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Why a single aisle miniload system is not simple to model

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ABSTRACT

In order to test the performance of various storage assignment policies of a miniload warehouse system a general simulation model was developed. Even though the system concept was relatively simple, the simulation model became quite complex. This is because there are numerous factors in the design and operation of even a simple, single aisle system which influence performance. This inherent complexity has contributed to the difficulty in anticipating the performance of large, automated warehouses. A set of assumptions is given which can realistically be expected to simplify a simulation model. Some of the factors which make a general simulation of this model difficult to construct are then considered. Simulation input parameters and output statistics are used to illustrate the generality of the model developed.

1. INTRODUCTION

Large warehouses which are, to one degree or another, computer controlled are becoming more and more prevalent both in industry and the military. These automated storage facilities have developed problems which need to be overcome. One example of an automated warehouse problem that has occurred is in the control of automatic guided vehicles (AGVs) around the warehouse aisles so that they avoid collisions and take efficient routes as they store and retrieve items. Another problem is developing guidelines that govern the location of the items to be stored so that the travel time of the pickup vehicles is minimized. Because of the complexity of these storage systems, simulation has obvious utility in their modelling for analysis. We will show that even for one of the most basic warehouse configurations, modelling is not simple. There are so many variables that need to be considered that a realistic simulation model will be complex.

One advantage that simulation modelling has over strictly analytic modelling is that an approach can be taken which starts with a simple model and embellishes it until the desired degree of reality is reached. This increasing complexity is relatively easy to add in successive versions of a model and helps the validation process. The analytic modelling approach usually requires the reformulation of the problem with each change in the model (Pritsker 1987).

With this view of starting with a less elaborate model, we look at one of the simplest warehouse systems, that is, a single aisle, automatic storage and retrieval (S/R) warehouse with containers of the same size on either side of the aisle. This warehouse will be what is known as a miniload system. Miniload systems are used in warehousing and manufacturing environments to store a large number of small items in inventory. Miniload systems have become a major component in the operation of warehousing and manufacturing systems because they can reduce material handling costs, speed delivery, and keep precise control of the inventory. The most important justification of a miniload system is that it can process a large number of retrieval orders for the items in inventory (Gomez 1988).

The performance of different storage assignment rules has been studied by Graves, Hausman, and Schwarz (Graves, Hausman, and Schwarz 1977, Hausman, Schwarz, and Graves 1976, Schwarz, Graves, and Hausman 1978) and Bozer and White (Bozer and White 1984, Bozer 1985). General simulation models have been developed by Lynn and Wysk (Linn and Wysk 1984) and by Medeiros, Enscore, and Smith (Mederirus, Ensore and Smith 1986) for miniload systems. These models can be used to determine the average travel time of the S/R machine and the number of container retrievals performed by a miniload system per period of time. The model developed for this work represents an extension to add more of the system factors so that the average number of retrieval orders completed by a miniload system per time period may be determined. The main difference from past work is that the number of container retrievals required to process each retrieval order is not assumed to be constant. Previous models assumed that the dispersion levels of like items in the containers did not affect the number of retrieval orders completed per period. One of the motivations for the development of this model was to see what influence different storage assignment rules had on item dispersion and the effect the resulting dispersions had on the average number of retrievals.

2. SIMPLYING ASSUMPTIONS

The model of the miniload system is simpler than other possible models in several ways:

- There is only one aisle. Most actual warehouses would have several aisles. If the S/R machines, either AGVs or human driven, can go to more than one aisle than the system is greatly complicated by routing and collision avoidance considerations.

- The storage and retrieval system is automatic. The performance of the S/R machine is constant. Its speeds are always the same. If a person is operating the S/R machine then human variability, rest breaks, etc. would have to be taken into consideration.

- There is a pickup and delivery (P/D) station at one end of the aisle manned by a worker. The S/R machine picks up and delivers containers to only one place.

- The S/R machine does not have to adapt to different size containers. While the containers are not necessarily the same size, the S/R machine operation is fairly simple in that it goes through the same motions for each storage and retrieval operation.

- The containers are captive to the system. Their number will not increase or decrease.

- Each container is assigned to one specific location in the aisle.

- The vertical distance separating each pair of containers is constant.

- The containers themselves are moved by the S/R machine. The S/R machine does not have to slide out draws, pick individual items, etc.

- The S/R machine has the capacity to move only one container at a time.

- The aisle is symmetric. Both sides of the aisle have the same characteristics.

- Inventory quantities and locations are recorded on a computer. The storage and retrieval orders are computer driven. No human error for misplacing items need be modelled. The loader at the end of the aisle is a person physically taking items out of the containers to fill orders and putting other items in the containers to store items. There will be human interaction with the computer at this point. How much interaction depends on the storage system being used; that is, the rules governing which items go into which containers.

- All the retrieval orders for one day are given at the beginning of that day. The computer is loaded with the orders that have been previously received and are to be filled during the day. This way, it is not necessary to figure out demand distributions over the course of a day.

- The retrieval orders arriving at the system are served using only the current inventory stored in the containers.

- The rate of demand of the items is constant.

