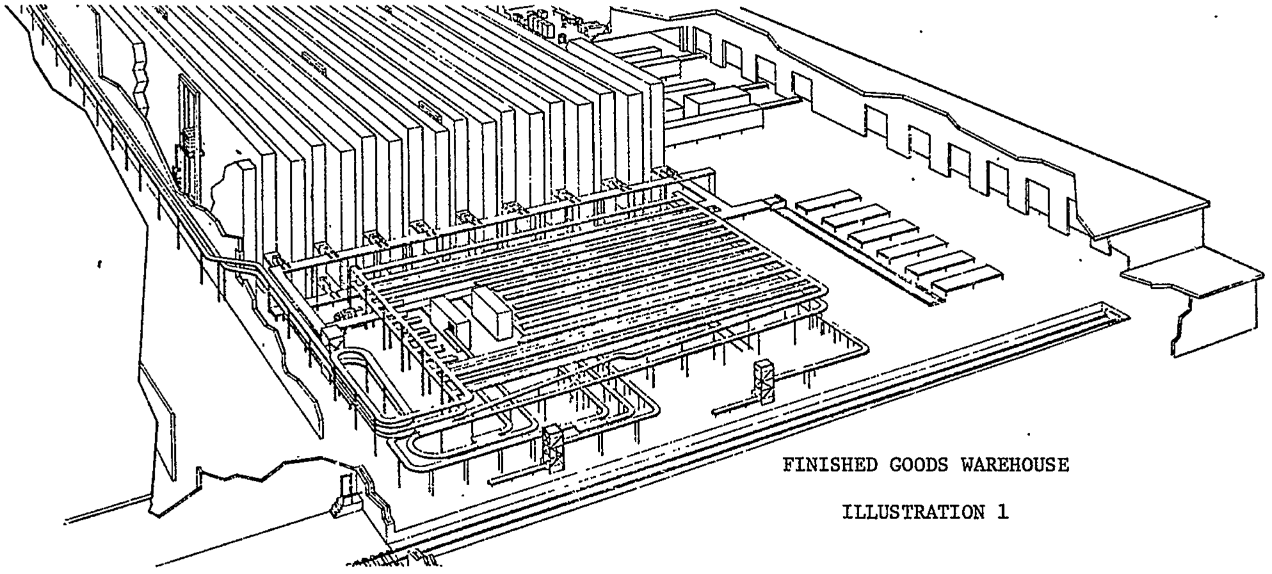
SIMULATION OF AN AUTOMATED STACKER STORAGE SYSTEM

R. Miles Waugh and Richard A. Ankener

Philip Morris, USA
Richmond, Virginia



FINISHED GOODS WAREHOUSE

ILLUSTRATION 1

ABSTRACT

The Management Sciences Department at Philip Morris has been investigating areas of optimization within the Finished Goods Warehouse. In pursuing these studies, simulation models have been used as analytical tools. For modelling, GASP IV Simulation Language was selected since it provides exceptional flexibility.

The most recently developed model simulates operation of the automated stacker storage and retrieval system. Through analysis of model behavior, Management Sciences evaluates a variety of algorithms. Concepts such as surge controlled interleaving, zones based on turnover, and load leveling have been tested.

After determining which algorithms provide the greatest efficiency, Management Sciences submits reports to appropriate managers. Additional studies are being accomplished by analyzing model behavior at higher production levels to identify system bottlenecks.

INTRODUCTION

Located in Richmond, Virginia is the largest production facility for Philip Morris, Inc. This Manufacturing Center contains the most recently developed cigarette production equipment, including "state-of-the-art" computerized control systems. As Philip Morris has continued to experience dramatic sales increases, corresponding increases in production requirements have made total system optimization of paramount concern. In this direction, every effort is being undertaken to determine the greatest efficiency in operating the Manufacturing Center.

