Proceedings of the 1986 Winter Simulation Conference
J. Wilson, J. Henriksen, S. Roberts (eds.)

INTERACTIVE SIMULATION MODELING OF AUTOMATED STORAGE RETRIEVAL SYSTEMS

Sethuraman Raghunath, Ronald Perry, Thomas Cullinane
Department of Industrial Engineering
Northeastern University, Boston, Massachusetts

ABSTRACT

Owing to the complexity and enormous cost involved in Automated Material Handling Systems, there is a growing need to use computer simulation in both the physical system and control software design of such systems. Simulation models can be developed to test not only the final system configuration, but also each installation phase. This paper describes the development of an interactive and flexible simulation software for Automated Storage/Retrieval Systems(AS/RS) of the Miniload variety. A modular approach is taken in the development of the simulation software so that the user, through an interactive menu, has the capability to model an AS/RS by selecting a combination of modules that define the AS/RS. The user then enters the values of the system variables specified for each module. This user-defined simulation model is translated into a simulation language source code and then executed.

1. INTRODUCTION

The automated factory requires the use of numerous key elements such as automated production machines, numerically controlled machining centers, robotics, automatic assembly machines and the technologies of automated storage/retrieval systems(AS/RS), which include automated storage, automated transportation, automated material identification and tracking equipment, and real-time computerized inventory control.

Figure 1 shows the layout of an AS/RS with a popular configuration, a loop conveyor. In this configuration, bins are selected and dispatched, under computer control, to specific workstations based on the status of all workstations. The stacker cranes execute either single commands(either storage or retrieval of a bin) or dual commands(storage of one bin and retrieval of another on the same trip), depending on various system measures. Bins are initially deposited at deposit stations at the end of the aisles, and are then transferred to the conveyor as space becomes available. Upon reaching a workstation, bins are transferred to the input buffer of the workstations. The required picking activity is performed on the bin by an operator and it is then placed on the output buffer for eventual transfer onto the conveyor. The conveyor transports the processed bins to their respective pickup stations at the end of the aisles. The stacker cranes transport the bins from the pickup stations to their respective storage locations. If there is no room for a bin at the pickup station or an input buffer at a workstation, the bin is recycled on the conveyor.

Many papers have been published on the development of simulation models for the design, analysis and evaluation of control algorithms for automated material storage and movement components such as AS/RS and AGV's[1, 2, 3, 4, 5]. With respect to modeling of AS/RS, detailed simulation models have been developed for a specific configuration of the system to address design and control policy issues. What has not been addressed, however, is the development of a simulation model, with an user interface, to study the system performance of the AS/RS for different physical configurations. This paper presents a simulation approach which allows the user to select a particular system configuration from a menu of configurations and enter the values of the variables associated with it. The simulation is then performed for the specific configuration, This gives the user flexibility in modeling the AS/RS for different components and configurations.

2. AN APPROACH TO MODELING AS/RS

2.1 The objective of the approach

The simulation software for AS/RS described here is designed to be used on a microcomputer-based environment(IBM-PC, PC/XT, PC/AT). No additional hardware is required. This will provide a less expensive alternative to users for AS/RS modeling.

The proposed simulation software has a two-pronged objective :

(1) To offer the user flexibility in modeling by breaking down AS/RS into modules, and developing the simulation software for each one of these modules.

(2) To provide user interaction by incorporating a menu which allows the user to select the required modules and then enter the values for the system variables defined for each component in the modules.

2.2 Description of AS/RS modules

There are five AS/RS modules(a central module and four support modules) defined for possible inclusion in a model. They are as follows :

a. Central Module

This module is defined by those system variables that are common to most AS/RS. Some such variables are : Number of aisles, dimensions of a rack face, number of storage slots in a rack face, dimensions of storage bins, and stacker crane characteristics.

