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USING SIMULATION TO OPTIMIZE A HORIZONTAL CAROUSEL STORAGE SYSTEM

Todd LeBaron

AutoSimulations Inc.
655 Medical Drive
Bountiful, UT 84010 U.S.A.

Michael L. Hoffman

Hewlett Packard
18110 SE 34th Street
Vancouver, WA 98683 U.S.A.

ABSTRACT

Carousel storage systems are often used to increase storage density, throughput and efficiency while reducing inventory and man-hours. The Hewlett-Packard company has developed a computer simulation model in an effort to fully optimize its horizontal carousel storage system. HP assembles and packages a wide range of inkjet printers at its Vancouver, Washington (VCD) manufacturing facility.

The simulation project was initiated to provide an accurate prediction of system performance based on a given set of input parameters. Case study scenarios can test parameters such as different storage algorithms, selection criteria, carousel speeds, rotation direction, production rates, and more. Changes to the control logic can be analyzed without implementing them in the real control system. The effects of new product types and production plans can also be analyzed prior to production change-overs. The simulation model provides an accurate statistical report from which each scenario can be evaluated.

This paper presents a flexible, carousel simulation model built using a general purpose simulation language. This data-driven model serves as a template which can easily test configurations and options used in the real system. The advantages of this carousel simulation model as an analysis tool and the benefits that have come to HP as a result of simulation analysis are presented.

Note: This paper reflects that state of the HP carousel system at the time the model was developed.

1 INTRODUCTION

Hewlett Packard assembles and packages a wide range of inkjet printers at its Vancouver, Washington (VCD) manufacturing facility. The assembly operation consumes raw components that must be available and delivered to the assembly lines in a timely manner. The horizontal carousel storage system serves as a storage buffer between the raw parts store and the assembly lines. Each of the active assembly lines assembles a certain type of printer. As printers are assembled, raw components are consumed. When the assembly line inventory level of any component has been depleted below its defined level, an order is sent to the carousel requesting more components be pulled and routed via conveyor to the assembly line. In addition, when the inventory of any given component within the carousel system falls below a defined level, an order to the main store is sent requesting a certain quantity to be on the next supply truck. Therefore, the carousel system is continually pulling tote orders needed at the assembly lines, and storing totes of raw materials that come from the main store.

2 HORIZONTAL CAROUSEL SYSTEM

The horizontal carousel system used at the HP VCD production facility serves as a storage buffer between the parts store and the assembly lines. Components, or stock keeping units (SKUs) are transported in totes. Each tote contains a single SKU with varying quantities. The storage system is comprised of 24 horizontal carousels set up in a configuration of 12 double-high stacks (Figure 1). Each carousel has 84 bins connected to form an oval ring that rotates horizontally. Each bin has 10 shelves. Each shelf can hold a single tote. Therefore, the storage capacity of each carousel is 840 totes, and the storage capacity of the system is 20,160 totes.