Management Sciences Department of Philip Morris is involved in the effort to increase total system efficiency. After performing investigations, modelling, and analysis, the department provides results to managers who use the information in selecting the best alternative. Through effective communication links, close interaction has been established with all other departments. Users contribute directly to project development, and the "team effort" enhances department visibility. In three years, Management Sciences has evolved from one individual to a department of eight, and the scope of its activity has broadened to include many areas of study.

The Finished Goods Warehouse is one of three major divisions of the Manufacturing Center. As completed cases of cigarettes arrive, computers control their sorting, palletization, storage, and finally, retrieval of pallets for shipment. A hierarchy of one supervisory computer and three minicomputers (F1,F2,F3) control all automated operations. The conveyorized sorting and automatic palletization is controlled by F1. Pallet storage and retrieval is accomplished by F2. Retrieved pallets are then distributed to appropriate loading spurs by F3.

In 1975, Management Sciences developed a combined discrete and continuous simulation model of the case sorting and palletization system in the warehouse.[1] The area modelled is shown in the foreground of Illustration 1. Study of model behavior demonstrated that it would be necessary to expand warehouse capability to sort and palletize cases. Other adjustments concerning mechanized controls were made to improve system efficiency. Continuing studies have resulted in implementation optimizing algorithms which reduce case overflow and increase pallet flow rate.

In April 1977, the department developed a discrete simulation model of the automated stacker storage and retrieval system. The stacker model is part of an ongoing study to further improve efficiency of the Finished Goods Warehouse. The relative position of stacker storage within the warehouse is shown in the background of Illustration 1.

The objective in developing the stacker model was to provide a tool that could be used in evaluating various algorithms which control stacker operation. Practical optimization is a primary factor in that both implementability and computation (time vs. benefit) require serious consideration. In the following section of this paper, the automated stacker storage system will be described. The remaining sections are devoted to the stacker model and key algorithms tested under different operating environments.

AUTOMATED STACKER STORAGE SYSTEM

Physical System

The system consists of 9 stacker cranes which store and retrieve palletized loads within an array of bin locations. Each stacker crane travels along a fixed track and has access to bins on either side of the aisle. The track passes 54 columns, horizontally, and the vertical lift reaches 7 levels. This provides approximately 703 available bin locations per stacker crane with total system capacity of 6330.

