MNILL *
* then *
* NO

V
***************************************************************************
* Check first *
* aisle to the *
* left *
***************************************************************************

***********************************************************************
* V
* *
* If *
* aisle num- * YES
* ber is less than ***********
* bay number *
* then *
* *
* NO
* V

* If *
* aisle * YES
* is occu- ***********
* pied *
* then *
* *
* NO
* V
* * * * *
* If *
* trans- * NO
* action is * **********
* waiting * *
* then *
* *
* YES V V V V
* V
* *******************
* Call *
* Subroutine *
* STRANS *
* *******************
* V V V V
* *
* If *
* higher pri-** NO
* ority transaction**********)
* is waiting *
* then *
* *
* YES *
* V V V V
* *******************
* Assign S / R *
* machine number *
* to ATRIB (10) *
* *******************
* *
* V V V V
* *******************
* Select *
* transaction *
* *
* *******************
* *
* V V V V
* *******************
* Compute *
* interaisele *
* travel time *
* *******************
* *
* V V V V
* Add travel time to ATRIB (4) *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]

* Reassign values *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]

* Set IFLAG equal to +1 *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]

* Return *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]

* Check aisle to the right *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]

* If * aisle number * YES * bay number * then *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]

* NO *

\[
\begin{array}{cccccc}
& V & V & V & V & V \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
V & * & * & * & * & * \\
\end{array}
\]
* If aisle * YES
* is occupied * """
* then *
* NO
* V
* *
* * If * trans-
* * action is * NO
* * waiting * """
* * then *
* * YES
* V
* *
* Call *
* Subroutine *
* STRANS *
* *
* V
* *
* If * 
* * higher priority transaction * NO
* * is waiting * """
* * then *
* * YES
* V
* *
* Assign S / R *
* machine number *
* to ATRIB (10) *
* *
* V
* *
* Select *
* transaction *
* *
* V
Compute interaisle travel time

\[ V \]

Add travel time to ATRIB (4)

\[ V \]

Reassign IAISLE (I,J) values

\[ V \]

Set IFLAG equal to time + 1

\[ V \]

Return

\[ V \]

If all aisles have been tested?

\[ V \]

If YES has S/R machine is assigned

\[ V \]

If NO
* Check next aisle
* * *********
* V
*****<**********

* Set IFLAG equal to 0
* *
* V
**********
* *
* Return *
* *
**********
Subroutine TRANS

**************************************************************************
* Call *
* Subroutine *
* STRANS *
**************************************************************************

**************************************************************************
* Check *
* IFLAG *
**************************************************************************

**************************************************************************
* YES *
**************************************************************************

**************************************************************************
* If *
* higher priority transaction exceeds NO machine *
* is waiting * *
* then *

**************************************************************************
* YES *
**************************************************************************

**************************************************************************
* Initialize *
* aisle *
* number *
**************************************************************************

**************************************************************************
* YES *
**************************************************************************

**************************************************************************
* Initialize the *
* aisle numbers *
* by Bay *
**************************************************************************

**************************************************************************
* YES *
**************************************************************************

**************************************************************************
* Bay number exceedsBay exceeding number in Subroutine *
* then *

**************************************************************************
* NO *
**************************************************************************
* Check first aisle to the left

* If aisle number is less than bay number then
  * NO
  * V
  * If aisle is occupied then
    * YES V V
  * Initialize the S/R machine number
    * V V V
  * If S/R machine is idle then
    * YES V V V
  * Assign S/R machine number to ATRIB (10)
    * V V V V
Select transaction

Compute interaisle travel time

Add travel time to ATRIB (4)

Reassign IAISLE (I,J) values

Set IFLAG equal to + 1

Return

Check aisle to the right

V

V

V

V

V

V

V

V

V

V

V

V

V
* * * * * If * aisle number * YES
  * ber exceeds the bay number *
  * then *
  * * NO
  * V
  * *
  * If * aisle * NO
  * is occupied *
  * then *
  * *
  * YES
  * V
  * Initialize *
  * the S / R machine number *
  * ***************
  * * V V V
  * *
  * If * S / R * NO
  * machine is idle *
  * then *
  * *
  * YES
  * V
  * Assign S / R machine number * to ATRIB (10) *
  * ***************
  * * V V V
  * *
  * Select * transaction *
  * ***************
  * * V V V
Compute interaisle travel time

V

Add travel time to ATRIB (4)

V

Reassign IAISLE (I,J) values

V

Set IFLAG equal to + 1

V

If all aisles YES No S / R

have been tested?

* * *
* Check next aisle
* *
* V

**********

* Set IFLAG equal to 0
* *
* V

**********
Subroutine STRANS

*******************
* Initialize the *
* S / R machine *
* number *
*******************

V

*******************
* Initialize the *
* aisle numbers *
* per Bay *
*******************

V

*******************
* Initialize var-* *
* iables with buf-* *
* fer attributes *
*******************

V

* If *
* Bay *
* YES *
* number *
* exceeded *
* then *
* NO *

V

*******************
* Initialize var-* *
* iables with buf-* *
* fer attributes *
*******************

V

*******************
* Check first *
* aisle to the *
* left *
*******************

V
If aisle number is less than bay number then

* NO

V

If aisle is occupied then

* NO

V

If transaction is waiting then

* YES

V

Read priority of transaction

V

If higher priority transaction then

* YES

V

* No S / R

* machine is assigned

* YES

V

* V

* V

* V

* V
*  Set IFLAG  *
*  equal to  *
*   0      *

***************

*  V  V  V  V  V  *

***************

*  *

*  Return *
*  *

***************

*  *

***************

*  *

***************************************************

*  V  *

***************

*  Check aisle  *
*  to the      *
*  right      *

***************

*  *

*  V  *

*  *

*  If  *
*  *
*  aisle number  YES
*  ber exceeds the
*  bay number *
*  then *
*  *
*  NO  *

*  *

*  If  *
*  *
*  aisle  YES
*  is occu-
*  pied  *
*  then *
*  *
*  NO  *

*  *

*  If  *
*  *
*  transac-
*  tion is  NO
*  waiting *
*  then *
*  *
*  YES  *

*  *

V  V  V  V
*     Check     *
*     next     *
*     aisle    *
*     **********
*   V
*****<**********

*     Select     *
*     transaction     *
*     **********
*     V
**********
*     Set IFLAG     *
*     equal to     *
*     + 1     *
**********
*     V
**********
*     *
*     Return     *
*     *
**********
SLAM Control Statements

******************************************************************************
* Input general
* information
* for simulation
******************************************************************************
*
V
******************************************************************************
* Specify maximum
* no. of files,
* entities, etc.
******************************************************************************
*
V
******************************************************************************
* Clear statistic-
* al arrays begin-
* ning day shift
******************************************************************************
*
V
******************************************************************************
* Turn on
* SLAM
* trace
******************************************************************************
*
V
******************************************************************************
* Turn on
* AGVS
* trace
******************************************************************************
*
V
******************************************************************************
* Collect stats
* on time persis-
* tent variables
******************************************************************************
*
V
* Specify ranking of entities for each file *

* Enter step size information for AGVS *

* Enter network statements *

* Specify start and end time for simulation *

* Return *

*
Submodel Identify Resources

***************
* Identify *
* S / R *
* Machines *
***************
*
V
***************
* Identify *
* Input *
* Stations *
***************
*
V
***************
* Identify *
* Output *
* Stations *
***************
*
V
***************
* Identify *
* Control Points *
* for AGVS *
***************
*
V
***************
* Identify track *
* segments for *
* AGVS *
***************
*
V
***************
* Input *
* AGVS *
* specifications *
***************
Submodel Control Clock

* Accept customer *
* orders for the *
* next day's work *

* Stop accepting *
* orders for the *
* next day's work *
Submodel Schedule Events

*******************
* Sort orders *
* at beginning *
* of day shift *
*******************

V

*******************
* Lot orders *
* at beginning *
* of day shift *
*******************
Submodel AGVS

* Create * stow * transactions *

* V

* Assign * starting time * to ATRIB (1) *

* V

* Assign * priority number * to ATRIB (2) *

* V

* Assign aisle * number to * ATRIB (3) *

* V

* Assign lot * size to * ATRIB (5) *

* V

* Assign column * number to * ATRIB (6) *

* V

* Assign * type to * ATRIB (7) *
* Compute operating time for S/R machine

* Call USERF function

* Assign USERF value to ATRIB(4)

* Assign level number to ATRIB(8)

* Assign AGV destination to ATRIB(9)

* Hold stow pallets at receiving area

* Schedule idle AGVs by RIDL rule
* Select * transaction by * RJREQ rule *

* V *

* Load pallet * onto * AGV vehicle *

* V *

* Release *
* station *

* V *

* Transport *
* pallet *

* V *

* Select *
* dropoff *
* station *

* V *

* If * YES *
* transaction *
* is pick *
* then *

* NO *

* Submodel *

* Collect *

* Statistics *

* V
* If station is full then
*                  ***********
* Send AGV vehicle in LOOP
*                  ***********
*
* NO
*
**************************
* Unload pallet from AGV
**************************
*
**************************
* Release AGV
**************************
*
**************************
* Advance pallet at station
**************************
*
**************************
* Submodel S/R system
**************************
Submodel S/R System

* Create *
* "red" *
* orders *

***************

* V
* Assign priority to *
* ATRIB(2) *

***************

* V
* Assign *
* type to *
* ATRIB(7) *

***************

* V
* Assign starting *
* time to *
* ATRIB(1) *

***************

* V
* Assign aisle *
* number to *
* ATRIB(3) *

***************

* V
* Assign column *
* number to *
* ATRIB(6) *

***************

* V
* Assign priority to *
* ATRIB(2) *

***************

* V
* Assign *
* type to *
* ATRIB(7) *

***************

* V
* Assign starting *
* time to *
* ATRIB(1) *

***************

* V
* Assign aisle *
* number to *
* ATRIB(3) *

***************

* V
* Assign column *
* number to *
* ATRIB(6) *

***************

* V
* Assign priority to *
* ATRIB(2) *

***************

* V
* Assign *
* type to *
* ATRIB(7) *
* Assign level number to ATRIB (8)

* Assign AGV destination to ATRIB (9)

* Hold orders in File 1 until day shift

* Sequence by Submodel Schedule Events

* Release orders with Submodel Control Clock

* Open File 8

* BATCH orders using ATRIB(5) value

* Submodel AGVS

* V V
* Separate orders by aisle number
* Hold stow pallets at Input Stations
* V
* V
* Schedule idle S/R machines by Subroutine ALLOC
* V
* V
* Select transaction by priority
* V
* If YES transaction is stow then
* V
* NO
* V
* Perform pick operation
* V
* Select Output station
* V
* Load pallet onto S/R machine
* V
* Release Input station
* V
* Perform stow operation
* V
Submodel * Collect * Statistics *

V

***************(*************
V

*
* If *
* station * YES *
* is full **********>* S/R machine *
* then *
* *

*
* NO
V

***************
* Unload *
* S / R *
* machine *
***************

V

***************
* Release *
* S / R *
* machine *
***************

V

***************
* Advance *
* pallet at *
* station *
***************

V

***************
* Submodel *
* AGVS *
* system *
***************
Submodel Collect Statistics

******************************************************************************
* Determine *
* transaction *
* type *
******************************************************************************
* V *
* *
* If *
* transaction is a YES stow *
* then *
* *
* NO *
* *
******************************************************************************
* Unload *
* pallet from *
* AGV *
******************************************************************************
* *
******************************************************************************
* Release *
* AGV *
******************************************************************************
* *
******************************************************************************
* Collect *
* statistics *
******************************************************************************
* *
******************************************************************************
* Create *
* histogram *
******************************************************************************
* *
******************************************************************************
* Terminate *
* transaction *
******************************************************************************
************************
* Terminate            *
* transaction          *
*                      *
************************
APPENDIX C

Program Listings
THIS IS THE MAIN PROGRAM. THIS PROGRAM ALLOWS THE USER TO DIMENSION THE SLAM STORAGE ARRAYS NSET AND QSET WITHOUT THE NEED TO RECOMPILE THE SLAM EXECUTIVE CONTROL PROGRAM. THE FOLLOWING STATEMENTS ARE AFFECTED:

```
DIMENSION NSET (******)
COMMON QSET (******)
NSET = ******
```

```
DIMENSION NSET(75000)
COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II *, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE *, SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON QSET(75000)
EQUIVALENCE (NSET(1),QSET(1))
NSET=75000
NCRDR=5
NPRNT=6
NTAPE=7
CALL SLAM
STOP
END
```
SUBROUTINE INTLC

THIS SUBROUTINE ALLOWS THE USER TO:

1) SET INITIAL CONDITIONS
2) AND, SCHEDULE INITIAL EVENTS.

SLAM VARIABLES

PRIORITY OF TRANSACTIONS
XX (32) - PRIORITY OF A TRANSHIPMENT TRANSACTION
XX (33) - RED ORDER
XX (34) - GREEN ORDER
XX (35) - WHITE ORDER
XX (36) - STOW TRANSACTION

SPECIAL PURPOSE DATA
XX (42) - SPECIAL PURPOSE DATA (SPD) FOR BULK STOWAGE OPERATIONS: STANDARD 3251 (MIN / LINE ITEM)
XX (43) - SPECIAL PURPOSE DATA FOR BULK ISSUES STANDARD 3320 (MIN / LINE ITEM)

OTHER VARIABLES
XX (76) - SIMULATION TIME TO BEGIN FILLING CUSTOMER ORDERS

FORTRAN VARIABLES
PVAL(I) - NUMBER OF PICKS PER PALLET
PX(I) - CUMULATIVE PROBABILITY FOR EACH PVAL(I)

UNITS
- ALL TIMES IN MINUTES
- DISTANCES IN FEET

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II *, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNS, NTAPE *
SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON/UCOM1/ HLEVEL (50), PVAL (10), PX (10)
REAL RFX(8), FLEVEL(10)

SET INITIAL CONDITIONS

CUMULATIVE PROBABILITIES FOR EACH PVAL (I)
DATA RFX / .42, .61, .75, .83, .89, .93, .95, 1. /

INITIALIZE ARRAY PX(I) WITH THE CUMULATIVE PROBABILITIES EACH PVAL(I)
DO 10 I = 1, 8
PX(I) = RFX(I)
PVAL(I) = I * 1.0
10 CONTINUE
C
C PRIORITY OF TRANSACTIONS
  XX (32) = 1
  XX (33) = 2
  XX (34) = 3
  XX (35) = 4
  XX (36) = 5
C
C STANDARD PERFORMANCE DATA
  XX (42) = 14.57
  XX (43) = 7.70
C
C OTHER VARIABLES
  XX (76) = 390
C
C CALL SUBROUTINE TO INITIALIZE STORAGE
C STRUCTURE SPECIFICATIONS
  CALL INTLC2
C
C CALL SUBROUTINE TO INITIALIZE S / R
C AND AGV's SPECIFICATIONS
  CALL INTLC3
C
RETURN
END
SUBROUTINE INTLC2

THIS SUBROUTINE INITIALIZES THE STORAGE STRUCTURE SPECIFICATIONS

SLAM VARIABLES

AISLE NUMBERS PER BAY
XX (50) - INITIALIZE VARIABLE FOR AISLES
XX (51) - AISLE NUMBERS IN BAY 1
XX (52) - 2
XX (53) - 3
XX (54) - 4

STORAGE STRUCTURE SPECIFICATIONS

XX (68) - WIDTH PER PALLET POSITION
XX (69) - WIDTH PER AISLE
XX (70) - COLUMN LOCATION OF THE P / D STATION
XX (71) - ROW
XX (72) - NUMBER OF COLUMNS PER RACK
XX (73) - ROWS
XX (74) - NUMBER OF AISLES