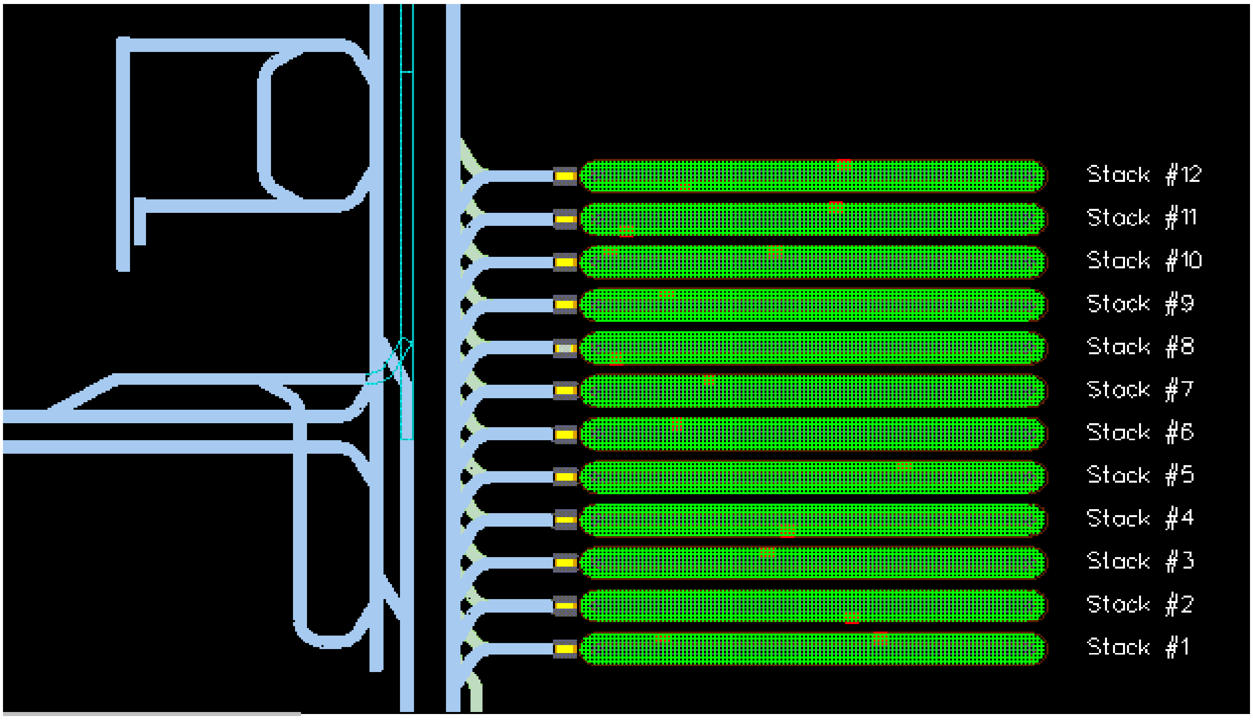

Figure 1: 12 Double High Carousel Stacks

An Inserter/Extractor (IE) is used to service each of the 12 carousel stacks. This IE is located at one end of the carousel and can store or pick totes from any shelf in the upper or lower carousel. The IE also services the inbound and outbound conveyor lanes. Within a stack, the upper and lower carousels rotate independently. This allows the IE to store or pick from one carousel while the other carousel is rotating into position for another possible store or pick.

Orders are sent from the assembly lines to the carousel system when one or more components have been depleted below the defined level for the specific SKU. Each SKU has a pre-defined order configuration based on consumption rates, part weight per totes, and part form factor. An order is for a single SKU and can be for any number of totes. For example, assembly line 42 may place an order requesting SKU 100 (three totes) and another order requesting SKU 200 (eight totes). Factors such as tote location, request activity, and carousel status are used in the order filling algorithm. The time it takes the carousel to fill an order is critical and varies depending on the control logic and other system variables described later.

Inbound totes containing raw components to be stored in the carousel are transported from the truck unloading area via conveyor. Prior to arrival at the carousels, the conveyor control system makes a carousel request to determine the appropriate stack into which the tote should be stored. The carousel control system then responds with a stack number (1-12). This information allows the conveyor control system to route the tote to the proper inbound conveyor lane to reach the desired stack (using the lower conveyor sections). Once the tote has arrived at the end of the inbound accumulation conveyor lane for the stack, the IE picks the tote from the inbound conveyor and stores it in the assigned carousel position. The tote remains in the carousel until it is selected to fill an order from the line. The interaction between the carousels, IEs, and inbound and outbound conveyors is illustrated in Figure 2.

The tote inbound and outbound activity at the carousel and surrounding conveyors can often impede the order filling process. The dynamics and interaction between the carousels, IEs, conveyors, and totes make it impossible to accurately predict system performance without simulation. The goal of the simulation model is to predict the performance of changes to control logic and other operating parameters prior to going through the expense of implementation in the real system. Several different optional algorithms and parameters were defined and coded within the simulation model allowing the flexibility to run a seemingly endless number of what-if scenarios.

