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USE OF DYNAMIC SIMULATION TO ANALYZE STORAGE AND RETRIEVAL STRATEGIES

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ABSTRACT

In the second half of 1998, shipment volumes at one of Intel's warehouses had increased beyond the storage and retrieval capabilities of the facility. An engineering improvement team began studying changes to the Warehouse Management System (WMS) that would increase throughput. From observation it was unclear what WMS code changes would actually improve throughput, and nearly impossible to predict the amount of improvement that would be realized in the facility. To solve these issues, the algorithms for storing product, releasing orders, and routing vehicles were first analyzed in a dynamic simulation model. Strategies that showed a significant increase in throughput were recommended for coding into the WMS software. Using a simulation model not only allowed the strategies to be prioritized, but also predicted the performance of each strategy.

The equipment and physical layout of the facility were comprehended in the simulation model. The storage area consisted of twelve aisles, each 112 bins long and 16 bins high. Product was stored in boxes, which were retrieved and stored by operators driving Stockpicker vehicles. Since both the storage and retrieval of material were entirely controlled by the WMS, it was imperative that a logical routing decision for each Stockpicker vehicle be made.

The initial storage and retrieval strategies were first coded in the simulation model to ensure that the model outputs were valid. Then, numerous storage and retrieval strategies were coded and analyzed to determine which ones would increase throughput.

The final simulation results showed that throughput could be increased by 110% per day by simply improving the WMS storage and retrieval strategies. No additional vehicles or headcount were required which resulted in a significant annual cost savings.

1 INTRODUCTION

In 1997, a warehouse was designed and built to move product from Intel to its customers. As the facility ramped up, receipts and shipments exceeded the original storage and retrieval requirements. As a short-term fix, operators were reassigned and required to work overtime to meet the demand. Engineering improvement teams were formed to study the current operating procedures and develop new alternatives that would increase system performance and reduce the need for overtime and employee reassignment.

As the improvement teams studied the situation it became apparent that the complexity of the system would not allow them to apply simple engineering practices to develop workable solutions. The decision was made to employ discrete event simulation to develop and analyze alternatives.

The intent of this paper is to describe how the study was performed and some of the modeling techniques that were used to improve model execution time. Also included is background information on the layout, equipment, and WMS followed by a description of the validation and sensitivity analysis performed. Finally, an account of all of the storage and retrieval strategies analyzed in the model is provided with an in-depth analysis of those strategies that were the most successful.

2 BACKGROUND INFORMATION

2.1 Layout and Equipment

The equipment and physical layout of the facility were comprehended in the simulation model. The storage area consisted of twelve, one-directional aisles that were 112 bins in length and 16 bins high. The storage area was divided into sections with the lower tiers for fast moving product and higher tiers for slower moving product. Product was stored in boxes, which were retrieved and stored by operators driving Stockpicker vehicles, a type of narrow-aisle forklift. A trolley on each Stockpicker vehicle held sixteen to fifty boxes, depending on the box type, and was used to carry boxes to be stored and retrieved.

2.2 Warehouse Management System

Although the WMS had no control over *which* boxes were allocated to an order due to specific customer requirements for some orders, it did have total control over *when* and *how* the boxes were moved from storage. Boxes were grouped into pick-bundles called units of work (UOWs) that had to be picked entirely by a single operator. Multiple UOWs were created for larger orders allowing multiple operators to pick boxes from the same order in parallel. The WMS communicated assignments to the Stockpicker drivers through a radio-frequency computer terminal mounted on the Stockpicker. Since both the storage and retrieval of material was entirely controlled by the WMS, it was imperative that a logical routing decision for each Stockpicker vehicle be made.

2.3 Need for Simulation Identified

Multiple attempts were made to identify the throughput constraint in the storage area and evaluate changes to the WMS. The first round of problem solving was to apply logical reasoning and analogous situations to explain the problem. Unfortunately, it was not clear which variable posed the largest constraint to throughput. Vehicle congestion, vehicle travel time, and inefficient storage and retrieval strategies were all proposed as the limiting factor. Furthermore, proposed strategies could not be reasoned through since some would reduce congestion, but increase travel time; others would improve storing time, but increase congestion.

Spreadsheet modeling also proved unsuccessful since the interaction of multiple vehicles moving through multiple aisles in the storage area could not be evaluated. Isolated scenarios could be modeled, but the spreadsheets had no visibility to the other vehicles or other orders in the storage area.