- The reorder point and maximum inventory level of each item is constant.

3. COMPLICATING FACTORS

In addition to the miniload system characteristics which tend to simplify any modelling effort, there are many characteristics that a real system would have that complicate the modelling effort. These factors are added because they influence the statistical results of the miniload operation and are needed for realistic analysis.

- The containers may have differing numbers of divisions (boxes). Since we are modelling a miniload system there are many small items to be stored. In this case, more than one type of item may by stored in different boxes of a container, but no one box may have more than one type of item in it. So that different types of containers are not mixed together in the aisle, the aisle is divided into sections. Each section has identical containers, i.e., containers with the same number of boxes.

- An order may not require a container retrieval. When a container is retrieved to fill an order for an item, the item needed for one of the next few retrievals will already be at the loader if it is in another box of the same container.

- The containers are stored in racks. Each rack consists of a given number of columns of storage locations, called bays. The bays in each storage rack can be divided into a number of different storage sections. Each storage section represents a number of consecutive bays on each side of the aisle. Each individual bay in the rack represents a column of identical containers. This means that the S/R machine must be able to move vertically as well as horizontally. The horizontal distance separating each pair of consecutive bays in the same storage section is constant.

- Each storage section is used to store a specific group of items. The items to be stored in a particular storage section cannot be stored using the containers of any of the other storage sections in the aisle. The items stored in the same storage section have a constant and equal rate of demand. All items stored in a specific storage section require the same number of boxes in order to store their maximum inventory level.

-The S/R machine has different speeds. The horizontal speed will typically be different from the vertical speed. There is also acceleration and deceleration to consider.

-The S/R machine can move both horizontally and vertically at the same time.

-The time it takes the S/R machines to pick up and deposit containers must be included.

-Interleave time should be included. Interleave time is the time it takes the S/R machine to move from the location where it just returned a container to where it will pick up the next container.

-The S/R machine may perform two or more consecutive storage or retrieval operations. Normally, the S/R machine operates in a dual cycle mode. In a dual cycle, the machine stores a container, performs an interleave, and retrieves another container. If there is not another storage or retrieval to be performed immediately, rather than remain idle, the S/R machine will perform a second container storage or retrieval operation.

-The P/D station, also called the workstation, has room to hold containers. The P/D station has three separate queues: one to hold containers waiting to have items removed, another for those waiting to be put back in the aisle, and a third to hold the items arriving from outside the aisle for storage. If these queues did not exist, then the S/R machine would often have to wait on the worker or the worker would have to wait on the S/R machine. With the queues, the S/R machine may still be blocked if the retrieval queue is full but, blocking would occur less often. The central position of the workstation, called the workcell, is where the worker stores and removes the items from the containers and communicates with the computer. The computer indicates to the worker the specific items to be stored and removed from each container.

-More than one retrieval may to necessary to fill on order. The storage and retrieval procedures will govern how items are to be stored in the aisle. While it is desireable to have like items together, they may become scattered over time. This item dispersion over time is largely dependent on the storage policy used. Filling an order for more than one of a particular type of item may require more than one container retrieval.

-Storage orders are issued when inventory level falls below the reorder point. The computer must monitor the number of each item on hand and issue orders for more when the number gets too low. Reorder point and lagtime until replacement items arrive are variables of the model which influence performance.

4. SIMULATION MODEL

A simulation model was written to take into account all of the considerations listed above. It was written in the SIMAN language (Pegden 1985) and can be run on an IBM compatible microcomputer with at least 640K of RAM memory. The simulation model was developed in order to determine the dynamic behavior and the long term performance characteristics of a miniload system run under various storage assignment policies.

The simulation model developed is unique in several ways. First, the model allows the user to specify the type of containers in terms of the number of boxes per container and the number of units of an item that can be stored in each box. Second, the state of the system is described in terms of the current utilization of the boxes in the containers, the current inventory level of the items, and the current storage location of each of the items. Third, the model allows the size of the individual retrieval orders to be specified as a random number. In addition, the specific containers needed to process a retrieval order are determined based on the current inventory level and the storage location of the item requested.

The performance measures determined by running the model include the number of retrieval orders completed per time period and the ratio of the number of retrieval orders completed to the number of container retrievals performed by the system during each period. This model was developed because previous models presented in the literature do not allow determination of these performance measures taking into consideration the dispersion level of the items among the containers.

4.1 Input Parameters

The input parameters defined in the model determine the flexibility of the model to represent different systems and conditions. In particular, the input parameters are used to describe each of the storage sections in the aisle, the workstation, the inventory policy, the arrival rate of the items, and the time considerations describing the system. Table I gives a list of input parameters the user must specify to describe each of the storage sections. The overall system input parameters are given in Table II. Both of these input parameters sets are specified by the user using an external data file. In the SIMAN experiment model the user must specify the items in Table III.

Table I. Input Parameters Describing Each Storage Section of the Aisle.

JST1 The code number of the storage section.

JST2 The number of boxes per container.

JST3 The total number of containers in the storage section.

JST4 The number of containers per bay.

JST5 The total number of bays in the storage section.