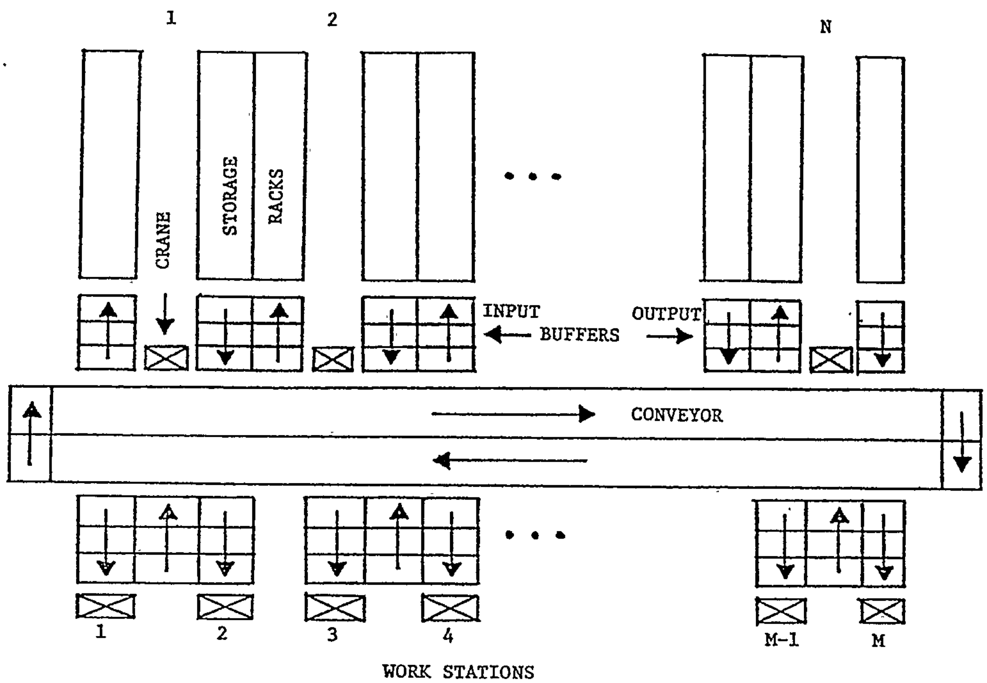


Figure 1. Physical Layout of Storage Retrieval System

b. Transporter Module

This module consists of the various possible transportation methods used to interface the AS/RS with a production or a distribution facility. Some possible components of this module are automatic guided vehicles, lift trucks, conveyors and monorails. The variables for each component are then defined.

c. Material Processing Function Module

This module deals with those functions performed on a bin prior to entering storage and after leaving storage. These functions include Load identification and sizing, sortation, and kitting.

d. Storage Configuration Module

This module deals with various storage location methods such as random storage(a location is assigned to a storage bin in a random manner), dedicated storage(storage racks are divided into zones and the bins are assigned to the zones depending on their picking frequency), and pattern search method (the storage location is selected by searching for the closest empty slot beginning with the lowest tier of the rack). This module also addresses possible sequencing rules such as first-in first-out, last-in first-out and shortest processing time.

e. Input/Output Configuration Module

This module consists of the various possible interfaces between the storage racks and the operators at workstations. Some possible interfaces are end-of-aisle configuration, loop conveyor systems, horseshoe configuration, and side shuttle station configuration.

These modules are illustrated in Fig.2.