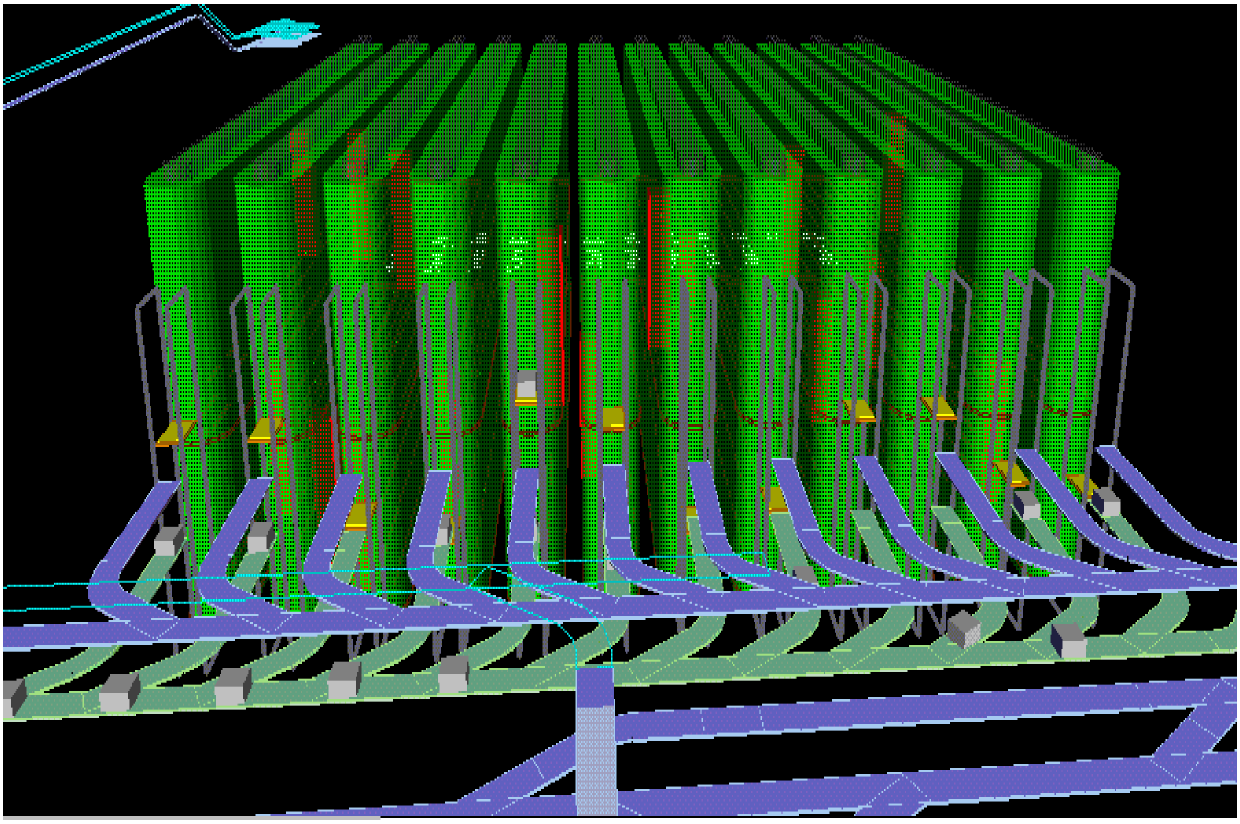

Figure 2: Interaction between Carousels, IEs, Inbound and Outbound Conveyors

3 FLEXIBLE SIMULATION MODEL

The application of simulation software packages to manufacturing problems typically presents two conflicting issues. Pure simulators are traditionally easy to use, but much is lost in the area of flexibility and model accuracy. On the other hand, simulation languages greatly improve model flexibility and accuracy, but ease-of-use is sacrificed. By utilizing a powerful simulation language and limiting the problem domain, the best of both worlds is achieved, as shown in this model.

HP VCD selected the AutoMod™ simulation software for this model. This decision was based on HP VCD Engineers' previous experience with the tool in other automated material handling applications and the compatibility of the tool to the analysis objectives.

The scope of this model was limited to the specific horizontal carousel system installed at the HP VCD facility. The carousel system itself is constrained to function within specific boundaries. These boundaries include a wide range of options for all areas relating to the horizontal carousel system. The simulation model provides for all possible boundary combinations and configurations the carousel system might encompass. The simulation software provided the flexibility needed to accurately develop the model. The interface associated with the software provides for ease-of-use in configuring the carousel model.