OTHER VARIABLES

XX (75) - MINIMUM DISTRIBUTION VALUE

FORTRAN VARIABLES

HLEVEL(NROW) - HEIGHT PER STORAGE LEVEL

UNITS

- ALL TIMES IN MINUTES
- DISTANCES IN FEET

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II *
*, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE *
*, SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON/UCOM1/ HLEVEL (50), PVAL (10), PX (10)
REAL RFX(8), FLEVEL(10)

SET INITIAL CONDITIONS

HEIGHT PER STORAGE LEVEL
DATA FLEVEL /2.5,3.0,3.0,3.5,3.5,4.0,4.0,4.5,5.0,5.0/

initialize array HLEVEL(I)
DO 10 I = 1, 10
HLEVEL(I) = FLEVEL(I)
10 CONTINUE
C AISLE NUMBER / BAY
XX (50) = 0
XX (51) = 9
XX (52) = 18
XX (53) = 27
XX (54) = 31

C STORAGE STRUCTURE SPECIFICATIONS
XX (68) = 4.67
XX (69) = 12.59
XX (70) = 0
XX (71) = 1
XX (72) = 64
XX (73) = 10
XX (74) = 31

C MINIMUM DISTRIBUTION VALUE
XX (75) = 1

C MAXIMUM DISTRIBUTION VALUES
XX (72) = XX (72) + 1
XX (73) = XX (73) + 1
XX (74) = XX (74) + 1

C RETURN
END
SUBROUTINE INTLC3

C THIS SUBROUTINE INITIALIZES THE VARIABLES FOR THE C S / R MACHINES AND THE AGV's. ARRAY IAISLE (I, J) C IS ALSO INITIALIZED C

C SLAM VARIABLES C

C INTERFACE TIMES C

C XX (37) - UNLOAD TIME FOR AGV C
C XX (38) - CONVEYOR TIME FOR I / O STATION C
C XX (39) - LOAD TIME FOR AGV C
C XX (40) - UNLOAD TIME FOR S / R MACHINE C
C XX (41) - LOAD ' C
C
C XX (45) - INITIALIZE VARIABLE FOR RESOURCES C
C XX (46) - S / R MACHINE NUMBERS IN BAY 1 C
C XX (47) - ' 2 C
C XX (48) - ' 3 C
C XX (49) - ' 4 C

C FORTRAN VARIABLES C
C IAISLE(I, J) - STORAGE AISLE OCCUPIED BY AN C S/R MACHINE C

C UNITS C
C - ALL TIMES IN MINUTES C
C - DISTANCES IN FEET C
C NOTE: UNLESS OTHERWISE INDICATED C

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II * , MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE * , SS(100), SSL(100), TNEXT, TNOW, XX(200) 
COMMON/UCOM3/ IAISLE(31, 2)

C SET INITIAL CONDITIONS C
C INITIALIZE ARRAY IAISLE (I, J) FOR SCHEDULING
C S / R MACHINES
   DO 10 I = 1, 31
      IAISLE (I, 1) = I
      IAISLE (I, 2) = 0
10 CONTINUE
C C S / R SPECIFICATIONS
  XX (40) = 0.33
  XX (41) = 0.33
  XX (55) = 17
  XX (56) = 440
  XX (57) = 60
  XX (58) = 2
  XX (59) = 1
  XX (60) = 88
  XX (61) = 5
C C S / R MACHINE NUMBER / BAY
  XX (45) = 0
  XX (46) = 5
  XX (47) = 10
  XX (48) = 15
  XX (49) = 17
C C CALCULATING THE ACCELERATION RATES FOR
C THE S / R MACHINE
  XX (58) = XX (58) * 60. * 60.
  XX (59) = XX (59) * 60. * 60.
C C AGV SPECIFICATIONS (NOTE: MOST SPECIFICATIONS FOR
C AGVS ARE DIRECTLY ASSIGNED IN THE SLAM PROGRAM)
  XX (37) = 0.5
  XX (39) = 0.5
C C DELAY TIME FOR THE I / O STATIONS
  XX (38) = 0.33
C C SUBROUTINE SCHEDI ASSIGNS THE LOCATION OF THE
C S / R MACHINE AT THE BEGINNING OF THE SHIFT
C CALL SCHEDI
C
RETURN
END
SUBROUTINE SCHEDI

THIS SUBROUTINE SCHEDULES THE LOCATION OF EACH S / R MACHINE AT THE BEGINNING OF THE SHIFT

SLAM VARIABLES

S / R SPECIFICATIONS

XX (55) - NUMBER OF S / R MACHINES

FORTRAN VARIABLES

IAISLE(I, J) - STORAGE AISLE OCCUPIED BY AN S/R MACHINE

INITIALIZE VARIABLE

NSRM = XX (55)

IF ( XX (55) .GT. XX (74)) THEN
    PRINT *, ' ***ERROR IN INTLC SUBROUTINE*** ONLY '
    PRINT *, ' ONE S / R MACHINE PER AISLE PERMITTED '
ENDIF

DO 10 I = 1, NSRM
    II = INT (XX (74) / ISRM * I)
    IAISLE (II, 2) = I
    WRITE (6,100) I, II
10 FORMAT (' MACHINE NO. ', I5 , ' AISLE NO. ',I5)

RETURN
END
SUBROUTINE EVENT(I)

THIS SUBROUTINE PROVIDES THE INTERFACE BETWEEN SLAM AND THE USER WRITTEN SUBROUTINES. THIS SUBROUTINE IS USED FOR:

1) ALTERING THE VALUE OF ONE OR MORE VARIABLES ASSOCIATED WITH THE SIMULATION.
2) ALTERING THE NUMBER OF ENTITIES PRESENT IN THE SYSTEM.
3) ALTERING THE VALUES ASSIGNED TO ONE OR MORE ATTRIBUTES OF AN ENTITY.
4) AND, ALTERING THE RELATIONSHIPS THAT EXIST AMONG ENTITIES THROUGH FILE MANIPULATIONS.

THE EVENT SUBROUTINE IS USED WHEN BLOCKS ARE UNABLE TO DESCRIBE ACCURATELY CHANGES IN THE SYSTEM.

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II *, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE *, SS(100), SSL(100), TNEXT, TNOW, XX(200)

IF (I .EQ. 1) THEN
CALL SUBROUTINE TO 'SORT' CUSTOMER ORDERS
CALL SORT
ELSE IF (I .EQ. 2) THEN
CALL SUBROUTINE TO 'LOT' CUSTOMER ORDERS
CALL LOT
ELSE
PRINT *, '***ERROR IN EVENT SUBROUTINE***'
PRINT *, 'NO SUCH EVENT'
ENDIF

RETURN
END
SUBROUTINE SORT

THIS SUBROUTINE SORTS THE CUSTOMER ORDERS BY:
- PRIORITY, AISLE, COLUMN, AND ROW. IF THE COLUMN
IS ODD THE ROW IS SORTED IN ASCENDING ORDER, AND
IF THE COLUMN IS EVEN THE ROW IS SORTED IN
DESCENDING ORDER.

SLAM VARIABLES:
- ATRIB (2) - PRIORITY OF TRANSACTION
- ATRIB (3) - ASSIGNED AISLE NUMBER
- ATRIB (6) - COLUMN LOCATION OF ITEM
- ATRIB (8) - LEVEL LOCATION OF ITEM
- QSET (I) - SLAM FILE STORAGE ARRAY

FORTRAN VARIABLE:
- CLMN - COLUMN NUMBER

THE NUMBER OF CUSTOMER ORDERS WAITING TO BE FILLED
INNQ = NNQ (1)

IF ZERO THEN RETURN
IF (INNQ .LE. 0) THEN
RETURN
ELSE IF (INNQ .EQ. 1) THEN
GOTO 20
ELSE
PRINT *, 'MORE THAN ONE CUSTOMER ORDER'
ENDIF

SORTING THE CUSTOMER ORDERS
DO 30 I = 1, INNQ
READ THE FIRST ORDER
NINQ = NNQ (1)
NTRY = MMFE (1)
IF (NINQ .EQ. 1) THEN
GO TO 20
ENDIF
C READ THE NEXT ORDER
NEXT = NTRY
CALL COPY (-NTRY, 1, ATRIB)

DO 20 J = 1, NINQ - 1

NATRB2 = ATRIB (2)
NATRB3 = ATRIB (3)
NATRB6 = ATRIB (6)
NATRB8 = ATRIB (8)

NEXT = NSUCR (NEXT)

ATRIB2 = QSET (NEXT + 2)
ATRIB3 = QSET (NEXT + 3)
ATRIB6 = QSET (NEXT + 6)
ATRIB8 = QSET (NEXT + 8)

CLMN = 2 * (ATRIB6 / 2)

COMPARE THE TWO CUSTOMER ORDERS
BY PRIORITY

IF (ATRIB2 .GT. NATRB2) THEN
    GOTO 20
ELSE IF (ATRIB2 .EQ. NATRB2) THEN

BY AISLE

IF (ATRIB3 .GT. NATRB3) THEN
    GOTO 10
ELSE IF (ATRIB3 .EQ. NATRB3) THEN

BY COLUMN

IF (ATRIB6 .GT. NATRB6) THEN
    GOTO 10
ELSE IF (ATRIB6 .EQ. NATRB6) THEN

BY ROW

IF ROW IS ODD, BY ASCENDING ORDER

IF ((ATRIB8 .GE. NATRB8).AND.
    * (ATRIB6 .NE. CLMN)) THEN
    GOTO 10
ENDIF
C IF ROW IS EVEN, BY DESCENDING ORDER
C
IF (((ATRIB8 .LE. NATRB8).AND.
    (ATRIB6 .EQ. CLMN)) THEN
  GOTO 10
ENDIF
ENDIF
ELSE IF (ATRIB2 .LE. NATRB2) THEN
  PRINT *, '***ERROR SORT SUBROUTINE***'
  PRINT *, 'ATTRIBUTES NOT IN AGREEMENT'
ENDIF
C
NTRY = NEXT
CALL COPY(-NTRY, 1, ATRIB)
C
10 CONTINUE
20 CONTINUE
C IF SECOND ORDER SHOULD BE PICKED BEFORE FIRST
C THEN PLACE AHEAD OF FIRST ORDER
C
CALL ULINK (-NTRY, 1)
CALL LINK (8)
C
WRITE (6,100) NATRB2, NATRB3, NATRB6, NATRB8
100 FORMAT(4 (5X, I8))
C
NINQ = NNQ (1)
C
30 CONTINUE
C
RETURN
END
SUBROUTINE LOT

THIS SUBROUTINE LOTS THE ENTITIES BY A USER DEFINED DISTRIBUTION AND THEN COMPUTES THE OPERATING TIMES FOR THE S/R MACHINE TO RETRIEVE A LOT OR BATCH THE CUSTOMER ORDERS

SLAM VARIABLES:
- ATRIB (6) - COLUMN LOCATION OF ITEM
- ATRIB (8) - LEVEL LOCATION OF ITEM
- XX (70) - COLUMN LOCATION OF THE P/D STATION
- XX (71) - ROW
- QSET (I) - SLAM FILE STORAGE ARRAY

FORTRAN VARIABLE:
- PVAL(I) - NUMBER OF PICKS PER PALLET
- PX(I) - CUMULATIVE PROBABILITY FOR EACH PVAL(I)
- BTCHSZ - NUMBER OF CUSTOMER ORDERS IN A LOT

INITIALIZE VARIABLES
- ATRIB6 = XX (70)
- ATRIB7 = XX (70)
- ATRIB8 = XX (71)
- ATRIB9 = XX (71)

THE NUMBER OF CUSTOMER ORDERS TO BE LOTTED
- NINQ = NNQ (8)

IF ZERO, NO LOTTING REQUIRED
- IF (NINQ .EQ. 0) THEN
  - GOTO 40
ENDIF

OTHERWISE READ FIRST ORDER
- NTRY = MMFE (8)
- NEXT = NTRY
10 CONTINUE
C
C INITIALIZE MORE VARIABLES
NBCHSZ = 0
SUMT = 0.0
ATRIB7 = ATRIB6
ATRIB9 = ATRIB8
C
C READ PRIORITY AND AISLE OF CUSTOMER ORDER
NTRIB2 = QSET (NTRY + 2)
NTRIB3 = QSET (NTRY + 3)
C
C LOT ORDERS BY A USER DEFINED DISTRIBUTION
C
BTCHSZ = DPROB (PX, PVAL, 10, 1)
C
DO 20 I = 1, BTCHSZ
C
C READ PRIORITY AND AISLE NUMBER OF NEXT CUSTOMER ORDER
ATRIB2 = QSET (NEXT + 2)
ATRIB3 = QSET (NEXT + 3)
C
C IF ORDER HAS A DIFFERENT PRIORITY OR AISLE NUMBER
    IF ((ATRIB2 .GT. NTRIB2) .OR.
         *(ATRIB3 .GT. NTRIB3)) THEN
C
C TERMINATE LOT AND RETURN TO OUTPUT STATION AND DISPATCH
    GOTO 30
ENDIF
NBCHSZ = NBCHSZ + 1.
C
C OTHERWISE READ COLUMN AND ROW LOCATION
ATRIB6 = QSET (NEXT + 6)
ATRIB8 = QSET (NEXT + 8)
C
C COMPUTE TRAVEL BETWEEN STORAGE LOCATIONS
CALL PICK (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)
C
C ADD TRAVEL TIME TO THE TOTAL LOT TIME
SUMT = SUMT + TT
C
C INITIALIZE COLUMN AND ROW LOCATION FOR NEXT TRANSACTION
ATRIB7 = ATRIB6
ATRIB9 = ATRIB8
C
C READ NEXT CUSTOMER ORDER
NEXT = NSUCR (NEXT)
C IF NO MORE ORDERS TO PICK THEN RETURN TO OUTPUT STATION
   IF (NEXT .EQ. 0) THEN
      GOTO 30
   ENDIF

C 20 CONTINUE
30 CONTINUE
C INITIALIZE COLUMN AND ROW LOCATION WITH OUTPUT STATION
C VALUES
   ATRIB6 = XX (70)
   ATRIB8 = XX (71)
C
C COMPUTE TRAVEL TIME FOR RETURN TRIP
   CALL PICK (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)
C
C ADD THE TRAVEL TIME TO TOTAL PICK TIME FOR THE LOT
   SUMT = SUMT + TT
   BTCHSZ = NBCHSZ
C
C ASSIGN THE PICK TIME TO ATTRIBUTE 4 OF THE FIRST ENTITY
C OF THE LOT
   QSET (NTRY + 4) = SUMT
C
C ASSIGN LOT SIZE TO ATTRIBUTE 5 OF THE FIRST ENTITY
   QSET (NTRY + 5) = BTCHSZ
   GT = QSET (NTRY + 4)
   PS = QSET (NTRY + 5)
C
   WRITE (6,100) ATRIB3, GT, PS
100 FORMAT (' AISLE NO. ', I8, ' PICK TIME ', F8.5,
      * ' LOT SIZE ', F8.5)
C
   NTRY = NEXT
C
C IF NO MORE CUSTOMER ORDERS THEN STOP LOTTING
   IF (NTRY .EQ. 0) THEN
      GOTO 40
C
C ELSE DO UNTIL ALL ORDERS HAVE BEEN LOTTED
   ELSE
      GOTO 10
   ENDIF
C
40 CONTINUE
C
   RETURN
   END
SUBROUTINE PICK (ATRIB6, ATRIB7, ATRIB8, ATRIB9, SUMT)

THIS SUBROUTINE COMPUTES THE TIME REQUIRED TO RETRIEVE A LOT OF CUSTOMER ORDERS

FORTRAN ARGUMENTS:
- ATRIB6 - INITIAL COLUMN LOCATION
- ATRIB7 - FINAL COLUMN LOCATION
- ATRIB8 - INITIAL ROW LOCATION
- ATRIB9 - FINAL ROW LOCATION
- TT - OPERATING TIME FOR THE S / R MACHINE

SLAM VARIABLES
- XX (43) - SPECIAL PURPOSE DATA FOR BULK ISSUES
- XX (70) - COLUMN LOCATION OF THE P / D STATION
- XX (71) - ROW

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II *
- MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE *
- SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON/UCOM1/ HLEVEL (50), PVAL (10), PX (10)
COMMON/UCOM3/ IAISLE(31, 2)
INTEGER ATRIB6, ATRIB7, ATRIB8, ATRIB9

INITIALIZE VARIABLE

SUMT = 0.