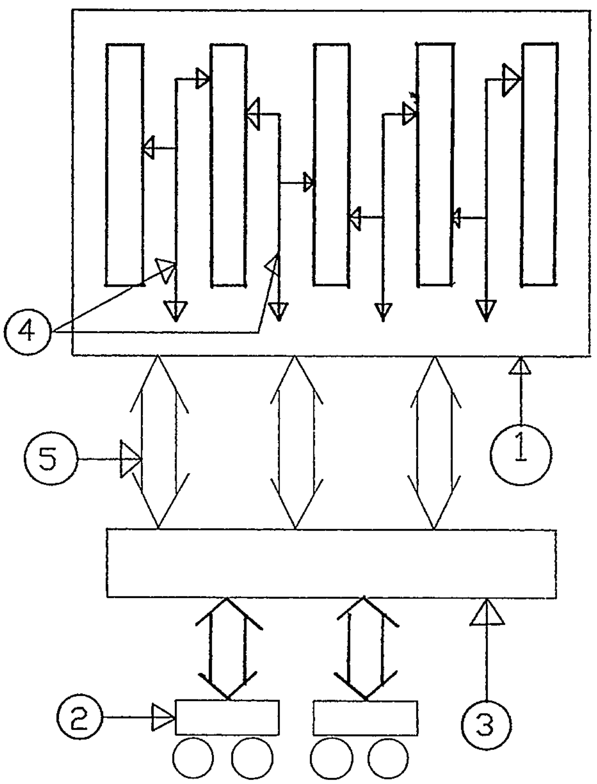
3. SIMULATION SOFTWARE DESIGN

The simulation language used to model the various AS/RS modules is SIMAN. SIMAN was chosen due to its capabilities to model various material handling components like conveyors and transporters. Also, model building is accomplished through various SIMAN blocks which are well suited for material flow applications. A BASIC program provides the environment within which the user defines the AS/RS model.

The menu for the modular approach is organized into three levels. Level 1 consists of the five modules mentioned in Section 2. Level 2 contains the components of each support module. For example, possible components for the input/output configuration module would be end-of-aisle configuration, horseshoe configuration and loop conveyor configuration. Level 3 defines the variables associated with the central module and each component of the support module. Figure 3 illustrates these levels for the central module and one support module, the input/support configuration module.

The BASIC program provides the user with the menu through which the AS/RS is defined. The menu is illustrated in Fig.4a. The user first selects a module from the menu, say, the input/output configuration module. The menu display at this stage is illustrated in Fig.4b. Then, a component from the module(e.g. loop conveyor system) is selected and the user enters the values

PROPOSED MODULES OF AN AS/RS SYSTEM



1 - CENTRAL MODULE
2 - TRANSPORTER MODULE
3 - MATERIAL PROCESSING FUNCTION MODULE
4 - STORAGE CONFIGURATION MODULE
5 - INPUT/OUTPUT CONFIGURATION MODULE

Figure 2

of system variables for that component. This explicitly defines the model component for the simulation model. The menu display at this stage is illustrated in Fig.4c.

The simulation software organization is shown in Figure 5. After the user has defined the AS/RS through the menu, the BASIC program then accesses those files containing the SIMAN language code for the modules selected, and generates the model and experimental files for SIMAN. Transfer of control then passes to SIMAN software from BASIC, wherein the model and experimental files are linked and executed to generate a standard SIMAN summary report which is displayed at the end of the simulation run. The user then has the option of going back to the BASIC menu to try another simulation run, maybe with different modules this time. Thus, the user will have the capability to easily define and execute models of AS/RS with different system components and operating policies.

4. EMPHASIS OF THIS PAPER

This paper demonstrates the feasibility of the above mentioned approach by developing the interactive simulation software for the central module and one supporting module, which is the input/output configuration module.

4.1 Modeling Assumptions

The major modeling assumptions in developing the software for the central module and input/output configuration module are as follows :

(i) Only one product type is stored in each bin.

(ii) Each storage bin is of the same size and capacity.

(iii) The storage location algorithm used is based on storage racks being divided into several zones. Bins are assigned to these zones such that bins containing fast moving items are stored in zones closer to the workstation than those containing slow moving items.

(iv) To simplify crane travel time calculations, it is assumed that each bin from a particular zone is located at the centroid of that zone.

(v) One stacker crane per aisle with storage racks on both sides of the stacker crane.

(vi) The crane's three drives for horizontal, vertical and shuttle(extractor mechanism) movements operate independently and simultaneously.

(vii) The effect of acceleration, deceleration of the crane and the creep velocity of the shuttle are assumed to be negligible while calculating crane cycle time.

(viii) The crane executes single and command cycles, with dual cycles used whenever possible.