The model design implements a unique user interface providing a spreadsheet application used to edit the model input files prior to running the model. This interface allows input parameters to be altered, without requiring the model to recompile. Output files containing system statistics are written at the end of the model run and can also be accessed through the user interface. This provides the ability to run many different case studies or what-if scenarios without leaving the run-time environment.

4 DATA INPUT

Easy-to-use edit tables facilitate data input and model flexibility. The model options contained in the data input files can be altered to achieve any system configuration. Six data input files are used to define the carousel system. The number of data input files may seem large. However, for any set of what-if scenarios, typically only one or two files are altered between runs. Three categories of data input define the horizontal carousel system: line production options, carousel options, and downtime options.

4.1 Line Production Options

The simulation model uses a parts list file and a production file to determine the activity at the carousel. The parts list file currently accommodates six product types and contains the bill of materials of all of the sub-components that make up each product type. For each component, the following information is included:

- Number of components used in each product type
- Number of components fitting into a tote
- Reorder point for this component at the assembly line
- Number of components that are reordered when an order is made

The production file controls the 13 production lines that are serviced by the horizontal carousel system. For each production line, the following information is included:

- Line status (“On” or “Off”)
- Product type the line assembles
- Rate at which the line produces assemblies (given in seconds per printer)

The information contained in these two files determines the activity in the simulation model. As each active line builds up assemblies of its assigned product type and at the assigned production rate, components are consumed. This, in turn, triggers orders for the carousel to fill. As totes are pulled from the carousel and routed to the lines, additional orders are sent to the store for carousel replenishing.

4.2 Carousel Options

A speed control file and a rule file are used to configure the carousel. The speed control file is used to set the pick and place times of the IEs and to control the rotational velocity of each horizontal carousel. The rule file is used to set the search and store algorithms and other rules used to select the carousel, bin, and shelf location for inbound or outbound totes. The predefined options available are as follows:

4.2.1 Inbound Stack Assignment

Two rules are defined. These rules are used in assigning a temporary storage location within the carousel system for each inbound tote. Rule 1 (default) assigns the carousel stack based on an even distribution across all available stacks. Each tote needing a stack assignment (1-12) has an equal chance of being assigned to all stacks that are “Up” regardless of SKU. Rule 2 is similar, but the assignment is made to distribute each tote of similar SKUs evenly across all stacks. Rule 2 is used to reduce the vulnerability that results from storing all totes of one SKU in the same stack.

4.2.2 Inbound Position Assignment

After a tote has been assigned a stack, it is routed via conveyor to the inbound conveyor lane of the respective stack. At this point, the carousel (upper or lower) bay and shelf location is assigned. Two rules have been defined. Rule 1 (default) assigns the closest empty bin on either the upper or lower carousel. Rule 2 alternates between the upper and lower carousel.

4.2.3 Horizontal Carousel Rotation Assignment

The carousel system is configured as bi-directional (default) or one-directional.

4.2.4 Tote Selection Rule

When an order is issued, the tote selection rule is used to determine which tote(s) fill the order. Rule 1 (default FIFO) picks the oldest tote in the system first, regardless of its position or carousel status. Rule 2 (FIFO window) filters through all totes of the required SKU in the carousel system that fall within a certain time tolerance of the oldest tote, then selects the tote that can be delivered soonest. Tote location with respect to the front of the carousel, and carousel status are used in this determination. The time tolerance is defined through data input.

4.2.5 Tote Retrieval Sequence Rule

As totes fill orders there may be many different totes waiting to be picked at any given time. Two order picking rules have been implemented, reflecting two different algorithms. Rule 1 (default FIFO) picks the orders based on when the requests were received.

Rule 2 is used to optimize carousel rotation by tabling all outstanding orders. As the carousel rotates to pick the next FIFO order, it continually checks to see if the bin at the IE location has a tote that needs to be picked. If it does, the carousel stops rotating, the pick is made, and the order revised. Rule 2 (optimize carousel rotation) is used at the expense of response time to initial orders.