IF FIRST ORDER OF LOT
  IF ((ATRIB7 .EQ. XX (70)) .AND. *
     (ATRIB9 .EQ. XX (71))) THEN

COMPUTE TRAVEL TO FIRST LOCATION
  CALL SRMACH (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)

ADD TRAVEL TIME & STANDARD PERFORMANCE DATA 3320
  SUMT = TT + XX (43)

ELSE IF LAST ORDER IN LOT THEN RETURN TO OUTPUT STATION
  ELSEIF ((ATRIB6 .EQ. XX (70)) .AND. *
            (ATRIB8 .EQ. XX (71))) THEN
    CALL SRMACH (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)

PICK TIME EQUAL TO TRAVEL TIME
  SUMT = TT
C OTHERWISE MORE THAN ONE PER LOT
ELSE
    CALL SRMACH (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)

C ADD TRAVEL TIME & STANDARD PERFORMANCE DATA 3320
    SUMT = TT + XX (43)
ENDIF

C WRITE (6, 100) ATRIB6, ATRIB8, TT
    100 FORMAT (' COLUMN ',I8,' ROW ',I8,' TRAVEL TIME ',F8.5)

C RETURN
END
REAL FUNCTION USERF (I)

THIS FUNCTION PROVIDES THE INTERFACE BETWEEN SLAM AND THE USER WRITTEN FUNCTIONS. A USERF FUNCTION MAY BE CALLED IN TWO SITUATIONS.

- ASSIGNING ATTRIBUTES (ASSIGN NODE), OR
- SPECIFYING ACTIVITY DURATION (ACTIVITY NODE).

IN THIS SUBROUTINE THE USERF FUNCTION IS USED TO SPECIFY THE ACTIVITY DURATION TO STORE A LINE ITEM

SLAM VARIABLES
ATRIB (6) - COLUMN LOCATION OF ITEM
ATRIB (8) - LEVEL LOCATION OF ITEM
XX (42) - SPECIAL PURPOSE DATA (SPD) FOR BULK STOWAGE OPERATIONS: STANDARD 3251 (MIN / LINE ITEM)
XX (70) - COLUMN LOCATION OF THE P / D STATION
XX (71) - ROW

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II*, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE*, SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON/UCOM1/ HLEVEL (50), PVAL (10), PX (10)
COMMON/UCOM3/ IAISLE (31, 2)
INTEGER ATRIB2, ATRIB3, ATRIB6, ATRIB7, ATRIB8, ATRIB9

INITIALIZE VARIABLES
SUMT = 0.0

IF (I .EQ. 1) THEN
ATRIB6 = ATRIB (6)
ATRIB7 = XX (70)
ATRIB8 = ATRIB (8)
ATRIB9 = XX (71)

TRAVEL TO STORAGE LOCATION
CALL SRMACH (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)

COMPUTE BOTH TO AND FROM TRAVEL TIME
SUMT = 2 * TT

ADD THE STANDARD PERFORMANCE DATA 3251
SUMT = SUMT + XX (42)
C ASSIGN THE STOWAGE TIME TO ATTRIBUTE 4
  USERF = SUMT
C
  WRITE (6,100) ATRIB3, ATRIB6, ATRIB8, USERF
  100 FORMAT (' Aisle No. ', I8, ' Column ', I8, ' Row ', I8,
           ' Stow Time ', F8.5)
C
C NO SUCH USER FUNCTION
  ELSE
    PRINT *, ' ***ERROR IN USERF FUNCTION***'
    PRINT *, ' NO SUCH FUNCTION'
  ENDIF
C
RETURN
END
SUBROUTINE SRMACH (ATRIB6, ATRIB7, ATRIB8, ATRIB9, TT)

This subroutine computes the travel time for an S/R machine between storage locations. The travel time is determined by computing both horizontal and vertical travel times and selecting the maximum value. This subroutine assumes the storage and retrieval machine operates in both vertical and horizontal directions simultaneously.

**FORTRAN Arguments:**
- ATRIB6 - Initial column location
- ATRIB7 - Final column location
- ATRIB8 - Initial row location
- ATRIB9 - Final row location
- TT - Operating time for the S/R machine

**SLAM Variables:**
- XX(56) - Horizontal speed of S/R machine
- XX(57) - Vertical speed
- XX(58) - Horizontal acceleration of S/R machine
- XX(59) - Vertical acceleration of S/R machine
- XX(68) - Width per pallet position

**FORTRAN Variables**
- HLEVEL(NROW) - Height per storage level

```
C CALCULATE THE HORIZONTAL TRAVEL TIME
HACCLT = XX(56) / XX(58)
IF (ATRIB7 .GT. ATRIB6) THEN
   HDIST = (ATRIB7 - ATRIB6) * XX(68)
   GOTO 10
ELSE
   HDIST = (ATRIB6 - ATRIB7) * XX(68)
ENDIF
C
10 CONTINUE
```
HHDIST = HDIST / 2.
HADIS = ( XX (58) * HACCLT ** 2.) / 2.
IF ( HHDIST .LT. HADIS ) THEN
  GOTO 20
ELSE
  HDISSP = HDIST - 2. * (XX (58) * HACCLT ** 2. ) /2.)
  TTMHS = HDISSP / XX (56)
  HTT = 2. * HACCLT + TTMHS
  GO TO 30
ENDIF

20 HTT = 2. * (( 2. * HHDIST ) / XX (58)) ** 0.5

CALCULATE THE VERTICAL TRAVEL TIME

30 VACCLT = XX (57) / XX (59)
VDIST = 0.
IF (ATRIB9 .GT. ATRIB8) THEN
ADD THE DISTANCE BETWEEN LEVELS IN ASCENDING ORDER
  DO 40 I = ATRIB8, ATRIB9
    VDIST = VDIST + HLEVEL (I)
  40 CONTINUE
ELSE
ADD THE DISTANCE BETWEEN LEVELS IN DESCENDING ORDER
  DO 50 J = ATRIB9, ATRIB8
    VDIST = VDIST + HLEVEL (J)
  50 CONTINUE
ENDIF

HVDIST = VDIST / 2.
VADIS = (XX (59) * VACCLT ** 2.) / 2.
IF (HVDIST .LT. VADIS) THEN
  GOTO 60
ELSE
  VDISSP = VDIST - 2. * (XX (59) * VACCLT ** 2. ) /2.)
  TTMVS = VDISSP / XX (57)
  VTT = 2. * VACCLT + TTMVS
  GO TO 70
ENDIF

60 VTT = 2. * (( 2. * HVDIST ) / XX (59)) ** 0.5
SELECT THE LARGER OF THE HORIZONTAL AND VERTICAL TRAVEL TIMES
70  IF (HTT .GT. VTT) THEN
     TT = HTT
     GOTO 80
   ELSE
     TT = VTT
   ENDIF
C
80  CONTINUE
C
C  WRITE (6,100) ATRIB6, ATRIB8, TT
C  100 FORMAT(' COLUMN ',I5,' ROW ',I5,' TRAVEL TIME ',F8.4)
C
RETURN
END
SUBROUTINE ALLOC (I, IFLAG)

SUBROUTINE ALLOCATE IS CALLED BY SLAM WHEN AN ENTITY ARRIVES AT AN AWAIT NODE WHOSE RESOURCE IS SPECIFIED AS ALLOC (I). IT IS ALSO CALLED WHEN THE FILE ASSOCIATED WITH THE AWAIT NODE IS POLLED AS THE RESULT OF A NEWLY AVAILABLE RESOURCE.

SLAM II VARIABLES
I - ARGUMENT CODE FOR PASSING CONTROL FROM SLAM PROGRAM TO A USER WRITTEN ALLOCATE FUNCTION.
IFLAG - THE RESOURCE NUMBER SELECTED

SLAM VARIABLES
XX (45) - INITIALIZE VARIABLE FOR RESOURCES
XX (46) - S / R MACHINE NUMBERS IN BAY 1
XX (47) - 2
XX (48) - 3
XX (49) - 4
XX (50) - INITIALIZE VARIABLE FOR AISLES
XX (51) - AISLE NUMBERS IN BAY 1
XX (52) - 2
XX (53) - 3
XX (54) - 4

FORTRAN VARIABLES
IAISLE (I, J) - STORAGE AISLE OCCUPIED BY AN S / R MACHINE

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II*, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNSET, NTAPE*, SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON/UCOM1/ HLEVEL (50), PVAL (10), PX (10)
COMMON/UCOM3/ IAISLE(31, 2)

INITIALIZE VARIABLES
IFLAG = 0

NBAY0 = XX (50)
NBAY1 = XX (51)
NBAY2 = XX (52)
NBAY3 = XX (53)
NBAY4 = XX (54)

NRES0 = XX (45)
NRES1 = XX (46)
NRES2 = XX (47)
NRES3 = XX (48)
NRES4 = XX (49)
IS THE ALLOCATION FOR BAY 1?
IF ((I .GT. NBAY1) .AND. (I .LE. NBAY1)) THEN
  DO 10 J = NRES0 + 1, NRES1
C
C  CONDITION 1: IF AN S / R MACHINE IS AVAILABLE AND A
C  TRANSACTION IS WAITING THEN ATTEMPT TO ALLOCATE AN S / R
C  MACHINE
IF (NNRSC (J) .EQ. 1) THEN
  DO 20 K = NBAY0 + 1, NBAY1
    IF (NNQ (97 + 2 * K) .GT. 0) THEN
      GOTO 90
    ENDIF
  20 CONTINUE
ENDIF

CONDITION 2: IF AN S / R MACHINE IS NOT AVAILABLE OR A
TRANSACTION IS NOT WAITING THEN DO NOT ATTEMPT TO
ALLOCATE AN S / R MACHINE
RETURN
ENDIF
10 CONTINUE
RETURN

BAY 2

ELSE IF ((I .GT. NBAY1) .AND.
  (I .LE. NBAY2)) THEN
  DO 30 J = NRES1 + 1, NRES2
    IF (NNRSC (J) .EQ. 1) THEN
      DO 40 K = NBAY1 + 1, NBAY2
        IF (NNQ (97 + 2 * K) .GT. 0) THEN
          GOTO 90
        ENDIF
      40 CONTINUE
    RETURN
  ENDIF
30 CONTINUE
RETURN

BAY 3

ELSE IF ((I .GT. NBAY2) .AND.
  (I .LE. NBAY3)) THEN
  DO 50 J = NRES2 + 1, NRES3
    IF (NNRSC (J) .EQ. 1) THEN
      DO 60 K = NBAY2 + 1, NBAY3
        IF (NNQ (97 + 2 * K) .GT. 0) THEN
          GOTO 90
        ENDIF
      60 CONTINUE
    RETURN
  ENDIF
50 CONTINUE
RETURN
ENDIF
50 CONTINUE
RETURN
C
C ELSE IF (I .LE. NBAY4) THEN
C
DO 70 J = NRES3 + 1, NRES4
IF (NNRSC (J) .EQ. 1) THEN
DO 80 K = NBAY3 + 1, NBAY4
IF (NNQ (97 + 2 * K) .GT. 0) THEN
GOTO 90
ENDIF
80 CONTINUE
RETURN
ENDIF
70 CONTINUE
RETURN
C
C OTHERWISE
C ELSE
C
PRINT *, ' *** ERROR IN ALLOC SUBROUTINE ***'
PRINT *, ' BAY NUMBER EXCEEDED '
ENDIF
C
90 CONTINUE
C
FILE NUMBER
N = 97 + 2 * I
C
S / R MACHINE NO.
NRES = IAISE (I, 2)
C
CONDITION 3: IF NO TRANSACTION IS WAITING AND NO S / R MACHINE IS IN THE AISLE THEN PRINT ERROR!!!
IF (NNQ (N) .EQ. 0) THEN
IF (IAISE (I, 2) .EQ. 0) THEN
PRINT *, ' *** ERROR IN ALLOC SUBROUTINE *** '
PRINT *, ' CONDITION 3 CANNOT BE TRUE '
ELSE
C
CONDITION 4: IF NO TRANSACTION WAITING AND THE S / R MACHINE IS BUSY THEN PRINT ERROR!!!
IF (NNRSC (NRES) .EQ. 0) THEN
PRINT *, ' *** ERROR IN ALLOC SUBROUTINE *** '
PRINT *, ' CONDITION 4 CANNOT BE TRUE '
C
CONDITION 5: IF NO TRANSACTION WAITING AND THE S / R MACHINE IS IDLE THEN CHECK OTHER AISLES
ELSE
II = I
CALL MNILL (II, IIIFLAG)
I = II
IFLAG = IIFLAG
IF (IFLAG .EQ. 0) THEN
    RETURN
ENDIF
ENDIF
ENDIF

C ELSE

C CONDITION 6: IF A TRANSACTION IS WAITING AND NO S/R MACHINE IS IN THE AISLE THEN ALLOCATE THE S/R MACHINE TO AISLE WITH THE HIGHEST PRIORITY AND THEN SEIZE THE
C S/R MACHINE
    IF (IAISLE (I, 2) .EQ. 0) THEN
        II = I
        CALL TRANS (II, IIFLAG)
        I = II
        IFLAG = IIFLAG
    C CONDITION 7: IF A TRANSACTION IS WAITING AND THE S/R MACHINE IS BUSY THEN DO NOT ALLOCATE THE S/R MACHINE ELSE
    IF (NNSC (NRES) .EQ. 0) THEN
        IFLAG = 0
        RETURN
    C CONDITION 8: IF A TRANSACTION IS WAITING AND THE S/R MACHINE IS IDLE THEN ALLOCATE THE S/R MACHINE TO THE
    ELSE
        II = I
        CALL STRANS (II, IIFLAG)
        I = II
        IFLAG = IIFLAG
        IF (IFLAG .EQ. 0) THEN
            RETURN
        ENDIF
    ENDIF
    ENDIF
    ENDIF

C WRITE (6,100) I, ATRIB(10)
100 FORMAT (' AISLE NO. ', I5, ' RESOURCE NO. ', F8.4)
C RETURN
END
SUBROUTINE MNILL (I, IFLAG)

C THIS SUBROUTINE ATTEMPTS TO ASSIGN AN S / R MACHINE TO ANOTHER AISLE WITH THE HIGHEST PRIORITY TRANSACTION WAITING IF THE S / R MACHINE HAS BECOME IDLE

C FORTRAN ARGUMENTS
I - ARGUMENT CODE FOR PASSING CONTROL FROM SLAM PROGRAM TO A USER WRITTEN ALLOCATE FUNCTION.
IFLAG - THE RESOURCE NUMBER SELECTED