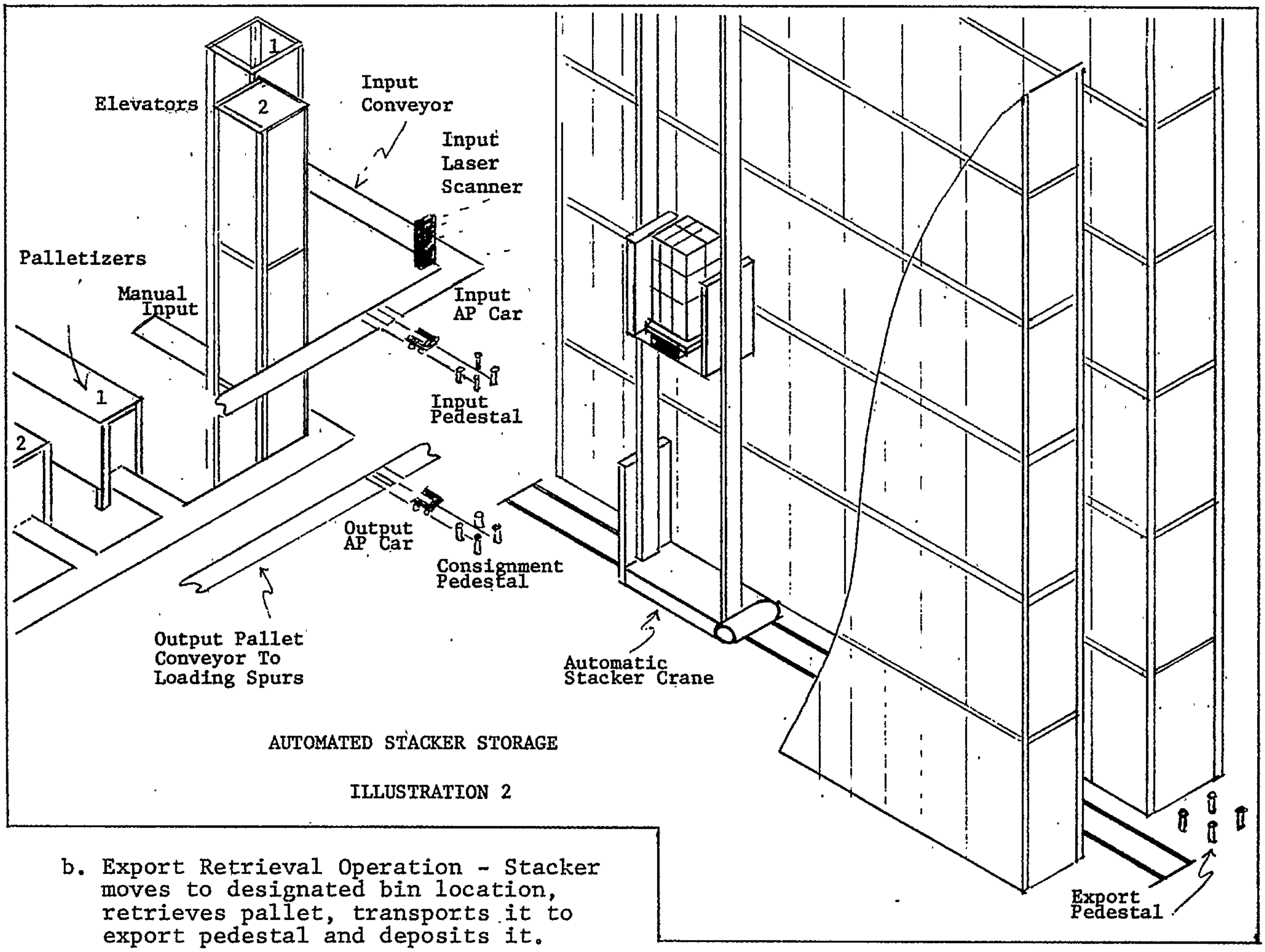
Each stacker has its own input pedestal from which incoming pallets are picked up and transported to an assigned bin storage location. Each stacker also has two output pedestals, one for consignment retrievals, the other for export retrievals.

Incoming pallets arrive on the input conveyor (Illustration 2) and are transferred by the input AP car to the input pedestal for stacker pickup. Retrieved consignment pallets are transferred by the output AP car from the consignment pedestal to an output pallet conveyor for distribution to loading spurs. Retrieved export pallets are removed by forklift from the export pedestal and taken to the export shipping area.

System Operation and Control

Preset Controls: The system is retrieval driven which gives priority to execute retrieval commands. The following preset processes govern the sequence of stacker operations.

1. Each stacker crane has an associated retrieval command queue which contains future retrievals to be performed on first in, first out (FIFO) basis.
2. Each stacker has a storage command queue, capacity of one. A store command is generated when an incoming pallet is available for pickup on the input pedestal.
3. Subsequent retrieval orders are filled with FIFO discipline. The stacker with the oldest available product gets the retrieval command added to its queue.
4. A stacker crane can be in only one of five distinct categories of operation at a given instant:
    a. Store Operation - Stacker moves to input pedestal, picks up pallet, then transports it to designated bin location and stores it.



AUTOMATED STACKER STORAGE

ILLUSTRATION 2

  b. Export Retrieval Operation - Stacker moves to designated bin location, retrieves pallet, transports it to export pedestal and deposits it.
  c. Consignment Retrieval Operation - Stacker moves to designated bin location, retrieves pallet, transports it to consignment pedestal and deposits it.
  d. Stacker Inoperative - A malfunction prevents the stacker from operating.
  e. Stacker Idle - There are no store or retrieval commands for stacker to execute.