(ix) The stacker crane movements follow the pursuit mode where the stacker stays at the current position, after completing a command, until the next command is issued.

(x) An idle crane may stay somewhere in the aisle or at the end of the aisle where the workstation is located.

(xi) The impact of component failures is not included in the model.

4.2 System description of input/output configuration module

The input/output configuration module developed has three possible forms :

(1) End-of-aisle delivery configuration

(2) Horseshoe configuration and

(3) Loop conveyor configuration

End-of-aisle delivery configuration

For an AS/RS with this interface, a storage bin, upon retrieval from its location by the stacker, is transported to the workstation at the end of the aisle. The operator at the workstation performs the required picking operation on the bin while the bin is still on the stacker platform. Once the picking activity is completed, the crane transports the bin back to its location. The operator, meanwhile, waits for the next bin to be transported by the crane

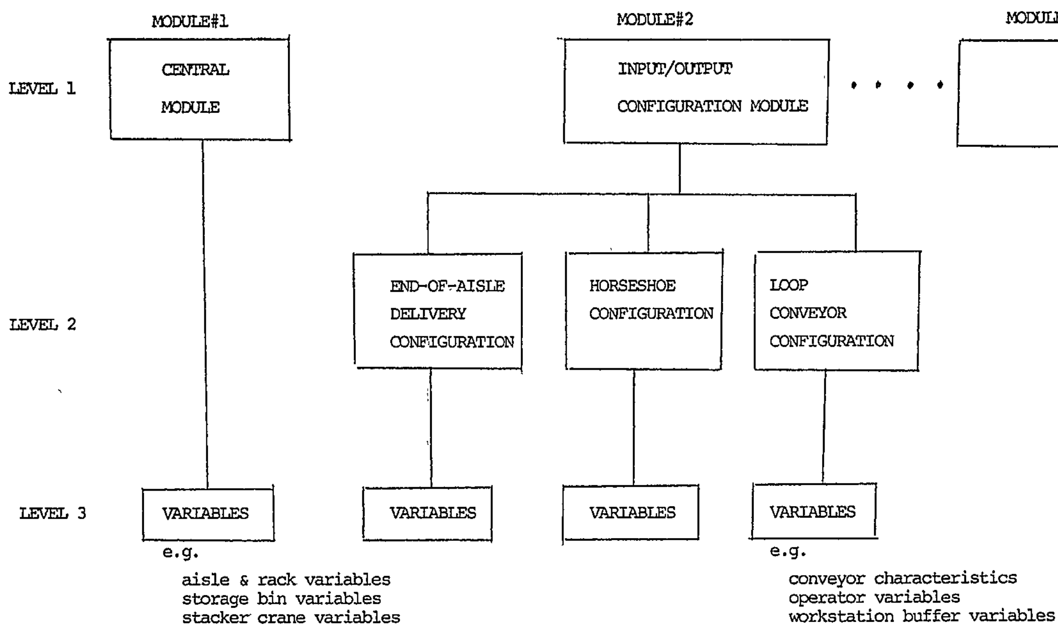


Figure 3 -- MENU ORGANIZATION

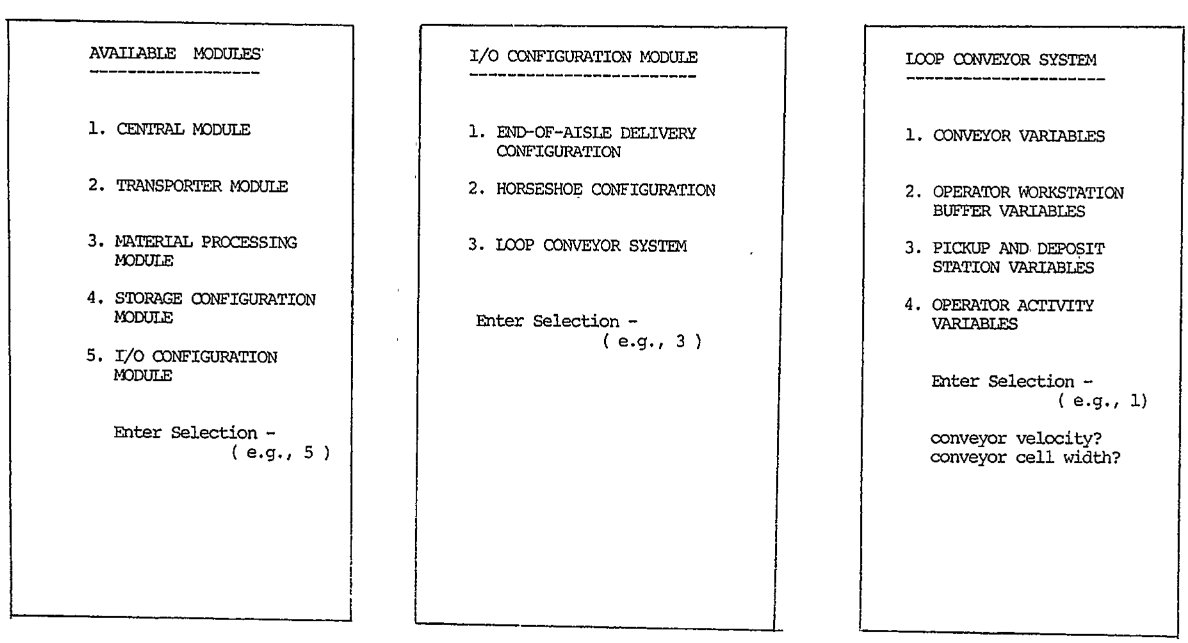


FIG. 4a FIG. 4b FIG. 4c

FIG.4 -- SAMPLE MENU

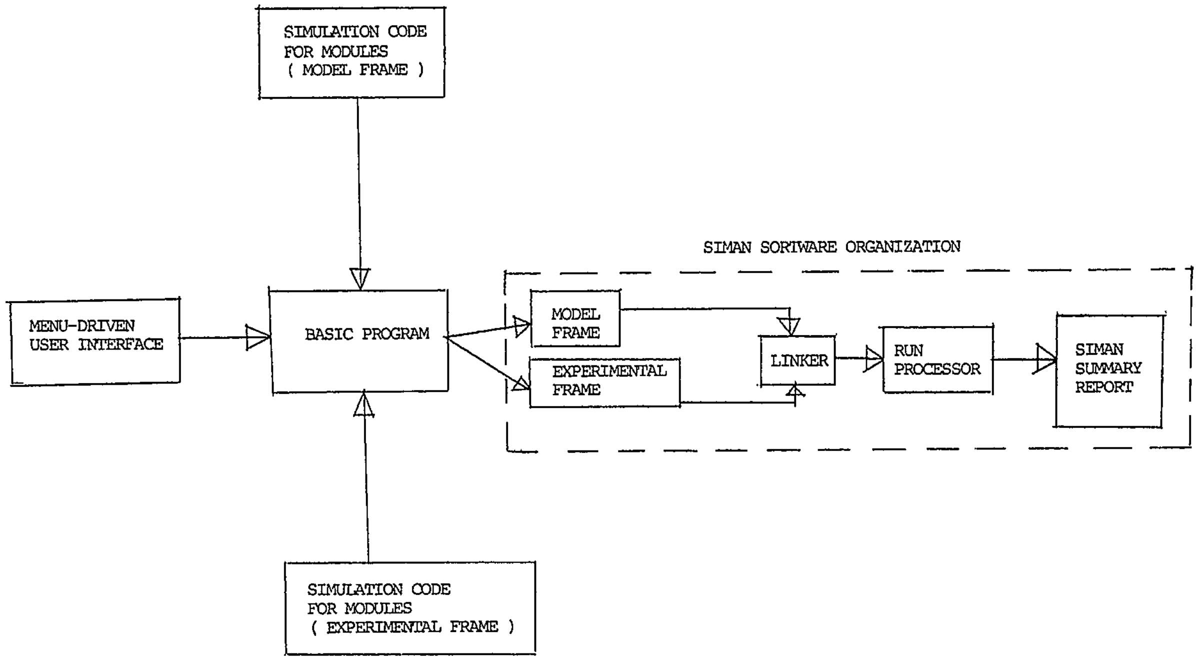


Figure 5 -- PROPOSED SIMULATION SOFTWARE ORGANIZATION

to the workstation before the next picking activity can be performed.