C SLAM VARIABLES
XX (50) - INITIALIZE VARIABLE FOR AISLES
XX (51) - AISLE NUMBERS IN BAY 1
XX (52) - ' 2
XX (53) - ' 3
XX (54) - ' 4
XX (60) - INTERAILSE TRAVEL SPEED OF S / R MACHINE
XX (61) - STANDARD PERFORMANCE TIME FOR INTERAILSE TRAVEL TIME

C FORTRAN VARIABLES
IAISLE (I, J) - STORAGE AISLE OCCUPIED BY AN S / R MACHINE

C RESOURCE NUMBER THAT IS IDLE
NRES = IAISLE (I, 2)

C IS ALLOCATION FOR BAY 1?
IF ((I .GT. XX (50)) .AND. (I .LE. XX (51))) THEN
   NBMIN = XX (50)
   NBMAX = XX (51)
ELSE IF ((I .GT. XX (51)) .AND. (I .LE. XX (52))) THEN
   NBMIN = XX (51)
   NBMAX = XX (52)
ELSE IF ((I .GT. XX (52)) .AND. (I .LE. XX (53))) THEN
   NBMIN = XX (52)
   NBMAX = XX (53)
ELSE IF (I .LE. XX (54)) THEN
   NBMIN = XX (53)
   NBMAX = XX (54)
   
   OTHERWISE
   PRINT *, ' **ERROR IN NMIN SUBROUTINE** ' 
   PRINT *, ' BAY NUMBER EXCEEDED ' 
   ENDIF
   
   J = 1
   
   CHECK THE NEAREST AISLE TO THE LEFT
C 10 CONTINUE
   IF (((I - J) .LE. NMIN) THEN
      GOTO 20 
   ELSE
      NXTILL = I - J
   
   IF THE AISLE IS NOT OCCUPIED AND THERE IS A TRANSACTION
   WATING THEN ALLOCATE THE S / R MACHINE TO THAT AISLE
   IF (IAISLE (NXTILL, 2) .EQ. 0) THEN
      IF (NNQ (97 + 2 * NXTILL) .GT. 0) THEN
         CALL SEIZE (NRES, 1)
         CALL RMOVE (1, 97 + 2 * NXTILL, ATRIB)
         ATRIB (10) = NRES
      
      TRAVEL TO NEXT AISLE, AND ADD TIME TO ATTRIBUTE 4
      ENTAIL = ABS (NXTILL - I) * (XX(69) / XX(60))
      + XX (61)
      ATRIB (4) = ATRIB (4) + ENTAIL
   
   WRITE (6,100) ENTAIL
   100 FORMAT (' INTERAISLE TRAVEL TIME ',F8.4)
   
   IAISLE (NXTILL, 2) = NRES
   IAISLE(I, 2) = 0
   I = NXTILL
   IFLAG = +1
   RETURN
   ENDIF
   ENDIF
   ENDIF
   C
C 20 CONTINUE
   
   CHECK THE NEAREST AISLE TO THE RIGHT
   IF ((I + J) .GT. NMAX) THEN
      GOTO 30 
   ELSE
      NXTILL = I + J
C IF THE AISLE IS NOT OCCUPIED AND THERE IS A TRANSACTION
C WAITING THEN ALLOCATE THE S / R MACHINE TO THE AISLE
IF (IAISLE (NXTILL, 2) .EQ. 0) THEN
   IF (NNQ (97 + 2 * NXTILL) .GT. 0) THEN
      CALL SEIZE (NRES, 1)
      CALL RMOVE (1, 97 + 2 * NXTILL, ATRIB)
      ATRIB (10) = NRES
   ENDIF
C TRAVEL TO THE NEXT AISLE AND ADD TIME TO ATTRIBUTE 4
   ENTAIL = ABS (NXTILL - I) * (XX(69) / XX(60))
   * 
   ATRIB (4) = ATRIB (4) + ENTAIL
C WRITE (6,200) ENTAIL
200 FORMAT (' INTERAISLE TRAVEL TIME ',F8.4)
C IAISLE (NXTILL, 2) = NRES
IAISLE (I, 2) = 0
I = NXTILL
IFLAG = +1
RETURN
ENDIF
ENDIF
C 30 CONTINUE
C IF ALL AISLES HAVE BEEN TESTED THEN NO S / R MACHINE IS
C ALLOCATED
IF (((I - J) .LE. NMIN) .AND.
   * 
   ((I + J) .GT. NMAX)) THEN
   IFLAG = 0
RETURN
C IF ALL THE AISLES HAVE NOT BEEN CHECKED THEN DO SO
ELSE
   J = J + 1
   IF (J .GT. 100) THEN
      PRINT *, ' ***ERROR IN MNILL SUBROUTINE***'
      PRINT *, ' STUCK IN A LOOP '
      IFLAG = 0
      RETURN
   ENDF
GOTO 10
ENDIF
C RETURN
END
SUBROUTINE TRANS (I, IFLAG)

THIS SUBROUTINE ASSIGNS AN S / R MACHINE TO THE AISLE WITH THE HIGHEST PRIORITY TRANSACTION WAITING IF NO S / R MACHINE IS IN THE AISLE

FORTRAN ARGUMENTS

I - ARGUMENT CODE FOR PASSING CONTROL FROM SLAM PROGRAM TO A USER WRITTEN ALLOCATE FUNCTION.

IFLAG - THE RESOURCE NUMBER SELECTED

SLAM II VARIABLES

XX (50) - INITIALIZE VARIABLE FOR AISLES
XX (51) - AISLE NUMBERS IN BAY 1
XX (52) - " 2
XX (53) - " 3
XX (54) - " 4
XX (60) - INTERAISLE TRAVEL SPEED OF S / R MACHINE
XX (61) - STANDARD PERFORMANCE TIME FOR INTERAISLE TRAVEL TIME

FORTRAN VARIABLES

IAISLE (I, J) - STORAGE AISLE OCCUPIED BY AN S / R MACHINE

COMMON/SCOM1/ ATRIB(100), DD(100), DDL(100), DTNOW, II *, MFA, MSTOP, NCLNR, NCRDR, NNRUN, NNSET, NTAPE *
*, SS(100), SSL(100), TNEXT, TNOW, XX(200)
COMMON/UCOM1/ HLEVEL (50), PVAL (10), PX (10)
COMMON/UCOM3/ IAISLE(31, 2)

INTIALIZE VARIABLES

IIFLAG = +2
FILE NUMBER
N = 97 + 2 * I

IF A TRANSACTION WITH A HIGHER PRIORITY IS WAITING IN ANOTHER AISLE THAT IS NOT OCCUPIED THEN DO NOT ATTEMPT TO ASSIGN AN S / R MACHINE

CALL STRANS (I, IIFLAG)
IF (IIFLAG .EQ. 0) THEN
IFLAG = 0
RETURN
ENDIF
C IS ALLOCATION FOR BAY 1?
IF ((I .GT. XX (50)) .AND. (I .LE. XX (51))) THEN
   NMIN = XX (50)
   NMAX = XX (51)

ELSE IF ((I .GT. XX (51)) .AND. (I .LE. XX (52))) THEN
   NMIN = XX (51)
   NMAX = XX (52)

ELSE IF ((I .GT. XX (52)) .AND. (I .LE. XX (53))) THEN
   NMIN = XX (52)
   NMAX = XX (53)

ELSE IF (I .LE. XX (54)) THEN
   NMIN = XX (53)
   NMAX = XX (54)

OTHERWISE
   ELSE
      PRINT *, ', ***ERROR IN TRANS SUBROUTINE***'
      PRINT *, ', BAY NUMBER EXCEEDED '
   ENDF

J = 1

CHECK THE NEAREST AISLE TO THE LEFT

10 CONTINUE

IF ((I - J) .LE. NMIN) THEN
   GOTO 20
ELSE
   NXTILL = I - J

IF THE AISLE IS NOT OCCUPIED AND THERE IS A TRANSACTION WAITING THEN ALLOCATE THE S / R MACHINE TO THE AISLE
IF (IAISLE (NXTILL, 2) .GT. 0) THEN
   NRES = IAISLE (NXTILL, 2)
   IF (NNRSC (NRES) .EQ. 1) THEN
      CALL SEIZE (NRES, 1)
      ATRIB (10) = NRES

TRAVEL TO THE NEXT AISLE AND ADD TIME TO ATTRIBUTE 4
ENTAIL = ABS (NXTILL - I) * (XX(69) / XX(60))
   + XX (61)
   ATRIB (4) = ATRIB (4) + ENTAIL

WRITE (6,100) ENTAIL
100 FORMAT (' INTERAISLE TRAVEL TIME ',F8.4)
C

IAISLE (NXTILL, 2) = 0
IAISLE (I, 2) = NRES
IFLAG = +1
RETURN
ENDIF
ENDIF
ENDIF

20 CONTINUE
C

CHECK THE NEAREST AISLE TO THE RIGHT
IF ((I + J) .GT. NMAX) THEN
GOTO 30
ELSE
    NXTILL = I + J
C
IF THE AISLE IS NOT OCCUPIED AND THERE IS A TRANSACTION
C WAITING THEN ALLOCATE THE S / R MACHINE TO THE AISLE
    IF (IAISLE (NXTILL, 2) .GT. 0) THEN
        NRES = IAISLE (NXTILL, 2)
        IF (NNRSC (NRES) .EQ. 1) THEN
            CALL SEIZE (NRES, 1)
            ATRIB (10) = NRES

C TRAVEL TO THE NEXT AISLE AND ADD TIME TO ATTRIBUTE 4
    ENTAIL = ABS (NXTILL - I) * (XX(69) / XX(60))
    + XX (61)
    ATRIB (4) = ATRIB (4) + ENTAIL
C
WRITE (6,200) ENTAIL
200 FORMAT (' INTERAISLE TRAVEL TIME ',F8.4)
C
IAISLE (NXTILL, 2) = 0
IAISLE (I, 2) = NRES
IFLAG = +1
RETURN
ENDIF
ENDIF

30 CONTINUE
C
IF ALL THE AISLES HAVE BEEN TESTED THEN NO S / R
C MACHINE IS ALLOCATED
    IF (((I - J) .LE. NMIN) .AND. 
    * ((I + J) .GT. NMAX)) THEN
        IFLAG = 0
    RETURN
C
C IF ALL AISLES HAVE NOT BEEN CHECKED THEN DO SO ELSE
   J = J + 1
   IF (J .GT. 100) THEN
      PRINT *, '***ERROR IN TRANS SUBROUTINE***'
      PRINT *, 'STUCK IN A LOOP'
      IFLAG = 0
      RETURN
   ENDIF
   GOTO 10
ENDIF

C RETURN
END
SUBROUTINE STRANS (I, IFLAG )

THIS SUBROUTINE ASSIGNS THE S / R MACHINE TO THE
PRESENT AISLE UNLESS A HIGHER PRIORITY TRANSACTION
IS WAITING AT ANOTHER AISLE WITHIN THE BAY

FORTAN ARGUMENTS
I - ARGUMENT CODE FOR PASSING CONTROL FROM SLAM
PROGRAM TO A USER WRITTEN ALLOCATE FUNCTION.
IFLAG - THE RESOURCE NUMBER SELECTED

SLAM II VARIABLES
XX (50) - INITIALIZE VARIABLE FOR AISLES
XX (51) - AISLE NUMBERS IN BAY 1
XX (52) - * 2
XX (53) - * 3
XX (54) - * 4
XX (60) - INTERAISLE TRAVEL SPEED OF S / R MACHINE
XX (61) - STANDARD PERFORMANCE TIME FOR INTERAISLE TRAVEL TIME

FORTRAN VARIABLES
IAISLE (I, J) - STORAGE AISLE OCCUPIED BY AN S / R MACHINE

FILE NUMBER
N = 97 + 2 * I
IFL = N
K = I

S / R MACHINE NO.
NRES = IAISLE (I, 2)

IS ALLOCATION FOR BAY 1?
IF ((I .GT. XX (50)) .AND. (I .LE. XX (51))) THEN
NMIN = XX (50)
NMAX = XX (51)
ELSE IF ((I .GT. XX (51)) .AND. (I .LE. XX (52))) THEN
NMIN = XX (51)
NMAX = XX (52)
ELSE IF ((I .GT. XX (52)) .AND. 
* 
(I .LE. XX (53))) THEN
  NMIN = XX (52)
  NMAX = XX (53)
ENDIF

ELSE IF (I .LE. XX (54)) THEN
  NMIN = XX (53)
  NMAX = XX (54)
ENDIF

OTHERWISE
  PRINT *, ' ***ERROR IN STRANS SUBROUTINE***'
  PRINT *, ' BAY NUMBER EXCEEDED '
  ENDIF

INITIALIZE VARIABLES WITH BUFFER ARRAY ATTRIBUTES

  ATRB1 = ATRIB (1)
  NATRB2 = ATRIB (2)
  NATRB3 = ATRIB (3)
  ATRB4 = ATRIB (4)
  NATRB5 = ATRIB (5)
  NATRB6 = ATRIB (6)
  NATRB7 = ATRIB (7)
  NATRB8 = ATRIB (8)
  NATRB9 = ATRIB (9)
  NTRB10 = ATRIB (10)
  NTRB11 = ATRIB (11)
  ATRB12 = ATRIB (12)
  ATRB13 = ATRIB (13)
  ATRB14 = ATRIB (14)

J = 1

CHECK THE NEAREST AISLE TO THE LEFT

10 CONTINUE

  IF ((I - J) .LE. NMIN) THEN
    GOTO 20
  ELSE
    NXTILL = I - J
  ENDIF

IF AISLE IS NOT OCCUPIED AND A TRANSACTION WITH A HIGHER
PRIORITY IS WAITING THEN DO NOT ALLOCATE THE S / R
MACHINE

  IF (IAISLE (NXTILL, 2) .EQ. 0) THEN
    IF (NNQ (97 + 2 * NXTILL) .GT. 0) THEN
      NTRY = MMFE (97 + 2 * NXTILL)
      CALL COPY (-NTRY, 1, ATRIB)
      IATRB2 = ATRIB (2)
IF (IATRB2 .LT. NATRB2) THEN
  IFLAG = 0
  RETURN
ENDIF
ENDIF
ENDIF
ENDIF
C
20 CONTINUE
C
CHECK THE NEAREST AISLE TO THE RIGHT
IF ((I + J) .GT. NMAX) THEN
  GOTO 30
ELSE
  NXTILL = I + J
C
IF AISLE IS NOT OCCUPIED AND A TRANSACTION WITH A HIGHER PRIORITY IS WAITING THEN DO NOT ALLOCATE THE S/R MACHINE
IF (IAISLE (NXTILL, 2) .EQ. 0) THEN
  IF (NNQ (97 + 2 * NXTILL) .GT. 0) THEN
    NTRY = MMFE (97 + 2 * NXTILL)
    CALL COPY (-NTRY, 1, ATRIB)
    IATRB2 = ATRIB (2)
  C

IF (IATRB2 .LT. NATRB2) THEN
  IFLAG = 0
  RETURN
ENDIF
ENDIF
ENDIF
ENDIF
C
30 CONTINUE
C
IF ALL THE AISLES HAVE BEEN CHECKED THEN ALLOCATE THE S/R MACHINE TO THE PRESENT AISLE. RELOAD THE FIRST TRANSACTION'S ATTRIBUTES
IF (((I - J) .LE. NMIN) .AND. ((I + J) .GT. NMAX)) THEN
  ATRIB (1) = ATRB1
  ATRIB (2) = NATRB2
  ATRIB (3) = NATRB3
  ATRIB (4) = ATRB4
  ATRIB (5) = NATRB5
  ATRIB (6) = NATRB6
  ATRIB (7) = NATRB7
  ATRIB (8) = NATRB8
  ATRIB (9) = NATRB9
  ATRIB (10) = NTRB10
  ATRIB (11) = NTRB11
ATRIB (12) = ATR12
ATRIB (13) = ATRB13
ATRIB (14) = ATRB14
ATRIB (10) = NRES