5. After completing an assigned operation, the stacker remains at its current position until the stacker processor has selected the next command for the stacker to execute.
6. When a stacker completes operation 4a or 4b, the stacker processor selects the next command from the queue in the order indicated:
    a. Retrieval Command Queue
    b. Store Command Queue
7. When the stacker completes operation 4c, the stacker processor selects the next command from the queue in the reverse order, i.e. 6b, then 6a.
8. After an incoming pallet has arrived on a stacker's input pedestal and another incoming pallet is enroute or already on the same stacker's input AP car, then the stacker becomes temporarily locked out from receiving additional incoming pallets. The lock out condition persists until the stacker removes a pallet from the input pedestal.

Interleaving: In tracing stacker movement through a complete cycle, it can be seen that interleaving (alternation of store and retrieval operations) is at random.

First, assume that the stacker has completed storing an incoming pallet (4a) to its assigned bin storage location. The stacker now has to be directed to perform its next operation. The stacker processor checks the retrieval command queue for that particular stacker and removes the oldest retrieval command. If the oldest command happens to be an export retrieval, the stacker executes the complete export retrieval operation (4b) and is ready for its next operation.

Stacker Storage Model (continued)

Assume the stacker is at the export pedestal. Again the stacker processor checks the retrieval command queue for the oldest command. Another export retrieval cannot be performed, since there is a pallet occupying the export pedestal; therefore, only a consignment retrieval can be executed. Assume there is such a command and the stacker is so directed. The stacker now proceeds to perform a consignment retrieval operation.

After completing the consignment retrieval (4c), the stacker processor checks the store command queue for an incoming pallet on the input pedestal. If there is a pallet at input ready for pickup, the stacker is directed to perform the store operation (4a). Upon completion of the store operation, the cycle is complete.

Interleaving can be described as random in view of the many possible variations in sequence of operations (4a,4b,4c) that can occur within a cycle. Depending upon which operation (4a,4b,4c) was currently completed and the presence and ordering of commands in the retrieval command queue and presence of a command in the store queue, the number of variations is large.

The current retrieval driven system with random interleaving is inflexible to system surges and stacker malfunctions. In a situation where the incoming pallet load saturates the capability of remaining operational stacker cranes, the priority for performing store operations remains secondary. Consequently, backups occur at pallet input and may extend further upstream to the automatic palletizers and beyond.

Selection of Storage Location for Incoming Pallets: Currently, the stacker storage algorithm uses random storage assignment. The rule for bin selection is lowest tier-then side of aisle-then closest open column location. Using this rule, any pallet is equally likely to be assigned to a particular bin storage location regardless of turnover. Unfortunately, this rule reduces stacker travel efficiency in favor of expediency. Under the present rule, Figure 1 indicates that the incoming pallet would be stored in position # although there are closer open locations in the upper tiers.

Random Storage Assignment

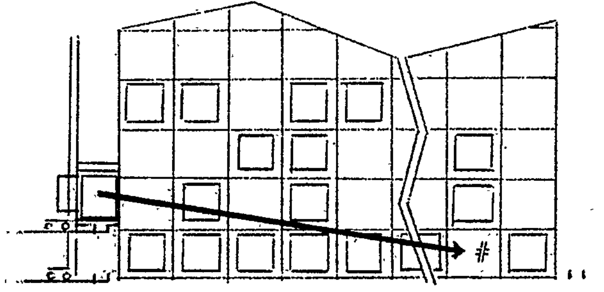


Figure 1

Operational Environment

Load Distribution: As a practical consideration, operating policy may place a disproportionate share of stacker crane workload on certain shifts. Although a warehousing operation may be on a 24 hour basis, retrievals and specified inputs may be restricted to day and evening shift. This policy may result in late night shift having a substantially reduced workload. As a hypothetical example, Figure 2 indicates a time integrated approximation with late night shift having 70%, and both day and evening shifts having 115% of the average 24 hour workload.