4.3 Downtime Options

An equipment downtime file is used to define preventive maintenance and random downtimes each carousel stack might experience. For each stack, the following information is included:

- Turned “On” or “Off”
- Preventive maintenance schedules can be assigned
- Random downtime distributions can be assigned (MTBF)
- Random repair time distributions can be assigned (MTTR)

5 MODEL VERIFICATION AND VALIDATION

The model provides both graphical and statistical output. After the model has been configured through data input, the model can be immediately run. During the model run, the user can switch the graphical animation on or off. The graphical animation provides visual verification that the model is performing as intended. Carousel rotations, IE moves, conveyor systems and active totes are all animated accurately. Running the model without the animation provides much faster simulation speed: approximately one hour of simulation time is compressed to nine seconds. Order delivery statistics and carousel statistics are some of the output responses used to evaluate and validate the model.

The simulation model was validated against the current system. The current production schedules and volumes were used. In addition, efforts were made to get exact carousel and IE speeds. This was done by using a stopwatch to take many different sample times. A historical report log generated by the actual carousel system was used to provide samples for random carousel downtimes and also included the time it took to repair. From these samples, a general purpose curve fitting software was used to assign an accurate random distribution used in the mean time between failure (MTBF) and mean time to repair (MTTR) events. This random distribution was then input into the appropriate input file. The rules and algorithms used in order selection and location assignment were set to the default rules (which are the rules currently being used by the system).

Five simulation runs were made using different random number streams and a 95 percent confidence interval. Each run included a one week warm-up period The results were compared with actual system results. The sequence of evaluating the statistics, comparing them with the actual system statistics, identifying any discrepancy, re-coding the model, and rerunning the model was repeated until the system results were within the 95 percent confidence interval of the corresponding model results.

6 SIMULATION RESULTS

Initial experimentation was conducted and the results were compared to the base case. Two rules were tested as shown in Table 1. The first rule tested (experiment 1) was the tote retrieval sequence rule. The base case rule (rule 1) picks the orders based on when the requests were received. Rule 2 (optimize carousel rotation) was tested to see the effects of optimizing carousel rotation. This rule resulted in reduced carousel rotation, and faster order delivery times as shown in Figures 3 and 4.

Table 1: Initial Testing of Two Rules

Model Run	Tote Selection Rule	Tote Retrieval Sequence Rule
Base Case	Rule 1 (default FIFO)	Rule 1 (default FIFO)
Experiment 1	Rule 1 (default FIFO)	Rule 2 (Optimize Carousel Rotation)
Experiment 2	Rule 2 (FIFO Window)	Rule 1 (default FIFO)