C IF SUBROUTINE STRANS WAS CALLED BY SUBROUTINE TRANS THEN
C DO NOT ASSIGN S / R MACHINE IN THIS SUBROUTINE
    IF (IFLAG .EQ. +2) THEN
        WRITE (6, 100) IFLAG
100    FORMAT (' IFLAG ', I5)
    RETURN
    ENDIF
C CALL SEIZE (NRES, 1)
    IFLAG = +1
    RETURN
C C IF ALL AISLES HAVE NOT BEEN CHECKED THEN DO SO
ELSE
    J = J + 1
    IF (J .GT. 100) THEN
        PRINT *, ' ***ERROR IN STRANS SUBROUTINE*** '
        PRINT *, ' STUCK IN A LOOP '
        IFLAG = 0
        RETURN
    ENDIF
    GOTO 10
ENDIF
C RETURN
END
GEN, CRUM, CAPS SIMULATION, 3/20/87, 1, NO, NO;
;
RESOURCES
;
(1 - 31) - S / R MACHINES
(32 - 62) - INPUT STATIONS
(63 - 93) - OUTPUT
;

SERVICE ACTIVITIES
;
(1 - 31) - BLOCKING AISLE FOR S / R MACHINE
(32 - 62) - " " TRACK FOR AGVs
;

ASSIGNED ATTRIBUTES
;
ATRIB (1) - ARRIVING TIME OF TRANSACTION
ATRIB (2) - PRIORITY OF TRANSACTION
ATRIB (3) - ASSIGNED AISLE NUMBER
ATRIB (4) - S / R TRANSACTION TIME
ATRIB (5) - SIZE OF LOT
ATRIB (6) - COLUMN LOCATION OF ITEM
ATRIB (7) - ASSIGNED TRANSACTION TYPE
ATRIB (8) - LEVEL LOCATION OF ITEM
ATRIB (9) - CONTROL POINT OR DESTINATION OF AGV
ATRIB (10) - RESOURCE LABEL
ATRIB (11) - INDEX OF BATCH MEMBERSHIP
ATRIB (12) - USED BY SLAM
ATRIB (13) - IDENTIFICATION OF THE AGV UNIT ALLOCATED
ATRIB (14) - USED BY SLAM
;

GLOBAL VARIABLES
;
XX (1 - 31) - AISLE LOCATION OF N S/R MACHINE
XX (32) - PRIORITY OF A TRANSHIPMENT TRANSACTION
XX (33) - " " RED ORDER " "
XX (34) - " " GREEN ORDER " "
XX (35) - " " WHITE ORDER " "
XX (36) - " " STOW TRACTION
XX (37) - UNLOAD TIME FOR AGVs
XX (38) - CONVEYOR TIME FOR I / O STATIONS
XX (39) - LOAD TIME FOR AGVs
XX (40) - UNLOAD TIME FOR S / R MACHINE
XX (41) - LOAD " "
XX (70) - COLUMN LOCATION OF THE I / O STATION
XX (71) - ROW " "
XX (72) - NUMBER OF COLUMNS / RACK
XX (73) - " " ROWS " "
;
FILE NUMBERS

(1) - ARRIVING CUSTOMER ORDERS
(2 - 7) - RECEIVING STATIONS
(8) - SORTED ORDERS
(9, 11, ..., 69) - DROP OFF STATIONS
(10, 12, ..., 70) - PICKUP STATIONS
(72 - 77) - SHIPPING STATIONS
(78) - ROUTE AGV
(99, 101, ..., 159) - INPUT STATIONS
(100, 102, ..., 160) - OUTPUT STATIONS
(161) - REQUEST FOR ALL AGVs
(162) - COLLECT STATISTICS
(170 - 200) - QUEUES FOR AISLES
(201 - 231) - AGV TRACK SEGMENTS

UNITS
- ALL TIMES ARE IN SECONDS
- DISTANCES IN FEET
SUBMODEL FOR THE SLAM CONTROL STATEMENTS

; MFIL MATR MNTRY
LIMIT, 235, 14, 900;

; CLEAR STATISTIC ARRAYS BEGINNING DAY SHIFT
; OPTION TFRST TSEC
MONTR, CLEAR, 390;

; TRACE EACH EVENT OF SLAM PROGRAM
; OPTION TFRST TSEC
MONTR, TRACE, 413, 415;

; TRACE SELECTED EVENTS OF THE AGVS
; OPTION DETAIL DMIN DMAX
MHMONTR, ATRACE (NODETAIL), 390, 870;

; SPECIFY RANKING OF ENTITIES IN FILES
; IFL RANKING IFL RANKING IFL RANKING IFL RANKING
PRIORITY / 1, LVF(2) / 8, LVF(2) / 99, LVF(2) / 101, LVF(2)/
103, LVF(2) / 105, LVF(2) / 107, LVF(2) / 109, LVF(2)/
111, LVF(2) / 113, LVF(2) / 115, LVF(2) / 117, LVF(2)/
119, LVF(2) / 121, LVF(2) / 123, LVF(2) / 125, LVF(2)/;

PRIORITY / 127, LVF(2) / 129, LVF(2) / 131, LVF(2) / 133, LVF(2)/
135, LVF(2) / 137, LVF(2) / 139, LVF(2) / 141, LVF(2)/
143, LVF(2) / 145, LVF(2) / 147, LVF(2) / 149, LVF(2)/
151, LVF(2) / 153, LVF(2) / 155, LVF(2) / 157, LVF(2)/;

PRIORITY / 159, LVF(2) / 2, LVF(2) / 3, LVF(2) / 4, LVF(2)/
5, LVF(2) / 6, LVF(2) / 7, LVF(2)/;

; CONTINUOUS, , , , , N;

; DTMIN DTMAX NO WARNING
VCONT, 0.0125, 1.0, NO;

; NETWORK;
SUBMODEL IDENTIFY RESOURCES

THIS SUBMODEL IDENTIFIES THE RESOURCES TO BE USED FOR THE SIMULATION MODEL

DEFINE S/R RESOURCES

<table>
<thead>
<tr>
<th>BAY 1</th>
<th>RNUM</th>
<th>RLBL</th>
<th>IFL's</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESOURCE / 1, SR1,</td>
<td>99, 101, 103, 105, 107, 109, 111, 113, 115;</td>
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<td>RESOURCE / 2, SR2,</td>
<td>99, 101, 103, 105, 107, 109, 111, 113, 115;</td>
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<td>RESOURCE / 3, SR3,</td>
<td>99, 101, 103, 105, 107, 109, 111, 113, 115;</td>
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<td>RESOURCE / 4, SR4,</td>
<td>99, 101, 103, 105, 107, 109, 111, 113, 115;</td>
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<td>RESOURCE / 5, SR5,</td>
<td>99, 101, 103, 105, 107, 109, 111, 113, 115;</td>
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<th>RNUM</th>
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<th>IFL's</th>
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<td>RESOURCE / 6, SR6,</td>
<td>117, 119, 121, 123, 125, 127, 129, 131, 133;</td>
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<td>RESOURCE / 7, SR7,</td>
<td>117, 119, 121, 123, 125, 127, 129, 131, 133;</td>
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<td>RESOURCE / 8, SR8,</td>
<td>117, 119, 121, 123, 125, 127, 129, 131, 133;</td>
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<td>RESOURCE / 9, SR9,</td>
<td>117, 119, 121, 123, 125, 127, 129, 131, 133;</td>
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<td>RESOURCE / 10, SR10,</td>
<td>117, 119, 121, 123, 125, 127, 129, 131, 133;</td>
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<th>RNUM</th>
<th>RLBL</th>
<th>IFL's</th>
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<td>RESOURCE / 11, SR11,</td>
<td>135, 137, 139, 141, 143, 145, 147, 149, 151;</td>
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<tr>
<td>RESOURCE / 12, SR12,</td>
<td>135, 137, 139, 141, 143, 145, 147, 149, 151;</td>
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<tr>
<td>RESOURCE / 13, SR13,</td>
<td>135, 137, 139, 141, 143, 145, 147, 149, 151;</td>
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<tr>
<td>RESOURCE / 14, SR14,</td>
<td>135, 137, 139, 141, 143, 145, 147, 149, 151;</td>
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<tr>
<td>RESOURCE / 15, SR15,</td>
<td>135, 137, 139, 141, 143, 145, 147, 149, 151;</td>
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</table>
BAY 4

RESOURCE / 16, SR16, 153,155,157,159;
RESOURCE / 17, SR17, 153,155,157,159;

DEFINE INPUT CONVEYOR RESOURCES

<table>
<thead>
<tr>
<th>RNUM</th>
<th>RLBL</th>
<th>CAP</th>
<th>IFL's</th>
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BAY 1

RESOURCE / 32, I1 (3), 9;
RESOURCE / 33, I2 (3), 11;
RESOURCE / 34, I3 (3), 13;
RESOURCE / 35, I4 (3), 15;
RESOURCE / 36, I5 (3), 17;
RESOURCE / 37, I6 (3), 19;
RESOURCE / 38, I7 (3), 21;
RESOURCE / 39, I8 (3), 23;
RESOURCE / 40, I9 (3), 25;

BAY 2

RESOURCE / 41, I10 (3), 27;
RESOURCE / 42, I11 (3), 29;
RESOURCE / 43, I12 (3), 31;
RESOURCE / 44, I13 (3), 33;
RESOURCE / 45, I14 (3), 35;
RESOURCE / 46, I15 (3), 37;
RESOURCE / 47, I16 (3), 39;
RESOURCE / 48, I17 (3), 41;
RESOURCE / 49, I18 (3), 43;

BAY 3

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RESOURCE / 51, I20 (3), 47;
RESOURCE / 52, I21 (3), 49;
RESOURCE / 53, I22 (3), 51;
RESOURCE / 54, I23 (3), 53;
RESOURCE / 55, I24 (3), 55;
RESOURCE / 56, I25 (3), 57;
RESOURCE / 57, I26 (3), 59;
RESOURCE / 58, I27 (3), 61;

BAY 4

RESOURCE / 59, I28 (3), 63;
RESOURCE / 60, I29 (3), 65;
RESOURCE / 61, I30 (3), 67;
RESOURCE / 62, I31 (3), 69;
DEFINE OUTPUT CONVEYOR RESOURCES

RNUM  RLBL  CAP  IFL's

BAY 1

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RESOURCE / 64, 02   (3), 102;
RESOURCE / 65, 03   (3), 104;
RESOURCE / 66, 04   (3), 106;
RESOURCE / 67, 05   (3), 108;
RESOURCE / 68, 06   (3), 110;
RESOURCE / 69, 07   (3), 112;
RESOURCE / 70, 08   (3), 114;
RESOURCE / 71, 09   (3), 116;

BAY 2

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RESOURCE / 73, 011  (3), 120;
RESOURCE / 74, 012  (3), 122;
RESOURCE / 75, 013  (3), 124;
RESOURCE / 76, 014  (3), 126;
RESOURCE / 77, 015  (3), 128;
RESOURCE / 78, 016  (3), 130;
RESOURCE / 79, 017  (3), 132;
RESOURCE / 80, 018  (3), 134;

BAY 3

RESOURCE / 81, 019  (3), 136;
RESOURCE / 82, 020  (3), 138;
RESOURCE / 83, 021  (3), 140;
RESOURCE / 84, 022  (3), 142;
RESOURCE / 85, 023  (3), 144;
RESOURCE / 86, 024  (3), 146;
RESOURCE / 87, 025  (3), 148;
RESOURCE / 88, 026  (3), 150;
RESOURCE / 89, 027  (3), 152;

BAY 4

RESOURCE / 90, 028  (3), 154;
RESOURCE / 91, 029  (3), 156;
RESOURCE / 92, 030  (3), 158;
RESOURCE / 93, 031  (3), 160;

GATE INFORMATION

GLBL  STATUS  IFL's

GATE / DSFT,  CLOSE,  1,  8;
GATE / GATEO,  OPEN,  72,  73,  74,  75,  78,  162;
99, 101, 103, 105, 107, 109, 111, 113, 115;
117, 119, 121, 123, 125, 127, 129, 131, 133,
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</table>
VSGMENT, 98, 95, 96, 6.3, UNI;
VSGMENT, 99, 96, 1, 6.3, UNI;

DEFINE AGV

NVEH ESPEED LSPD ACC DEC LEN DBUF
VFLEET, AGV, 12, 120.0, 80.0, , 3.0, 3.0, 
, 161 / PRI, STOP(96), 96/ 95/ 94/ 93/ 92/ 91/ 90/ 89/ 88/ 87/ 86/ 85; 84/ 83/ 82/ 81/ 80, YES;
CHKZ IFL / RJREQ RIDL ICPNUM ICPNUM ICPNUM ICPNUM REPIND
; SUBMODEL CONTROL CLOCK
; THIS SUBMODEL CONTROLS THE CLOCK. CUSTOMER ORDERS ARE
; RELEASED AT THE BEGINNING OF DAY SHIFT.
;
CREATE,,390;
;
RELEASE CUSTOMER ORDERS
;
OPEN,DSFT;
ACTIVITY,480;
CLOSE,DSFT;
ACTIVITY;
TERM;
;
SUBMODEL SCHEDULE EVENTS

THIS SUBMODEL SEQUENCES AND LOTS CUSTOMER ORDERS.
THE TRAVEL TIME IS COMPUTED FOR THE S/R MACHINE.

CREATE,,388;

SEQUENCE THE CUSTOMER ORDERS

EVENT,1;
ACTIVITY,1;

LOT THE ORDERS AND COMPUTE THE TRAVEL TIME
FOR THE S/R MACHINES.

EVENT,2;
GOON;
ACTIVITY,482;
TERM;
SUBMODEL AGV SYSTEM

THIS SUBMODEL REPRESENTS THE AGV SYSTEM AND THE INTERFACE DEVICES SHARED BY THE AGV AND S/R SYSTEMS

CREATE 109 STOW LINE ITEMS

CREATE, 3.0, 392, 1, 109;

ASSIGN CHARACTERISTICS TO EACH STOW ITEM.

<table>
<thead>
<tr>
<th>VAR VALUE</th>
<th>VAR VALUE</th>
<th>CHARACTERISTIC</th>
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<tbody>
<tr>
<td>ASSIGN, ATRIB(1) = XX(76);</td>
<td>STARTING TIME</td>
<td></td>
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<tr>
<td>ASSIGN, II = XX(36), ATRIB(2) = II;</td>
<td>PRIORITY</td>
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<tr>
<td>ASSIGN, II = UNFRM(XX(75), XX(74), 3), ATRIB(3) = II; AISLE NO</td>
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<td>ASSIGN, II = 1, ATRIB(5) = II;</td>
<td>LOT SIZE</td>
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<tr>
<td>ASSIGN, II = UNFRM(XX(75), XX(72), 2), ATRIB(6) = II; COLUMN NO</td>
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<td>ASSIGN, II = 5, ATRIB(7) = II; TRANSACTION TYPE</td>
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<tr>
<td>ASSIGN, II = UNFM(XX(75), XX(73), 3), ATRIB(8) = II; ROW NO</td>
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<tr>
<td>ASSIGN, ATRIB(4) = USERF(1), 1; S/R TRANSACTION TIME</td>
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<tr>
<td>ASSIGN, II = ATRIB(3) * 2 + 8, ATRIB(9) = II; CONTROL PT</td>
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</tbody>
</table>

WAIT AT THE RECEIVING AREA FOR AN AGV

(IFL) VFLBL CPNUM RVREQ REREL

CP2 VWAIT (2), AGV, 2, CLOSEST, TOP;

LOAD PALLET ONTO AGV

DUR

ACTIVITY, XX(39);

MOVE PALLET

CONTROL PT.