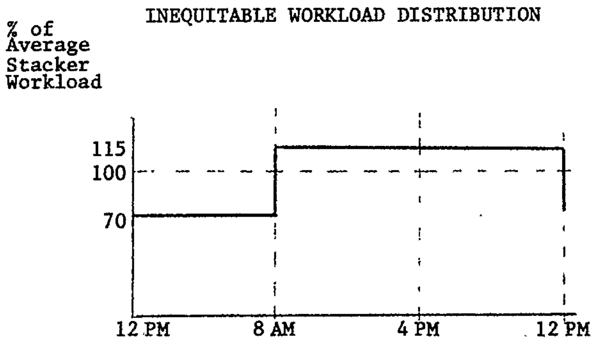


FIGURE 2

The inequitable load distribution could result in a stacker system experiencing surges and saturation during day and evening shifts. Under these conditions pallet input flow rate is reduced and retrieval delays occur.

Preventive Maintenance: The effective maintenance program emphasizes the concept of preventing unexpected equipment failures by scheduling equipment out of service on a periodic basis for inspections, adjustments, and replacement of worn parts. However, system reliability is not at 100%; therefore, some unexpected failures occur with an estimated frequency of distribution.

SIMULATION MODEL OF STACKER STORAGE SYSTEM

Model Language

Selection of GASP IV Simulation Language was based on several considerations.2

1. As a collection of FORTRAN subroutines, GASP allows the user to expand or modify as necessary.
2. GASP provides for combined discrete and continuous simulation.
3. GASP has fast execution speed.
4. Since it is FORTRAN based, GASP can be run on almost any computer and requires only FORTRAN programming skills not knowledge of a particular modelling language.

Model Description and Distinctive Features

The basic model represents operation of the present automated stacker storage system previously described. Since the model accounts for all pallet movement through the system, it serves as a tool to study stacker operations and to search for optimizing algorithms. The basic model, reflecting current operation, establishes the standard against which the effectiveness of test algorithms are gauged. Additionally, trade-off analysis is performed by comparing conditions or expenses associated with optimum efficiency to those associated with a variation that is less than optimum. In some areas, the cost to achieve a theoretical optimum may be impractical.

Other distinctive features of the system include modes of operation and travel times. Each stacker crane is capable of operating in one of four modes.

1. store only
2. store or retrieve
3. retrieve only
4. maintenance

The stacker array is rectangular in terms of stacker travel time because the stackers are able to travel through a succession of five horizontal speeds and two vertical speeds.

Modelling Technique

Standard FORTRAN programming conventions were followed throughout model development. The subroutines servicing event codes for all pallet flow and stacker operations are independent of a particular palletized product or stacker number. Programming efficiency has been accomplished by using subscripted variables, pointers, and linked lists.

Subscripted Variables: Logic flags, information arrays, and file pointers are initialized in subroutine INTLC and carried in user common. The logic and information arrays are then updated during simulation by appropriate subroutines. Two examples are shown below.

Elements of code for a stacker crane designated on malfunction follow -

```
MSK=ATRIB(5)  (MSK receives stacker number
                 # from attribute)
LSKMCD(MSK)=0   (logic array indicates
                  current stacker status)
```

Elements of code using file pointer to perform a file operation follow -

```
MSK=ATRIB(5)
CALL RMOVE(MFE(KFSKOP(MSK)),KFSKOP(MSK))
              (first command removed from
               stacker number # future
               operations file)
```