Horseshoe configuration

In this configuration, the storage bin, after being extracted from its location and transported to the workstation, is deposited on a small stretch of roller conveyor which serves as an input buffer to the operator at the workstation. The operator picks up the first bin from this buffer and performs the picking activity. The bin is deposited on anther roller conveyor that serves as the output buffer for the operator. The stacker picks up the bins from the output buffer as they become available and transports them back to their respective storage locations.

Loop conveyor configuration

This is a common configuration for an AS/RS where workstations are located along one side of a closed-loop, powered roller conveyor. This configuration is illustrated in Figure 1 and its operation is described in Section 1.

4.3 Programming considerations for user interaction and software flexibility

The term flexibility, with respect to the proposed modeling approach for AS/RS, refers to providing the user with the capability to easily model the system with different components and configurations. Flexibility, with respect to the software developed in this paper, refers to the capability of the user to model the AS/RS with the three different I/O configurations mentioned by selecting the desired configuration from the menu.

The approach taken in the software development to provide this flexibility is as follows : all SIMAN code, for both model and experimental frames, that is common to the three I/O configurations is placed is placed in two separate files(one for the model frame and the other for the experimental frame), referred to as "common files". For example, the common file for the model frame consists of the code for pre-loading the AS/RS, the generation of retrieval requests for bins and the transportation of the bins by the stacker, all of which are common code for the three I/O configurations. The SIMAN code that is unique to a particular configuration is placed in another file, referred to as "configuration file". For example, the configuration file(model frame) for the loop conveyor option consists of SIMAN code for modeling the conveyor and workstation aspects of the system. Two such configuration files are used for each configuration, one for the model frame and the other for the experimental frame.

A BASIC program generates the appropriate model and experimental frames for the configuration selected from the menu. For generating the model frame, the program always opens the common file for the model frame for reading. Then, depending on the configuration selected by the user, the program opens the corresponding configuration file for reading. The program then reads, sequentially, the common file and writes out the code, sequentially, to a new file, which will eventually contain the the complete SIMAN code for the model frame. This file is referred to as the "model file". This reading and writing process continues until a special character, placed appropriately in the common file is read. This now causes the program to read, sequentially, from the configuration file the SIMAN code and write out to the model file. This process continues until another special character, placed in the configuration file is read. This character denotes the end of a section of the SIMAN code to be read from the configuration file. The program then continues to read from the common file and write out the code to the model file. This approach allows the BASIC program to read, in the correct sequence, the SIMAN code from the common and configuration files and write out the code to the model file which will then contain the complete SIMAN code for the model frame for the selected configuration. The same approach is used to generate the experimental frame of the selected configuration.

Changes have to be made, by the BASIC program, to certain lines of code in the common and configuration files before they can be written out to the model file. These changes are with respect to QUEUE block file numbers, STATION block numbers and RESOURCE block capacities, which change for different values of system variables entered by the user. Empirical formulae were developed for each QUEUE block file number and STATION block number. These formulae are a function of the number of aisles in the AS/RS, the number of zones in a rack face, and the number of workstations along the conveyor(for loop conveyor configuration only). These formulae are different for each configuration and are stored in an array, along with RESOURCE block capacity variables, in the exact sequence in which these blocks are encountered in the common and configuration files. Figure 6 presents a flow chart which shows how the BASIC program performs the changes in the appropriate lines of SIMAN code in the common and configuration files.