VMOVE, ATRIB(9);

SELECT ROUTE

NLBL

ACTIVITY, , , RT;

CP3 VWAIT (3), AGV, 3, CLOSEST, TOP;

ACTIVITY, XX(39);

VMOVE, ATRIB(9);

ACTIVITY, , , RT;

CP4 VWAIT (4), AGV, 4, CLOSEST, TOP;

ACTIVITY, XX(39);

VMOVE, ATRIB(9);

ACTIVITY, , , RT;

CP5 VWAIT (5), AGV, 5, CLOSEST, TOP;

ACTIVITY, XX(39);

VMOVE, ATRIB(9);

ACTIVITY, , , RT;
CP6 VWAIT  (6), AGV,  6, CLOSEST, TOP;
   ACTIVITY, XX(39);  
   VMOVE,  ATRIB(9);  
   ACTIVITY,  ,  , RT;

CP7 VWAIT  (7), AGV,  7, CLOSEST, TOP;
   ACTIVITY, XX(39);  
   VMOVE,  ATRIB(9);  
   ACTIVITY,  ,  , RT;

WHAT IS THE DESTINATION?
   IFL GATE M
   RT AWAIT (78), GATEO,  , 1;

ASSIGN VALUE TO SLAM GLOBAL VARIABLE
   ASSIGN,  II = ATRIB (3) + 31,  1;

IF INPUT STATION IS FULL THEN LOOP
   COND  NLBL
   ACTIVITY,  , NNRSC (II) .LE. 0, LOOP;  
   ACTIVITY,  , NNRSC (II) .GT. 0, CONT;

ELSE UNLOAD AGV
   CONT GOON,  1;

   COND  NLBL
   ACTIVITY,  , ATRIB(3).EQ. 1,  BT9;  
   ACTIVITY,  , ATRIB(3).EQ. 2,  BT11;  
   ACTIVITY,  , ATRIB(3).EQ. 3,  BT13;  
   ACTIVITY,  , ATRIB(3).EQ. 4,  BT15;  
   ACTIVITY,  , ATRIB(3).EQ. 5,  BT17;  
   ACTIVITY,  , ATRIB(3).EQ. 6,  BT19;  
   ACTIVITY,  , ATRIB(3).EQ. 7,  BT21;  
   ACTIVITY,  , ATRIB(3).EQ. 8,  BT23;  
   ACTIVITY,  , ATRIB(3).EQ. 9,  BT25;  
   ACTIVITY,  , ATRIB(3).EQ. 10, BT27;  
   ACTIVITY,  , ATRIB(3).EQ. 11, BT29;  
   ACTIVITY,  , ATRIB(3).EQ. 12, BT31;  
   ACTIVITY,  , ATRIB(3).EQ. 13, BT33;  
   ACTIVITY,  , ATRIB(3).EQ. 14, BT35;  
   ACTIVITY,  , ATRIB(3).EQ. 15, BT37;  
   ACTIVITY,  , ATRIB(3).EQ. 16, BT39;  
   ACTIVITY,  , ATRIB(3).EQ. 17, BT41;  
   ACTIVITY,  , ATRIB(3).EQ. 18, BT43;  
   ACTIVITY,  , ATRIB(3).EQ. 19, BT45;  
   ACTIVITY,  , ATRIB(3).EQ. 20, BT47;  
   ACTIVITY,  , ATRIB(3).EQ. 21, BT49;  
   ACTIVITY,  , ATRIB(3).EQ. 22, BT51;  
   ACTIVITY,  , ATRIB(3).EQ. 23, BT53;
ACTIVITY, ,ATRIB(3).EQ. 24, BT55;
ACTIVITY, ,ATRIB(3).EQ. 25, BT57;
ACTIVITY, ,ATRIB(3).EQ. 26, BT59;
ACTIVITY, ,ATRIB(3).EQ. 27, BT61;
ACTIVITY, ,ATRIB(3).EQ. 28, BT63;
ACTIVITY, ,ATRIB(3).EQ. 29, BT65;
ACTIVITY, ,ATRIB(3).EQ. 30, BT67;
ACTIVITY, ,ATRIB(3).EQ. 31, BT69;

; MOVE LOADED AGV AROUND THE LOOP
; CONTROL PT.
LOOP VMOVE, 79;

; ACTIVITY;

; CONTROL PT.
VMOVE, ATRIB (9);

; SEND AGV BACK TO INPUT STATION
NLBL
ACTIVITY, , , RT;

; WAIT AT TRACK SEGMENT
IFL
BT9 QUEUE ( 201 );

; BLOCK TRACK SEGMENT IF DROP-OFF SPACE IS NOT AVAILABLE
A
ACTIVITY / 1;

; WAIT AT DROP-OFF STATION
IFL RLBL BLOCK
CP9 AWAIT (9), 11, BLOCK;

; UNLOAD PALLET FROM AGV
DUR
ACTIVITY, XX (37);

; RELEASE AGV
VFLBL
VFREE, AGV;

; ADVANCE PALLET AT STATION
DUR
NLBL
ACTIVITY, XX (38), , SA1;

BT11 QUEUE ( 202 );
ACTIVITY / 2;
CP11 AWAIT (11), I2, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA2;

; BT13 QUEUE ( 203 );
ACTIVITY / 3;
CP13 AWAIT (13), , I3, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA3;

; BT15 QUEUE ( 204 );
ACTIVITY / 4;
CP15 AWAIT (15), , I4, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA4;

; BT17 QUEUE ( 205 );
ACTIVITY / 5;
CP17 AWAIT (17), , I5, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA5;

; BT19 QUEUE ( 206 );
ACTIVITY / 6;
CP19 AWAIT (19), , I6, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA6;

; BT21 QUEUE ( 207 );
ACTIVITY / 7;
CP21 AWAIT (21), , I7, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA7;

; BT23 QUEUE ( 208 );
ACTIVITY / 8;
CP23 AWAIT (23), , I8, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA8;

; BT25 QUEUE ( 209 );
ACTIVITY / 9;
CP25 AWAIT (25), , I9, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA9;

BT27 QUEUE ( 210 );
   ACTIVITY /10;
CP27 AWAIT (27), I110, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA10;

BT29 QUEUE ( 211 );
   ACTIVITY /11;
CP29 AWAIT (29), I111, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA11;

BT31 QUEUE ( 212 );
   ACTIVITY /12;
CP31 AWAIT (31), I112, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA12;

BT33 QUEUE ( 213 );
   ACTIVITY /13;
CP33 AWAIT (33), I113, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA13;

BT35 QUEUE ( 214 );
   ACTIVITY /14;
CP35 AWAIT (35), I114, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA14;

BT37 QUEUE ( 215 );
   ACTIVITY /15;
CP37 AWAIT (37), I115, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA15;

BT39 QUEUE ( 216 );
   ACTIVITY /16;
CP39 AWAIT (39), I116, BLOCK;
   ACTIVITY, XX (37);
   VFREE, AGV;
   ACTIVITY, XX (38), , SA16;
BT41 QUEUE ( 217 );
ACTIVITY /17;
CP41 AWAIT (41), I17, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA17;
;
BT43 QUEUE ( 218 );

ACTIVITY /18;
CP43 AWAIT (43), I18, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA18;
;
BT45 QUEUE ( 219 );
ACTIVITY /19;
CP45 AWAIT (45), I19, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA19;
;
BT47 QUEUE ( 220 );
ACTIVITY /20;
CP47 AWAIT (47), I20, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA20;
;
BT49 QUEUE ( 221 );
ACTIVITY /21;
CP49 AWAIT (49), I21, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA21;
;
BT51 QUEUE ( 222 );
ACTIVITY /22;
CP51 AWAIT (51), I22, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA22;
;
BT53 QUEUE ( 223 );
ACTIVITY /23;
CP53 AWAIT (53), I23, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA23;
BT55 QUEUE (224);
ACTIVITY /24;
CP55 AWAIT (55), I24, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA24;
;
BT57 QUEUE (225);
ACTIVITY /25;
CP57 AWAIT (57), I25, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA25;
;
BT59 QUEUE (226);
ACTIVITY /26;
CP59 AWAIT (59), I26, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA26;
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BT61 QUEUE (227);
ACTIVITY /27;
CP61 AWAIT (61), I27, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA27;
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ACTIVITY /28;
CP63 AWAIT (63), I28, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA28;
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BT65 QUEUE (229);
ACTIVITY /29;
CP65 AWAIT (65), I29, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA29;
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BT67 QUEUE (230);
ACTIVITY /30;
CP67 AWAIT (67), I30, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), , SA30;
;
BT69 QUEUE (231);
ACTIVITY /31;
CP69 AWAIT (69), I31, BLOCK;
ACTIVITY, XX (37);
VFREE, AGV;
ACTIVITY, XX (38), SA31;

WAIT AT OUTPUT STATION FOR S / R MACHINE
IFL RLBL BLOCK
O1 AWAIT (100), O1, BLOCK;

UNLOAD S / R MACHINE
DUR
ACTIVITY, XX (40);

RELEASE S / R MACHINE
RES
FS1 FREE, ATRIB(10);

ADVANCE PALLET ON STATION
DUR
ACTIVITY, XX (38);

WAIT AT PICKUP STATION FOR AGV
IFL VFLVL CP RVREQ REREL
CP10 VWAIT (10), AGV, 10, CLOSEST, TOP;

LOAD PALLET ONTO AGV
DUR
ACTIVITY, XX(39);

RELEASE OUTPUT STATION
RLBL
F01 FREE, 01;

MOVE PALLET
CPNUM
VMOVE, ATRIB (9);

GO TO SHIPPING
NLBL
ACTIVITY,,,STAT;

O2 AWAIT(102), O2 , BLOCK;
ACTIVITY, XX (40);
FS2 FREE, ATRIB(10);
ACTIVITY, XX (38);
CP12 VWAIT (12), AGV, 12, CLOSEST, TOP;
ACTIVITY, XX(39);
F02 FREE, O2;
VMOVE, ATRIB(9);
ACTIVITY,,,STAT;
; 03 AWAIT(104), 03 , BLOCK;
ACTIVITY, XX (40);
FS3 FREE, ATRIB(10);
ACTIVITY, XX (38);
CP14 VWAIT (14), AGV, 14, CLOSEST, TOP;
ACTIVITY, XX (39);
F03 FREE, 03;
VMOVE, ATRIB(9);
ACTIVITY,,,STAT;
;
04 AWAIT(106), 04 , BLOCK;
ACTIVITY, XX (40);
FS4 FREE, ATRIB(10);
ACTIVITY, XX (38);
CP16 VWAIT (16), AGV, 16, CLOSEST, TOP;
ACTIVITY, XX (39);
F04 FREE, 04;
VMOVE, ATRIB(9);
ACTIVITY,,,STAT;
;
05 AWAIT(108), 05 , BLOCK;
ACTIVITY, XX (40);
FS5 FREE, ATRIB(10);
ACTIVITY, XX (38);
CP18 VWAIT (18), AGV, 18, CLOSEST, TOP;
ACTIVITY, XX (39);
F05 FREE, 05;
VMOVE, ATRIB(9);
ACTIVITY,,,STAT;
;
06 AWAIT(110), 06 , BLOCK;
ACTIVITY, XX (40);
FS6 FREE, ATRIB(10);
ACTIVITY, XX (38);
CP20 VWAIT (20), AGV, 20, CLOSEST, TOP;
ACTIVITY, XX (39);
F06 FREE, 06;
VMOVE, ATRIB(9);
ACTIVITY,,,STAT;
;
07 AWAIT(112), 07 , BLOCK;
ACTIVITY, XX (40);
FS7 FREE, ATRIB(10);
ACTIVITY, XX (38);
CP22 VWAIT (22), AGV, 22, CLOSEST, TOP;
ACTIVITY, XX (39);
F07 FREE, 07;
VMOVE, ATRIB(9);
ACTIVITY,,,STAT;
08 AWAIT(114), 08 , BLOCK;
    ACTIVITY, XX (40);
FS8 FREE,ATRIB(10);
    ACTIVITY,XX (38);
CP24 VWAIT (24), AGV, 24, CLOSEST, TOP;
    ACTIVITY,XX(39);
F08 FREE, 08;
    VMOVE,ATRIB(9);
    ACTIVITY,,,STAT;
;
09 AWAIT(116), 09 , BLOCK;
    ACTIVITY, XX (40);
FS9 FREE,ATRIB(10);
    ACTIVITY,XX (38);
CP26 VWAIT (26), AGV, 26, CLOSEST, TOP;
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F09 FREE, 09;
    VMOVE,ATRIB(9);
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010 AWAIT(118), 010 , BLOCK;
    ACTIVITY, XX (40);
FS10 FREE,ATRIB(10);
    ACTIVITY,XX (38);
CP28 VWAIT (28), AGV, 28, CLOSEST, TOP;
    ACTIVITY,XX(39);
F010 FREE, 010;
    VMOVE,ATRIB(9);
    ACTIVITY,,,STAT;
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011 AWAIT(120), 011 , BLOCK;
    ACTIVITY, XX (40);
FS11 FREE,ATRIB(10);
    ACTIVITY,XX (38);
CP30 VWAIT (30), AGV, 30, CLOSEST, TOP;
    ACTIVITY,XX(39);
F011 FREE, 011;
    VMOVE,ATRIB(9);
    ACTIVITY,,,STAT;
;
012 AWAIT(122), 012 , BLOCK;
    ACTIVITY, XX (40);
FS12 FREE,ATRIB(10);
    ACTIVITY,XX (38);
CP32 VWAIT (32), AGV, 32, CLOSEST, TOP;
    ACTIVITY,XX(39);
F012 FREE, 012;
    VMOVE,ATRIB(9);
    ACTIVITY,,,STAT;
013 AWAIT(124), 013, BLOCK;
   ACTIVITY, XX (40);
FS13 FREE, ATRIB(10);
   ACTIVITY, XX (38);
CP34 VWAIT (34), AGV, 34, CLOSEST, TOP;
   ACTIVITY, XX(39);
F013 FREE, 013;
   VMOVE, ATRIB(9);
   ACTIVITY,,,STAT;
;
014 AWAIT(126), 014, BLOCK;
   ACTIVITY, XX (40);
FS14 FREE, ATRIB(10);
   ACTIVITY, XX (38);
CP36 VWAIT (36), AGV, 36, CLOSEST, TOP;
   ACTIVITY, XX(39);
F014 FREE, 014;
   VMOVE, ATRIB(9);
   ACTIVITY,,,STAT;
;
015 AWAIT(128), 015, BLOCK;
   ACTIVITY, XX (40);
FS15 FREE, ATRIB(10);
   ACTIVITY, XX (38);
CP38 VWAIT (38), AGV, 38, CLOSEST, TOP;
   ACTIVITY, XX(39);
F015 FREE, 015;
   VMOVE, ATRIB(9);
   ACTIVITY,,,STAT;
;
016 AWAIT(130), 016, BLOCK;
   ACTIVITY, XX (40);
FS16 FREE, ATRIB(10);
   ACTIVITY, XX (38);
CP40 VWAIT (40), AGV, 40, CLOSEST, TOP;
   ACTIVITY, XX(39);
F016 FREE, 016;
   VMOVE, ATRIB(9);
   ACTIVITY,,,STAT;
;
017 AWAIT(132), 017, BLOCK;
   ACTIVITY, XX (40);
FS17 FREE, ATRIB(10);
   ACTIVITY, XX (38);
CP42 VWAIT (42), AGV, 42, CLOSEST, TOP;
   ACTIVITY, XX(39);
F017 FREE, 017;
   VMOVE, ATRIB(9);
   ACTIVITY,,,STAT;
;