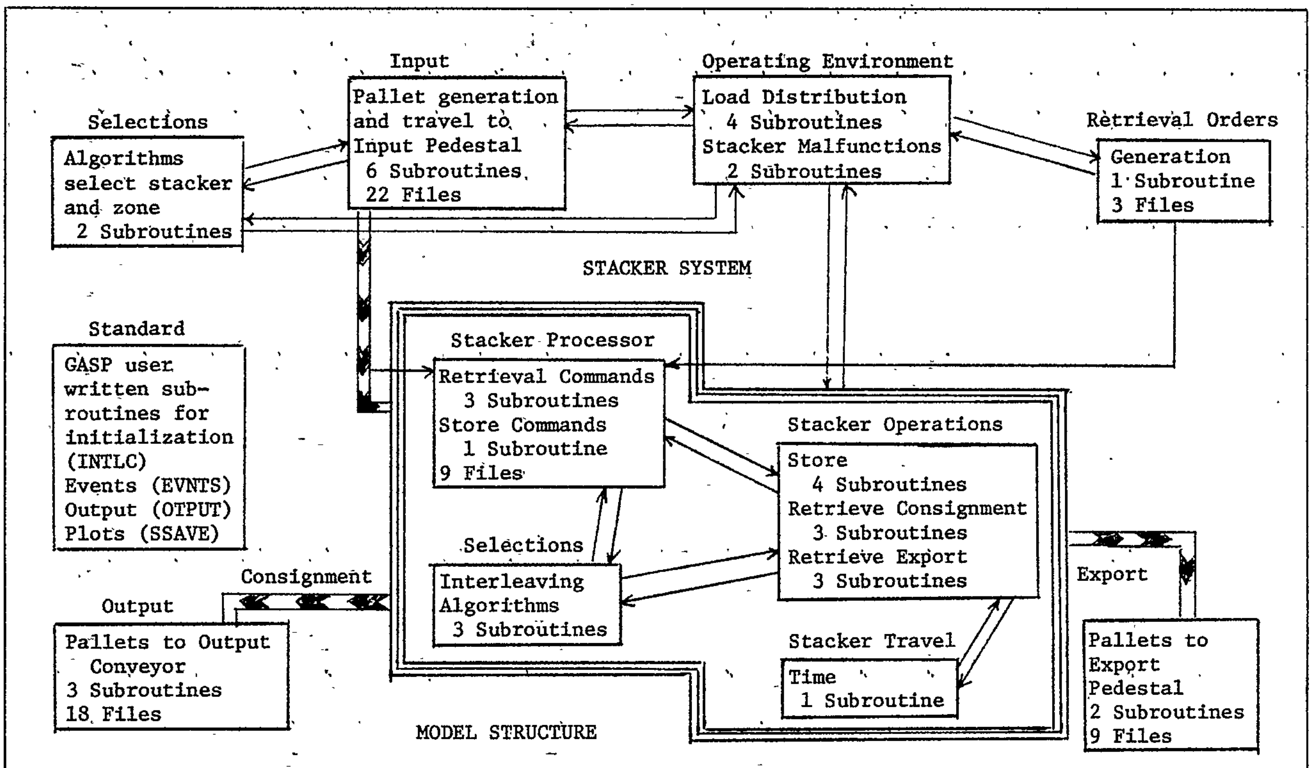
Linked Lists: Use of a linked list provides zone limits for the bin storage location with zones based on turnover. Elements of code for the linked list follow -

```
MSKPCD=ATRIB(3)  (MSKPCD receives pallet
                   product identification)
MINROW=ISSZLM(IPLZSQ(MSKPCD),N)
                  (IPLZSQ gives zone search
                   sequence and ISSZLM gives
                   zone limits that search
                   algorithm defaults
                   through)
```

Model Flexibility

The model was designed for dynamic flexibility in accepting variable parameters during initialization. This feature permits the model to be used in evaluation of other stacker systems as necessary:

1. Number of stacker cranes, 1 to 20
2. Number of levels, 1 to 10
3. Number of columns, 1 to 80
4. Number of product codes, 1 to 100
5. Dimensions of bins
6. Times for various mechanical operations
7. Speeds of vertical and horizontal stacker motion
8. Locations of input and output pedestals
9. Bin zone boundary information and zone sequence
10. Percent fill during initialization
11. Production rates and distribution parameters
12. Stacker malfunction distribution
13. Environmental workload distribution



MODEL STRUCTURE

FIGURE 3

Model Structure

In terms of GASP parameters the model would be considered large. The model consists of the following structure.

42	user written subroutines
114	files
101	collection statistics (COLCT)
37	time integrated statistics (TIMST)
9	histograms
2	plots
8	attributes
27	event codes

The general interaction of subroutines and process flow as related to the actual system is indicated in Figure 3.