5. USING THE SOFTWARE

To begin, the user selects the central module option from the menu and enters the system variable values associated with it. Some variables defined in this module are : rack and aisle variables(number of aisles, number of zones in a rack face, number of slots in a rack face etc.), storage bin variables(bin dimensions, bin capacity), stacker crane characteristics, distribution and activity of bins in zones of a rack face. The user then selects the I/O configuration module from the menu and picks one of its configurations. The values for the variables associated with this configuration are then entered by the user. For example, some variables for a loop conveyor configuration are operator workstation buffer capacities, pick-up and deposit station buffer capacities, operator variables(number of items picked from a bin, picking time for an item), and conveyor variables(velocity, conveyor capacity). The simulation software then creates the SIMAN code, runs the model and displays the output report for this configuration. The user has the option of running the simulation again, but with another configuration.

The output report generated by SIMAN consists of statistics collected for the measures of performance for the AS/RS and the display depends on the I/O configuration selected. For example, the following statistics will be displayed for the system with a loop conveyor configuration as part of the output:

a. System throughput(bins/unit time).
b. Throughput from each aisle for a multiple-aisle AS/RS.
c. The number of single and dual cycles executed by the stacker crane(s).
d. Utilization of the stacker crane(s).
e. Workstation operator utilization.
f. Queue at Pick-up and Deposit stations.
g. Queue at workstation buffers.

6. CONCLUSIONS AND SUGGESTIONS

This paper presents an approach to the development of an interactive and modular simulation software for AS/RS and the demonstration of the feasibility of this approach by the development of the software for two of the proposed five modules of the AS/RS.

Future work should focus on the development of the simulation software code for the remaining support modules and their integration with the central module. The user should then have the capability to model "what if" situations and study the impact of different system components and operating policies on system performance(e.g., different transporters, inventory policies, input/output configurations etc.). This flexibility and ease of use should lead to an enhancement in the design and analysis process for AS/RS and ultimately, to improved system designs.

Another aspect in further software development is the graphical display of output reports. SIMAN provides an output processor which can display the output as graphs, histograms, and bar charts. Also, the issues of graphical input of system parameters and the real-time animation of model execution should be addressed. The simulation software could make these graphical display aspects user selectable as part of future efforts.