018 AWAIT(134), 018 , BLOCK;
    ACTIVITY, XX (40);
    FS18 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP44 VWAIT (44), AGV, 44, CLOSEST, TOP;
    ACTIVITY, XX(39);
    FO18 FREE, 018;
    VMOVE, ATRIB(9);
    ACTIVITY,,,,STAT;
;
019 AWAIT(136), 019 , BLOCK;
    ACTIVITY, XX (40);
    FS19 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP46 VWAIT (46), AGV, 46, CLOSEST, TOP;
    ACTIVITY, XX(39);
    FO19 FREE, 019;
    VMOVE, ATRIB(9);
    ACTIVITY,,,,STAT;
;
020 AWAIT(138), 020 , BLOCK;
    ACTIVITY, XX (40);
    FS20 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP48 VWAIT (48), AGV, 48, CLOSEST, TOP;
    ACTIVITY, XX(39);
    FO20 FREE, 020;
    VMOVE, ATRIB(9);
    ACTIVITY,,,,STAT;
;
021 AWAIT(140), 021 , BLOCK;
    ACTIVITY, XX (40);
    FS21 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP50 VWAIT (50), AGV, 50, CLOSEST, TOP;
    ACTIVITY, XX(39);
    FO21 FREE, 021;
    VMOVE, ATRIB(9);
    ACTIVITY,,,,STAT;
;
022 AWAIT(142), 022 , BLOCK;
    ACTIVITY, XX (40);
    FS22 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP52 VWAIT (52), AGV, 52, CLOSEST, TOP;
    ACTIVITY, XX(39);
    FO22 FREE, 022;
    VMOVE, ATRIB(9);
    ACTIVITY,,,,STAT;
;
O23
AWAIT(144), 023, BLOCK;
ACTIVITY, XX (40);
FS23
FREE, ATRIB(10);
ACTIVITY, XX (38);
CP54
VWAIT (54), AGV, 54, CLOSEST, TOP;
ACTIVITY, XX (39);
FO23
FREE, 023;
VMOVE, ATRIB(9);
ACTIVITY, , , STAT;

; O24
AWAIT(146), 024, BLOCK;
ACTIVITY, XX (40);
FS24
FREE, ATRIB(10);
ACTIVITY, XX (38);
CP56
VWAIT (56), AGV, 56, CLOSEST, TOP;
ACTIVITY, XX (39);
FO24
FREE, 024;
VMOVE, ATRIB(9);
ACTIVITY, , , STAT;

; O25
AWAIT(148), 025, BLOCK;
ACTIVITY, XX (40);
FS25
FREE, ATRIB(10);
ACTIVITY, XX (38);
CP58
VWAIT (58), AGV, 58, CLOSEST, TOP;
ACTIVITY, XX (39);
FO25
FREE, 025;
VMOVE, ATRIB(9);
ACTIVITY, , , STAT;

; O26
AWAIT(150), 026, BLOCK;
ACTIVITY, XX (40);
FS26
FREE, ATRIB(10);
ACTIVITY, XX (38);
CP60
VWAIT (60), AGV, 60, CLOSEST, TOP;
ACTIVITY, XX (39);
FO26
FREE, 026;
VMOVE, ATRIB(9);
ACTIVITY, , , STAT;

; O27
AWAIT(152), 027, BLOCK;
ACTIVITY, XX (40);
FS27
FREE, ATRIB(10);
ACTIVITY, XX (38);
CP62
VWAIT (62), AGV, 62, CLOSEST, TOP;
ACTIVITY, XX (39);
FO27
FREE, 027;
VMOVE, ATRIB(9);
ACTIVITY, , , STAT;

;
O28 WAIT(154), 028, BLOCK;
    ACTIVITY, XX (40);
FS28 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP64 VWAIT (64), AGV, 64, CLOSEST, TOP;
    ACTIVITY, XX (39);
F028 FREE, 028;
    VMOVE, ATRIB(9);
    ACTIVITY, ..., STAT;
;
O29 WAIT(156), 029, BLOCK;
    ACTIVITY, XX (40);
FS29 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP66 VWAIT (66), AGV, 66, CLOSEST, TOP;
    ACTIVITY, XX (39);
F029 FREE, 029;
    VMOVE, ATRIB(9);
    ACTIVITY, ..., STAT;
;
O30 WAIT(158), 030, BLOCK;
    ACTIVITY, XX (40);
FS30 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP68 VWAIT (68), AGV, 68, CLOSEST, TOP;
    ACTIVITY, XX (39);
F030 FREE, 030;
    VMOVE, ATRIB(9);
    ACTIVITY, ..., STAT;
;
O31 WAIT(160), 031, BLOCK;
    ACTIVITY, XX (40);
FS31 FREE, ATRIB(10);
    ACTIVITY, XX (38);
CP70 VWAIT (70), AGV, 70, CLOSEST, TOP;
    ACTIVITY, XX (39);
F031 FREE, 031;
    VMOVE, ATRIB(9);
    ACTIVITY, ..., STAT;
;
SUBMODEL S/R MACHINE

THIS SUBMODEL REPRESENTS THE HARDWARE OF THE S/R SYSTEM

CREATE 58 'RED' CUSTOMER ORDERS
CREATE, 0.01, 0.0, 1, 58;

ASSIGN CHARACTERISTICS FOR EACH PICK ORDER
VAR VALUE VAR VALUE CHARACTERISTIC
ASSIGN, II = XX (33), ATRIB(2) = II; PRIORITY
ASSIGN, II = 2, ATRIB(7) = II; TRANSACTION TYPE

BRANCH TO PICKING FILE
NLBL ACTIVITY,,PQQ;

CREATE 96 'GREEN' CUSTOMER ORDERS
CREATE, 0.01, 0.0, 1, 96;
ASSIGN, II = XX (34), ATRIB(2)=II;
ASSIGN, II = 3, ATRIB(7) = II;
ACTIVITY,,PQQ;

CREATE 229 'WHITE' CUSTOMER ORDERS
CREATE, 0.01, 0.0, 1, 229;
ASSIGN, II = XX (35), ATRIB(2)=II;
ASSIGN, II = 4, ATRIB(7) = II;
ACTIVITY,,PQQ;

VAR VALUE CHARACTERISTIC
PQQ ASSIGN, ATRIB(1) = XX(76); STARTING TIME
ASSIGN, II=UNFRM(XX(75),XX(74),1),ATRIB(3)=II; AISLE NO
ASSIGN, II=UNFRM(XX(75),XX(72),1),ATRIB(6)=II;COLUMN NO
ASSIGN, II=UNFRM(XX(75),XX(73),2),ATRIB(8)=II; ROW NO
ASSIGN, II=ATRIB(7)+71,ATRIB(9)=II; AGV DESTINATION

HOLD FILE FOR SEQUENCING CUSTOMER ORDERS
IFL GATE QUE1 AWAIT (1), DSFT;
ACTIVITY;

HOLD FILE FOR LOTTING ORDERS AND COMPUTING TRAVEL TIME FOR THE S/R MACHINES
QUE8 AWAIT(8),DSFT;
BATCH THE CUSTOMER ORDERS FOR THE DAY

THRESH SAVE RETAIN M
BATCH, , ATRIB(5), , FIRST, ALL(11), 1;

ROUTE ORDERS TO THEIR appropriate AISLE

COND NLBL
ACTIVITY, , ATRIB(3).EQ. 1, SA1;
ACTIVITY, , ATRIB(3).EQ. 2, SA2;
ACTIVITY, , ATRIB(3).EQ. 3, SA3;
ACTIVITY, , ATRIB(3).EQ. 4, SA4;
ACTIVITY, , ATRIB(3).EQ. 5, SA5;
ACTIVITY, , ATRIB(3).EQ. 6, SA6;
ACTIVITY, , ATRIB(3).EQ. 7, SA7;
ACTIVITY, , ATRIB(3).EQ. 8, SA8;
ACTIVITY, , ATRIB(3).EQ. 9, SA9;
ACTIVITY, , ATRIB(3).EQ. 10, SA10;
ACTIVITY, , ATRIB(3).EQ. 11, SA11;
ACTIVITY, , ATRIB(3).EQ. 12, SA12;
ACTIVITY, , ATRIB(3).EQ. 13, SA13;
ACTIVITY, , ATRIB(3).EQ. 14, SA14;
ACTIVITY, , ATRIB(3).EQ. 15, SA15;
ACTIVITY, , ATRIB(3).EQ. 16, SA16;
ACTIVITY, , ATRIB(3).EQ. 17, SA17;
ACTIVITY, , ATRIB(3).EQ. 18, SA18;
ACTIVITY, , ATRIB(3).EQ. 19, SA19;
ACTIVITY, , ATRIB(3).EQ. 20, SA20;
ACTIVITY, , ATRIB(3).EQ. 21, SA21;
ACTIVITY, , ATRIB(3).EQ. 22, SA22;
ACTIVITY, , ATRIB(3).EQ. 23, SA23;
ACTIVITY, , ATRIB(3).EQ. 24, SA24;
ACTIVITY, , ATRIB(3).EQ. 25, SA25;
ACTIVITY, , ATRIB(3).EQ. 26, SA26;
ACTIVITY, , ATRIB(3).EQ. 27, SA27;
ACTIVITY, , ATRIB(3).EQ. 28, SA28;
ACTIVITY, , ATRIB(3).EQ. 29, SA29;
ACTIVITY, , ATRIB(3).EQ. 30, SA30;
ACTIVITY, , ATRIB(3).EQ. 31, SA31;

SCHEDULE AISLE TO BE WORKED BY WHAT S / R MACHINE

IFL RES BLOCK M
SA1 AWAIT ( 99 ), ALLOC(1), , 1;

IF STOW OPERATION

COND NLBL
ACTIVITY, , ATRIB(7).EQ. 5, F11;

OTHERWISE PICK
ACTIVITY, , ATRIB(7).NE. 5;
; BLOCK S/R MACHINE IF OUTPUT STATION IS FULL
; IFL
BA1 QUEUE   ( 170 );
;
; PERFORM PICK OPERATION
;     A   DUR     NLBL
     ACTIVITY / 32, ATRIB (4), , 01;
;
FI1 GOON;
;
; LOAD PALLET ONTO S / R MACHINE
;     DUR
   ACTIVITY, XX (41);
;
; RELEASE INPUT STATION
;     RLBL     M
FREE,  I1,  1;
;
; PERFORM STOW OPERATION
;     DUR     NLBL
   ACTIVITY, ATRIB (4), , STAT;
;
SA2 AWAIT ( 101 ), ALLOC(2), , 1;
    ACTIVITY, , ATRIB (7) .EQ. 5, FI2;
    ACTIVITY, , ATRIB (7) .NE. 5;
BA2 QUEUE   ( 171 );
   ACTIVITY / 33, ATRIB (4), , 02;
FI2 GOON;
   ACTIVITY, XX (41);
FREE,  I2,  1;
   ACTIVITY, ATRIB (4), , STAT;
;
SA3 AWAIT ( 103 ), ALLOC(3), , 1;
    ACTIVITY, , ATRIB (7) .EQ. 5, FI3;
    ACTIVITY, , ATRIB (7) .NE. 5;
BA3 QUEUE   ( 172 );
   ACTIVITY / 34, ATRIB (4), , 03;
FI3 GOON;
   ACTIVITY, XX (41);
FREE,  I3,  1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
;
SA4 AWAIT ( 105 ), ALLOC(4), , 1;
    ACTIVITY, , ATRIB (7) .EQ. 5, FI4;
    ACTIVITY, , ATRIB (7) .NE. 5;
BA4 QUEUE   ( 173 );
   ACTIVITY / 35, ATRIB (4), , 04;
FI4 GOON;
   ACTIVITY, XX (41);
FREE,  I4,  1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
SA5  AWAIT (107), ALLOC(5), ATRIB (7).EQ. 5, FI5;
      ACTIVITY, ATRIB (7).NE. 5;
BA5  QUEUE (174);
      ACTIVITY / 36, ATRIB (4), 05;
F15  GOON;
      ACTIVITY, XX (41);
      FREE, I5, 1;
      ACTIVITY, ATRIB (4), ATRIB (7).EQ. 5, STAT;

SA6  AWAIT (109), ALLOC(6), ATRIB (7).EQ. 5, FI6;
      ACTIVITY, ATRIB (7).NE. 5;
BA6  QUEUE (175);
      ACTIVITY / 37, ATRIB (4), 06;
F16  GOON;
      ACTIVITY, XX (41);
      FREE, I6, 1;
      ACTIVITY, ATRIB (4), ATRIB (7).EQ. 5, STAT;

SA7  AWAIT (111), ALLOC(7), ATRIB (7).EQ. 5, FI7;
      ACTIVITY, ATRIB (7).NE. 5;
BA7  QUEUE (176);
      ACTIVITY / 38, ATRIB (4), 07;
F17  GOON;
      ACTIVITY, XX (41);
      FREE, I7, 1;
      ACTIVITY, ATRIB (4), ATRIB (7).EQ. 5, STAT;

SA8  AWAIT (113), ALLOC(8), ATRIB (7).EQ. 5, FI8;
      ACTIVITY, ATRIB (7).NE. 5;
BA8  QUEUE (177);
      ACTIVITY / 39, ATRIB (4), 08;
F18  GOON;
      ACTIVITY, XX (41);
      FREE, I8, 1;
      ACTIVITY, ATRIB (4), ATRIB (7).EQ. 5, STAT;