Model Measurements

In addition to providing "system snapshots" at 60 minute intervals, system efficiency is measured in terms of the following factors:

1. Mean travel time per stacker trip
2. Stacker utilization as a time integrated statistic
3. Length and waiting times for pallets in input queue
4. Delays in executing retrieval commands
5. Occupancy of AP cars and pedestals

Model Execution

On the IBM 370/158 Mod 3, execution time varies with length of simulation time, production rates, complexity of algorithms and environmental characteristics. In evaluating interleaving and zone selection algorithms, the modified model has executed in 8 CPU minutes, using 492K core. As a measurement of computational efficiency, the 8 CPU minutes represent 48 hours of simulation time (2 complete work day cycles) which translates to a ratio of 360:1, simulation to CPU time.

The model is flexible enough to run for small periods of time since it can be initialized to a steady state. Depending on the algorithm being modelled, runs as short as 1 CPU minute can be made and yet still achieve good representation as well as verify algorithm logic.

ALGORITHMS TESTED WITH THE MODEL

Surge Controlled Interleaving

This algorithm interlaces stacker storage and retrieval operations based on the presence of a system surge. Figure 4 indicates how interlace control would be accomplished. When a surge occurs, the algorithm gives priority to freeing the input pedestal. Essentially, a temporary priority shift is forced toward the input side of the system which is done at the expense of creating a larger export retrieval delay.

Surge Controlled Interleave

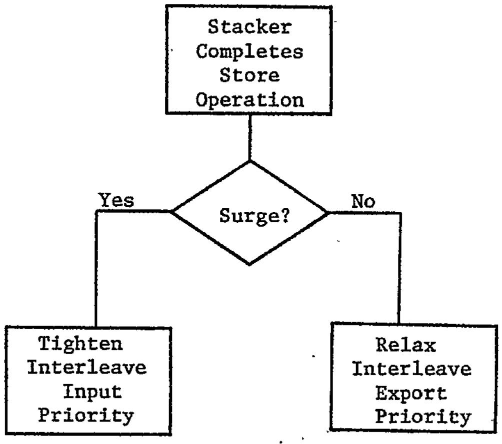
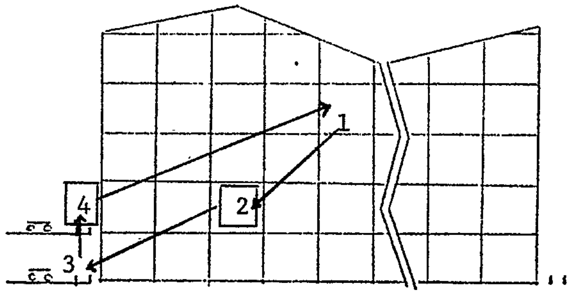


FIGURE 4

The algorithm detects a surge if the number of pallets in the input queue exceeds the number of available waiting positions (input AP cars and pedestals) in the stacker system. If a surge is present interleave is tightened (Figure 5) giving priority to input. When there is no longer a surge, interleave is relaxed (Figure 6) shifting priority to export retrievals.

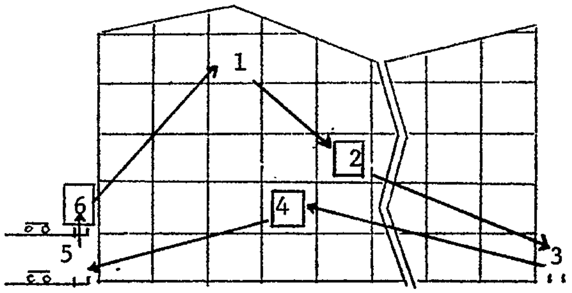
Tightened Interleave



1. Store Input Pallet
2. Retrieve Cons. Pallet
3. Deposit Pallet on Ped.
4. Pick up Input Pallet

Figure 5

Relaxed Interleave



1. Store Input Pallet
2. Retrieve Exp. Pallet
3. Deposit Pallet on Ped.
4. Retrieve Cons. Pallet
5. Deposit Pallet on Ped.
6. Pick up Input Pallet