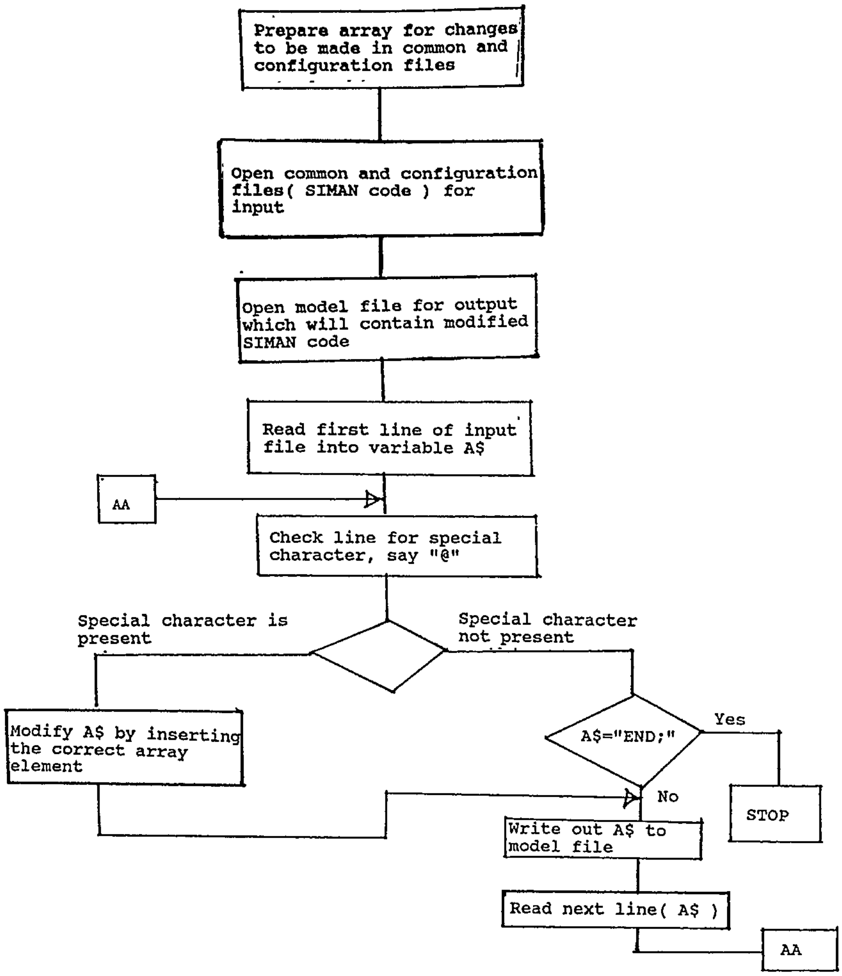


Figure 6 - Flow chart for changes to be made in SIMAN code by BASIC program

REFERENCES

1. Perry, R.F., Hoover, S.V., and Freeman, D.R., "An Optimum-seeking Approach to the Design of Automated Storage/Retrieval Systems", Proceedings of the Winter Simulation Conference, 1984.

2. Linn, R.J., Wysk, R., "A Simulation Model for Evaluating Control Algorithms of Automated Storage/Retrieval Systems", Proccedings of the Winter Simulation Conference, 1984.

3. Harmonsky, C.M., Sadowski, R.P., "A Simulation Model and Analysis : Integrating AGV's with Non-automated Material Handling Equipment", Proceedings of the Winter Simulation Conference, 1984.

4. Emerson, C.R., Schmatz, D.S., "Results of Modeling an Automated Warehouse System", AIIE Conference, 1982.

5. Winch, G.W., "Determination of Operating Capabilities of an Automated Coldstore using Simulation", Journal of Material Flow, 1982.

6. "AS/RS in the Automated Factory", Material Handling Institute Publication, 1983.

7. Phillips, D.T., "Simulation of Material Handling Systems : When and Which Methodology ?", Industrial Engineering, September 1980.

8. Bafna, K.M., "Use of Computer Simulation in Designing Complex Material Handling Systems", Proceedings of the Winter Simulation Conference, 1981.

9. Ashayeri, J., Gelders, L.J., "A Simulation Package for Automated Warehouses", Journal of Material Flow, 1983.

10. Pegden, C.D., "Introduction to SIMAN", Systems Modeling Corporation, 1985.

11. Kulwiec, Raymond(editor), "Material Handling Handbook", 1985.

BIOGRAPHICAL SKETCHES

SETHURAMAN RAGHUNATH has just completed his Master of Science degree in Industrial Engineering at Northeastern University, Boston. He has a Bachelor of Engineering degree in Production Engineering from the University of Madras, Madras, India. His research interests are in the areas of Automated Manufacturing and Material Handling Systems, and Systems Integration. He is a member of AIIE and SME(CASA division).

RONALD F. PERRY is an Associate Professor of Industrial Engineering and Information Systems at Northeastern University, Boston. He received his Ph.D. in Industrial and Operations Engineering from the University of Michigan. His current research interests include Simulation Analysis, MIS/Office Automation and Institutional Research. He is a senior member of AIIE and a member of ORSA, TIMS, AIR and SCS. He has presented papers regularly at the conferences of these organizations.

THOMAS P. CULLINANE is currently the Chairman of the Department of Industrial Engineering and Information Systems at Northeastern University, Boston. He received his Ph.D. from Virginia Polytechnic Institute and State University. His current research includes Materials Handling, Facilities Layout, Engineering Economic Analysis and Manufacturing. He has published over thirty articles and delivered talks to a wide range of audiences on topics related to modernization of manufacturing systems. He has extensive experience as a consultant on a wide range of engineering and material handling projects.