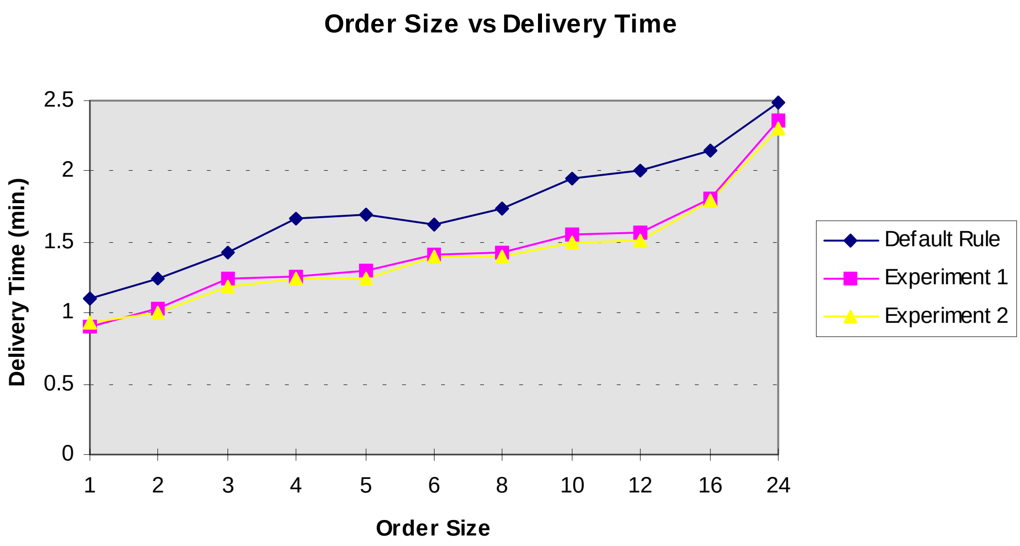

Figure 3: Order size vs delivery time

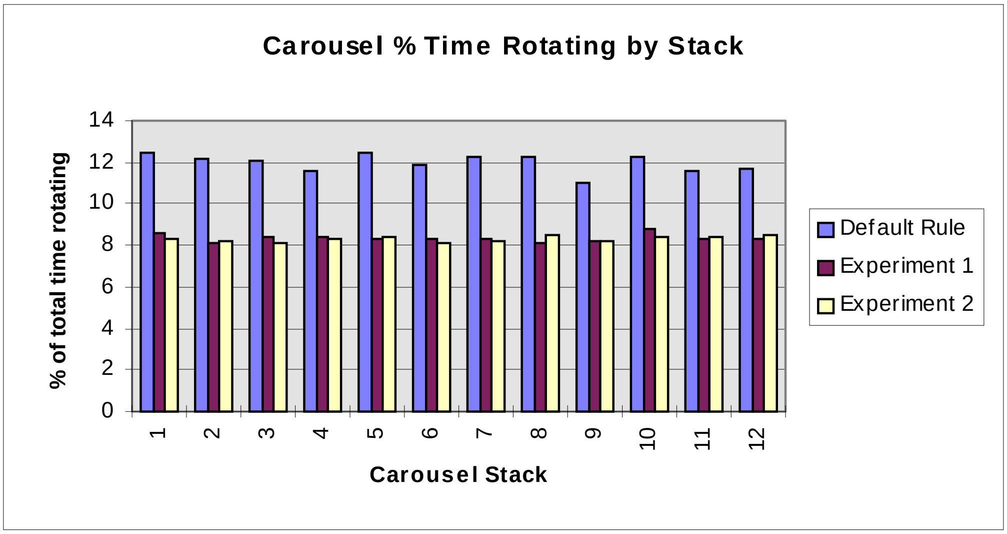

Figure 4: Carousel percent time rotating by stack

The second rule tested (experiment 2) was the tote selection rule. When an order is made, a query is made to the carousel system for all totes of the specified SKU. The base case system rule (rule 1) always selects the tote that has been in the system the longest (FIFO). Rule 2 (FIFO window) will select the tote that can be delivered the soonest, and also falls within the time tolerance of the tote that has been in the carousel the longest. The results of this rule also provided faster delivery time and reduced carousel rotation as shown in figures 3 and figures 4.

The results indicate that revisions to the current control logic can provide beneficial results. Both rules will improve order delivery time from the carousel. In addition, the carousel rotation requirement is decreased, reducing wear and tear on the system, resulting in fewer mechanical failures.

7 CONCLUSION

This flexible simulation model offers many benefits. The integration of new production plans and product types with revised parts list and tote requirements can be easily evaluated. Different rules and algorithms controlling the carousel logic can be tested. Different preventive maintenance schedules can be tested. The effects of random equipment failures can be identified. All of the experimentation can take place without the effort and cost of implementation in the real system. The simulation results provide the accurate data necessary to make intelligent decisions concerning the system.

As the simulation model gains acceptance, other model users have expanded its analytical use to include a variety of business situations. For example, capacity planning studies are being conducted to determine the maximum production levels for optimal usage of the storage equipment. The model is also being used as a scheduling tool by analyzing the effects of production shifts. The simulation model provides the understanding necessary to optimize the horizontal carousel storage system and production schedules, and serves as a valuable analytical tool at many levels.

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AUTHOR BIOGRAPHIES

H. TODD LEBARON has worked for AutoSimulations since 1990 as a Simulation Analyst, conducting numerous simulation studies over the past eight years in a variety of applications. He was recently made manager of the West Coast consulting group. He also teaches AutoMod training courses and provides consulting support. LeBaron received a B.S. in Manufacturing Engineering from Brigham Young University in 1988.

MICHAEL L. HOFFMAN is a Manufacturing Development Engineer with the Hewlett Packard Company inkjet printer factory in Vancouver, Washington. His background includes supervisory/controls system software for light industrial automation and semiconductor fabrication. Hoffman received a B.S. in Computer Systems Engineering from Oregon Institute of Technology in 1989.