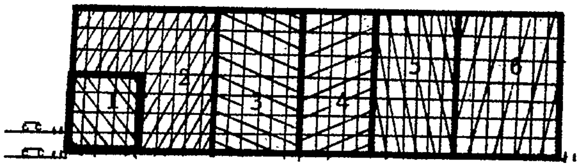
Figure 6

Generally, surge controlled interleaving manages interlacing of export retrievals within the total stacker operations cycle. Under most circumstances, improvement to system efficiency, as a measurement of stacker utilization, is negligible. However, the temporary shift in priority to input (temporary exclusion of export retrieval) may be critical to avoiding unacceptable backup at input queue.

Pallets Stored In Zones Based On Turnover

The bin storage array is divided into zones (Figure 7) based on product turnover. The algorithm matches the particular product on the incoming pallet with its corresponding turnover rate. Next, the algorithm searches for an empty bin location within the primary zone designated for the particular product. Using an exhaustive search process, the algorithm defaults as necessary through successive zones (from table of zone pattern search sequence, indexed by turnover rate) until an empty bin is located.

Zones Based on Turnover



1. High Volume Consignment
2. Medium Volume Consignment
3. Low Volume Consignment
4. High Volume Export
5. Medium Volume Export
6. Low Volume Export

Figure 7

The efficiency obtained from employing a zone based algorithm provides substantial improvement to stacker storage system efficiency. Compared with the basic model which uses random storage assignment, the modified model, under otherwise identical conditions, achieves approximately 13% reduction in mean stacker travel time and utilization. Other measurements show relative system improvement.

95% reduction in average waiting time in input queue, 36% reduction in retrieval delays.

OPERATING ENVIRONMENT CHANGES TESTED WITH THE MODEL

The effect that load equalization would have on system operation was tested with the model. A modification to the basic model equalized stacker workload distribution (Figure 2 shows weighted workload) over 24 hour cycle. The additional labor costs for increased night shift operation were not considered; however, total cost vs. benefit may cause load equalization to be ruled out.

Model behavior indicates that stacker crane operating efficiency remains unchanged. However, with frequency of surges greatly reduced and with system saturation virtually eliminated, system capability shows more effective utilization. As measurement of improved system operation, the following statistics are provided.

97% reduction in average waiting time in input queue

70% reduction in retrieval delays

CONCLUSION

The concepts of load equalization, interleaving, and zoned storage, are necessary elements for total system optimization. Many variations and combinations of these concepts can be tested and analyzed using the model, in addition to testing new concepts of stacker operation and other environmental changes.

The combined effect of the three concepts provides the greatest overall improvement to stacker system operating efficiency. Although further "fine tuning" may slightly increase system efficiency, preliminary studies show the following improvements, to date.

98% reduction in average waiting time in input queue

78% reduction in retrieval delays

50% reduction in occupancy of input AP cars and pedestals

13% reduction in stacker utilization

REFERENCES

[1] Garth L. Jarvis and Miles Waugh, "A GASP IV Simulation of an Automated Warehouse," Proceedings of the 1976 Bicentennial Winter Simulation Conference, Vol 2, pp 540-547.

[2] A. Alan B. Pritsker, The GASP IV Simulation Language, John Wiley & Sons, New York, 1974.

ACKNOWLEDGEMENTS

Mr. Jim Hill, Systems Supervisor, Philip Morris, Inc., is thanked for providing general information on stacker system operation.

Mr. Jerry Dunford, Electrical Maintenance Supervisor, Philip Morris, Inc., is thanked for providing mechanical and reliability information for stacker system operation.

Mr. Mike David, Industrial Engineer, Philip Morris, Inc., is thanked for providing timing sequences and product distribution for stacker system.

Mr. Ron McGuffin, Programmer Analyst, Philip Morris, Inc., is thanked for providing information on stacker crane operations and algorithm implementation.

Mrs. Beatrice Johnson, Technical Aide, Management Sciences Department, Philip Morris, Inc., is thanked for assisting in article preparation.