JST6 The vertical distance separating each pair of containers in the same bay.

JST7 The number of boxes required to store each of the individual items in the storage section.

JST8 The number of units that can be stored in each box.

JST9 The horizontal distance separating each pair of consecutive bays in the storage section.

JST10 The service priority for retrieval orders for items in this storage section.

JST11 The desired utilization level of the storage space specified as a percentage of the number of containersin the storage section.

JST12 The maximum number of different containers that can be used to store the inventory of an item.

At the beginning of each time period, the model creates the sequence of retrieval orders to be processed during the period. Each item in a storage section has the same rate of demand, but items in different storage sections can have different rates of demand. Storage sections are defined in this way in order to test different placements of items along the aisle depending on their demand rate.

A model database is kept containing records indicating the current inventory and the current storage location of each of the items in the system. Each order may require retrieving more than one container. The specific containers

Table II. Input Parameters Describing the System.

HSPEED The horizontal velocity of the S/R machine.

INDELA The time required by the S/R machine to store or remove a container from the storage racks.

JVAR1 The number of retrieval orders to be processed by the system per time period.

JVAR3 The number of containers in each side of the aisle.

JVAR5 The number of storage orders in the storage order queue that need not be chosen on a FCFS basis.

JVAR6 The number of different storage sections in the aisle.

LERAQ The size of the storage orders queue.

PAR4 An indicator of the reorder point of items in terms of their maximum inventory level.

PAR7 The number of work periods indicating how often the system checks the size of the storage orders queue.

PAR8 The delay time to receive each of the storage orders requested by the system.

PMO A number between 0 and 1 which, when multiplied by the maximum inventory level, will give the smallest number of units of an item that can be stored in a box.

POLICY A code specifying one of several storage policies.

VSPEED The vertical velocity of the S/R machine.

X(33) The number of containers that can be placed in the input queue at the workstation.

X(34) The number of containers that can be placed in the output queue at the workstation.

X(37) The time required by the S/R machine to place or remove a container from the conveyor line at the workstation.

X(50) The time length of each time period.

Table III. Inputs for The Experiment Model.

1 The fraction of the arriving retrieval orders corresponding to each of the different storage sections in the aisle.

2 The probability distributions used to determine the size of the retrieval orders.

3 The delay time required by the worker to remove the items from the containers.

4 The delay time of the worker to store the items in the containers.

5 The length of the simulation experiment.

required to process a retrieval order are retrieved in sequential order before the system continues to process the next retrieval order waiting in queue.

5. MODEL OUTPUT

Summary statistics can be divided into two groups: discrete statistics and time persistent statistics. These are listed in Tables IV and V, respectively. In addition, the simulation also creates a data file to store the individual observations recorded for the time discrete statistics representing the number of complete retrieval orders, the utilization level of the storage space, and the number of storage orders created during each time period. These reported observations can be plotted in order to observe the behavior of the system and to identify the transient period.

6. SUMMARY

Because of the large number of input parameters used to define how the miniload system simulation model is to be run, it can be used to analyze system performance under many different conditions. The two most valuable measures of system performance are the number of retrieval orders completed per time period and the ratio of the number of retrieval orders completed to the number of container retrievals performed per time period. Some of the parameters which may be analyzed are:

1) Storage policy,
2) Utilization level of the storage space,
3) Number of different storage sections in the aisle,
4) Size of the retrieval orders,
5) Number of containers that can be placed at the workstation,
6) Priority level of the retrieval orders corresponding to the different storage sections in the aisle,
7) Velocity of the S/R machine,
8) Distance between containers, and
9) Number of boxes per container.

The model of a single aisle miniload warehouse system is used to indicate how complex a warehouse simulation can become. A relatively simple situation was chosen for testing various storage policies. The resulting simulation model had to be quite general in nature in order to realistically compare the performance of the system under these different policies. The complexity of the program which developed illustrates how difficult it can be to model larger warehouse situations.

Table IV. Summary Output for Discrete Statistics.

1 The number of complete retrieval orders divided by the number of retrieval orders created per period.

2 The number of incomplete retrieval orders divided by the number of retrieval orders created per period.

3 The number of balked retrieval orders divided by the number of retrieval orders created per period.

4 The number of remove retrieval orders divided by the number of retrieval orders created per period.

5 The number of orders in the storage orders queue at the end of each time period.

6 The number of storage orders requested per period.

7 The average cycle time of a container during each period.

8 The utilization level of the storage space at the end of each time period.

9 The average one way travel time to retrieve a container during each time period.

10 The average interleave travel time of the S/R machine during each time period.

11 The average one way travel time to store a container during each time period.

12 The average dual cycle time of the S/R machine during each time period.

13 The number of dual cycles completed by the S/R machine during each time period.

Table V. Summary Output for Time Persistent Statistics

1	The utilization of the S/R machine.
2	The blocked time of the S/R machine.
3	The size of the input queue.
4	The utilization of the workcell.
5	The utilization of the worker.
6	The blocked time of the containers at the workcell.
7	The size of the retrieval orders queue.
8	The size of the output queue.
9	The size of the storage orders queue.

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