SA9  AWAIT (115), ALLOC(9), ATRIB (7).EQ. 5, FI9;
      ACTIVITY, ATRIB (7).NE. 5;
BA9  QUEUE (178);
      ACTIVITY / 40, ATRIB (4), 09;
F19  GOON;
      ACTIVITY, XX (41);
      FREE, I9, 1;
      ACTIVITY, ATRIB (4), ATRIB (7).EQ. 5, STAT;
SA10  AWAIT ( 117 ), ALLOC(10), 1;
   ACTIVITY, ATRIB (7) .EQ. 5, FI10;
   ACTIVITY, ATRIB (7) .NE. 5;
BA10  QUEUE ( 179 );
   ACTIVITY / 41, ATRIB (4), 010;
FI10  GOON;
   ACTIVITY, XX (41);
   FREE, I10, 1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
;
SA11  AWAIT ( 119 ), ALLOC(11), 1;
   ACTIVITY, ATRIB (7) .EQ. 5, FI11;
   ACTIVITY, ATRIB (7) .NE. 5;
BA11  QUEUE ( 180 );
   ACTIVITY / 42, ATRIB (4), 011;
FI11  GOON;
   ACTIVITY, XX (41);
   FREE, I11, 1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
;
SA12  AWAIT ( 121 ), ALLOC(12), 1;
   ACTIVITY, ATRIB (7) .EQ. 5, FI12;
   ACTIVITY, ATRIB (7) .NE. 5;
BA12  QUEUE ( 181 );
   ACTIVITY / 43, ATRIB (4), 012;
FI12  GOON;
   ACTIVITY, XX (41);
   FREE, I12, 1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
;
SA13  AWAIT ( 123 ), ALLOC(13), 1;
   ACTIVITY, ATRIB (7) .EQ. 5, FI13;
   ACTIVITY, ATRIB (7) .NE. 5;
BA13  QUEUE ( 182 );
   ACTIVITY / 44, ATRIB (4), 013;
FI13  GOON;
   ACTIVITY, XX (41);
   FREE, I13, 1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
;
SA14  AWAIT ( 125 ), ALLOC(14), 1;
   ACTIVITY, ATRIB (7) .EQ. 5, FI14;
   ACTIVITY, ATRIB (7) .NE. 5;
BA14  QUEUE ( 183 );
   ACTIVITY / 45, ATRIB (4), 014;
FI14  GOON;
   ACTIVITY, XX (41);
   FREE, I14, 1;
   ACTIVITY, ATRIB (4), ATRIB (7) .EQ. 5, STAT;
SA15 WAIT (127), ALLOC(15), 1;
   ACTIVITY, ATRIB(7), EQ. 5, FI15;
   ACTIVITY, ATRIB(7), NE. 5;
BA15 QUEUE (184);
   ACTIVITY / 46, ATRIB(4), 015;
FI15 GOON;
   ACTIVITY, XX(41);
   FREE, I15, 1;
   ACTIVITY, ATRIB(4), ATRIB(7), EQ. 5, STAT;
;
SA16 WAIT (129), ALLOC(16), 1;
   ACTIVITY, ATRIB(7), EQ. 5, FI16;
   ACTIVITY, ATRIB(7), NE. 5;
BA16 QUEUE (185);
   ACTIVITY / 47, ATRIB(4), 016;
FI16 GOON;
   ACTIVITY, XX(41);
   FREE, I16, 1;
   ACTIVITY, ATRIB(4), ATRIB(7), EQ. 5, STAT;
;
SA17 WAIT (131), ALLOC(17), 1;
   ACTIVITY, ATRIB(7), EQ. 5, FI17;
   ACTIVITY, ATRIB(7), NE. 5;
BA17 QUEUE (186);
   ACTIVITY / 48, ATRIB(4), 017;
FI17 GOON;
   ACTIVITY, XX(41);
   FREE, I17, 1;
   ACTIVITY, ATRIB(4), ATRIB(7), EQ. 5, STAT;
;
SA18 WAIT (133), ALLOC(18), 1;
   ACTIVITY, ATRIB(7), EQ. 5, FI18;
   ACTIVITY, ATRIB(7), NE. 5;
BA18 QUEUE (187);
   ACTIVITY / 49, ATRIB(4), 018;
FI18 GOON;
   ACTIVITY, XX(41);
   FREE, I18, 1;
   ACTIVITY, ATRIB(4), ATRIB(7), EQ. 5, STAT;
;
SA19 WAIT (135), ALLOC(19), 1;
   ACTIVITY, ATRIB(7), EQ. 5, FI19;
   ACTIVITY, ATRIB(7), NE. 5;
BA19 QUEUE (188);
   ACTIVITY / 50, ATRIB(4), 019;
FI19 GOON;
   ACTIVITY, XX(41);
   FREE, I19, 1;
   ACTIVITY, ATRIB(4), ATRIB(7), EQ. 5, STAT;
;
SA20 AWAIT (137), ALLOC(20), ATRIB(7).EQ. 5, FI20;
ACTIVITY,
ACTIVITY, ATRIB(7).NE. 5;
BA20 QUEUE (189);
ACTIVITY / 51, ATRIB(4), O20;
FI20 GOON;
ACTIVITY, XX(41);
FREE, I20, 1;
ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;

SA21 AWAIT (139), ALLOC(21), ATRIB(7).EQ. 5, FI21;
ACTIVITY,
ACTIVITY, ATRIB(7).NE. 5;
BA21 QUEUE (190);
ACTIVITY / 52, ATRIB(4), O21;
FI21 GOON;
ACTIVITY, XX(41);
FREE, I21, 1;
ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;

SA22 AWAIT (141), ALLOC(22), ATRIB(7).EQ. 5, FI22;
ACTIVITY,
ACTIVITY, ATRIB(7).NE. 5;
BA22 QUEUE (191);
ACTIVITY / 53, ATRIB(4), O22;
FI22 GOON;
ACTIVITY, XX(41);
FREE, I22, 1;
ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;

SA23 AWAIT (143), ALLOC(23), ATRIB(7).EQ. 5, FI23;
ACTIVITY,
ACTIVITY, ATRIB(7).NE. 5;
BA23 QUEUE (192);
ACTIVITY / 54, ATRIB(4), O23;
FI23 GOON;
ACTIVITY, XX(41);
FREE, I23, 1;
ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;

SA24 AWAIT (145), ALLOC(24), ATRIB(7).EQ. 5, FI24;
ACTIVITY,
ACTIVITY, ATRIB(7).NE. 5;
BA24 QUEUE (193);
ACTIVITY / 55, ATRIB(4), O24;
FI24 GOON;
ACTIVITY, XX(41);
FREE, I24, 1;
ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;
SA25 AWAIT (147), ALLOC(25), 1;
  ACTIVITY, ATRIB(7).EQ. 5, FI25;
  ACTIVITY, ATRIB(7).NE. 5;
BA25 QUEUE (194);
  ACTIVITY / 56, ATRIB(4), O25;
FI25 GOON;
  ACTIVITY, XX(41);
  FREE, I25, 1;
  ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;
;
SA26 AWAIT (149), ALLOC(26), 1;
  ACTIVITY, ATRIB(7).EQ. 5, FI26;
  ACTIVITY, ATRIB(7).NE. 5;
BA26 QUEUE (195);
  ACTIVITY / 57, ATRIB(4), O26;
FI26 GOON;
  ACTIVITY, XX(41);
  FREE, I26, 1;
  ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;
;
SA27 AWAIT (151), ALLOC(27), 1;
  ACTIVITY, ATRIB(7).EQ. 5, FI27;
  ACTIVITY, ATRIB(7).NE. 5;
BA27 QUEUE (196);
  ACTIVITY / 58, ATRIB(4), O27;
FI27 GOON;
  ACTIVITY, XX(41);
  FREE, I27, 1;
  ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;
;
SA28 AWAIT (153), ALLOC(28), 1;
  ACTIVITY, ATRIB(7).EQ. 5, FI28;
  ACTIVITY, ATRIB(7).NE. 5;
BA28 QUEUE (197);
  ACTIVITY / 59, ATRIB(4), O28;
FI28 GOON;
  ACTIVITY, XX(41);
  FREE, I28, 1;
  ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;
;
SA29 AWAIT (155), ALLOC(29), 1;
  ACTIVITY, ATRIB(7).EQ. 5, FI29;
  ACTIVITY, ATRIB(7).NE. 5;
BA29 QUEUE (198);
  ACTIVITY / 60, ATRIB(4), O29;
FI29 GOON;
  ACTIVITY, XX(41);
  FREE, I29, 1;
  ACTIVITY, ATRIB(4), ATRIB(7).EQ. 5, STAT;
;
SA30 AWAIT (157), ALLOC(30), 1;
ACTIVITY, ATRIB(7) .EQ. 5, FI30;
ACTIVITY, ATRIB(7) .NE. 5;
BA30 QUEUE (199);
ACTIVITY / 61, ATRIB(4), 030;
FI30 GOON;
ACTIVITY, XX(41);
FREE, I30, 1;
ACTIVITY, ATRIB(4), ATRIB(7) .EQ. 5, STAT;
;
SA31 AWAIT (159), ALLOC(31), 1;
ACTIVITY, ATRIB(7) .EQ. 5, FI31;
ACTIVITY, ATRIB(7) .NE. 5;
BA31 QUEUE (200);
ACTIVITY / 62, ATRIB(4), 031;
FI31 GOON;
ACTIVITY, XX(41);
FREE, I31, 1;
ACTIVITY, ATRIB(4), ATRIB(7) .EQ. 5, STAT;
;
; SUBMODEL COLLECT STATISTICS
; THIS SUBMODEL COLLECTS STATISTICS ON THE VARIOUS TYPES OF
; TRANSACTIONS
;
; IFL GATE M
STAT AWAIT (72), GATEO, 1;
;
; DETERMINE TRANSACTION TYPE
; COND NLBL
ACTIVITY, , ATRIB(7).EQ.1, CP73;
ACTIVITY, , ATRIB(7).EQ.2, CP74;
ACTIVITY, , ATRIB(7).EQ.3, CP75;
ACTIVITY, , ATRIB(7).EQ.4, CP76;
ACTIVITY, , ATRIB(7).EQ.5, CP77;

; TRANSHIPMENTS
; WAIT AT SHIPPING STATION
; IFL GATE
CP73 AWAIT (73), GATEO;
;
; UNLOAD PALLET FROM AGV
; DUR
ACTIVITY, XX(37);
;
; RELEASE AGV
; RES
VFREE, AGV;
;
; COLLECT STATISTICS
; HISTOGRAM
; TYPE ID NCEL HLOW HWID
SOTS COLCT, INT(1), TRANSHIPMENTS, 16 / 0 / 30;
;
; TERMINATE TRANSACTION
TERM;
;
; RED ORDERS
; CP74 AWAIT (74), GATEO;
ACTIVITY, XX(37);
VFREE, AGV;
;
; UNBATCH PALLET
; NATR
UNBATCH, ATRIB (11);
;
SOP1 COLCT, INT(1), RED ORDERS, 16 / 0 / 30;
ACTIVITY,,,TOTS;
GREEN ORDERS
CP75 AWAIT (75), GATEO;
   ACTIVITY, XX(37);
   VFREE, AGV;
   UNBATCH, ATRIB (11);
SOP2 COLCT,INT(1),GREEN ORDERS, 16 / 0 / 30;
   ACTIVITY,,,TOTS;

WHITE ORDERS
CP76 AWAIT (76), GATEO;
   ACTIVITY, XX(37);
   VFREE, AGV;
   UNBATCH, ATRIB (11);
SOP3 COLCT,INT(1),WHITE ORDERS, 16 / 0 / 30;
   ACTIVITY,,,TOTS;

ALL CUSTOMER ORDERS
TOTS COLCT,INT(1),ALL ORDERS, 16 / 0 / 30;
   TERM;

STOWS
CP77 AWAIT (162), GATEO;
   ACTIVITY, XX (40);
   FSR FREE, ATRIB(10);
SOS COLCT,INT(1),STOW ITEMS, 16 / 0 / 30;
   TERM;
; CONTINUATION OF THE CONTROL STATEMENTS
;
    ENDNET;
;
; RUN SIMULATION FOR A DAY
;  TTBEG  TTFIN
INIT,   0.,   870.0;
;
FIN;
APPENDIX D

USER SUPPORT AND CALLABLE SUBPROGRAMS OF SLAM II
USER SUPPORT AND
CALLABLE SUBPROGRAMS OF SLAM II

SUBROUTINE CLEAR
Reinitializes the statistical storage areas when called.

SUBROUTINE COPY(NRANK, IFILE, ATRIB)
Copies the values of the attributes of an entry into the vector ATRIB.

FUNCTION DPROB(CPROB, VALUE, NVAL, IS)
Returns a sample from a user-defined discrete probability function with cumulative probabilities and associated values.

SUBROUTINE FILEM (IFILE, ATRIB)
Files an entry with attributes stored in ATRIB into file IFILE.

SUBROUTINE FREE (NRES, IU)
Frees IU units of resource number NRES.

SUBROUTINE LINK(FILE)
Files an entry whose attributes are pointed to by MFA in the file IFILE.

FUNCTION MMFE(FILE)
Returns pointer to first entry in file.

FUNCTION NNQ(IFILE)
Returns number of entries in file.

FUNCTION NNRSC(NRES)
Return number of resource type NRES available.

FUNCTION NSCR(NTRY)
Returns pointer to the successor entry of the entry whose printer is NTRY.

SUBROUTINE RMOVE (NRANK, IFILE, ATRIB)
Removes an entry defined by the variable NRANK from a file defined by the variable IFILE. RMOVE loads the vector ATRIB with the attributes of the entry removed.

SUBROUTINE SEIZE (NRES, IU)
Sets IU units of resource number NRES busy.

SUBROUTINE SLAM
Calls the SLAM executive program.

SUBROUTINE ULINK
Removes entry with rank NRANK from the IFILE without copying its attribute values.
The following subprograms were used because SLAM II required special processing. Refer to Appendix C for more information on each.

SUBROUTINE ALLOC(N,IFLAG)
SUBROUTINE EVENT(JEVNT)
SUBROUTINE INTLC
PROGRAM MAIN
FUNCTION USER(N)
The following network input statements were used in the SLAM program.

- **ASSIGN Node** - assigns values to SLAM variables
- **AWAIT Node** - delays an entity in file until the number of resources are available.
- **BATCH Node** - releases the entities when the batch number is met.
- **CLOSE Node** - changes the status of a gate to closed.
- **COLCT Node** - collects statistics the time an entity arrives at an node.
- **CREATE Node** - generates entities within the network.
- **EVENT Node** - calls subroutine EVENT when an entity arrives.
- **FREE Node** - releases number of units of resource RES.
- **GOON Node** - provides a continuation mode where every entering entity passes through the node.
- **OPEN Node** - changes the status of gate to open.
- **QUEUE Node** - delays entities in file until a server becomes available.
- **TERMINATE Node** - destroys entities and/or terminates the simulation.
- **RESOURCE Block** - defines a resource by its label, number, and initial capacity or availability.
- **GATE Block**
- **REGULAR Activity** - used to delay entities by a specified duration, perform testing, and route entities to non-sequential nodes.
- **SERVICE Activity** - models single channel queues with identical servers.
- **UNBATCH Node** - release individual entities that were previously batched.
SLAM II CONTROL STATEMENTS

This section contains a list of SLAM II control statements used.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTINUOUS</td>
<td>enter step sizing information for differential and state equations.</td>
</tr>
<tr>
<td>FIN</td>
<td>end simulation.</td>
</tr>
<tr>
<td>GEN</td>
<td>enter general information about the simulation.</td>
</tr>
<tr>
<td>INITIALIZE</td>
<td>set the SLAM clock.</td>
</tr>
<tr>
<td>LIMITS</td>
<td>dimension the file capacity, number of attributes and number of entities.</td>
</tr>
<tr>
<td>MONTR</td>
<td>clear statistics or perform trace.</td>
</tr>
<tr>
<td>NETWORK</td>
<td>begin network statements.</td>
</tr>
<tr>
<td>PRIORITY</td>
<td>assign of file rankings.</td>
</tr>
<tr>
<td>SIMULATE</td>
<td>begin simulation.</td>
</tr>
<tr>
<td>STAT</td>
<td>collects statistics on SLAM variables and produce histogram.</td>
</tr>
<tr>
<td>TIMST</td>
<td>collects statistics on time persistent variables.</td>
</tr>
</tbody>
</table>
**MH EXTENSION STATEMENTS**

**NETWORK ELEMENT**

- **VCPOINT RESOURCE BLOCK**: enter information about control points.
- **VFLEET RESOURCE BLOCK**: enter information about AGV fleet.
- **VFREE NODE**: free AGV after delivery.
- **VMOVE ACTIVITY**: move AGV to destination, take shortest route.
- **VSGMENT RESOURCE BLOCK**: enter AGV track segment information.
- **VWAIT NODE**: request vehicle for transport.

**MH CONTROL STATEMENTS**

- **VCONTROL**: enter step sizing information for AGVS.