The engineering team soon realized that the complexity of the problem was beyond their current capabilities. The decision was made to develop a discrete event simulation model to construct and analyze possible strategies.

Discrete event simulation is an engineering tool that allows for the study of alternatives without costly changes and disruption to current production. Simulation mimics the operation of a system in a computer to determine the effect of proposed changes to the system. It is a proven engineering tool to measure how proposed changes will impact overall system performance (Shannon 1998).

Once it was obvious that a simulation model was necessary, a high-level model was constructed to determine if the throughput targeted by management could be met. The objective of the high-level model was to develop a model quickly and limit system constraints to determine if the system could perform at the desired level. If the high-level model could not achieve the needed production level, the constrained system would not been able to achieve the required production level either. The high-level model took only two days to develop and analyze and showed that the system could surpass the target throughput. Confident that the constrained problem would also be able to meet the target throughput, a detailed model was then constructed and used to analyze improvement strategies. In this study, the objectives were to:

1. Identify software control algorithms that would double throughput.
2. Prioritize the WMS software development changes.
3. Determine if additional equipment or staffing would solve the problem.

3 MODELING TECHNIQUES

The main objective of the simulation model was to increase the throughput in the storage area. Therefore, as strategies and changes to the system were analyzed, they were all compared based on the throughput realized. Although this was the main point of comparison, other statistics shown in Figure 1 were also gathered that proved to be extremely helpful in formulating new strategies.

Storage	Picking
Store time per trolley	Pick time per trolley
Aisles visited per trolley	Aisles visited per trolley
Bins visited per trolley	Bins visited per trolley

Figure 1: Additional Statistics Recorded

The execution of the model was divided into three phases. At model startup, the bins in the storage area were completely empty. Phase I stored product into the bins based on the storage strategy being evaluated. Phase II began when the capacity of the storage area reached a specified level. The goal of Phase II was to use the storage and retrieval strategies under evaluation to store and retrieve product at the same rate until steady state was reached. Storage capacity charts were monitored to determine the length of time needed to bring the system to a steady state. Phase III retrieved product at an accelerated rate while maintaining a constant storage rate. Thus, Phases I and II warmed-up the model, which allowed statistics on the effect of the strategies to be gathered during Phase III. Figure 2 graphically depicts the three phases that were modeled.

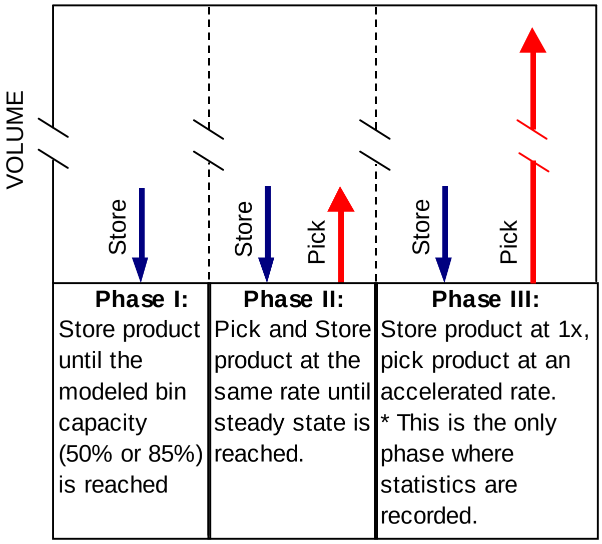

Figure 2: Three Phases of Execution

The initial simulation modeled all three phases sequentially and took 4.5 hours to perform one run. This run time limited the number of experiments that could be analyzed, and took too long to determine if a strategy improved system performance. To eliminate the length of time needed to run the model, the condition of the system at steady state was recorded. The recorded information included the location of each box, the number of units in each box, and the product type in each box. With the status of the model recorded at steady state, the model could be run multiple times starting at Phase III. This reduced the run time from 4.5 hours to 15 minutes. The results of the 4.5 hour model and 15 minute model were compared to determine if the 15 minute model represented the true performance of the system. It was discovered that there was no significant difference between the outputs of the two models.

Because of the volume of product within the system and the amount of overhead required to run a model of this size, variable arrays were used to store the attributes for each box within the storage area. No run time improvement was measured, but studies of similar systems have shown a 6X reduction in run time when variable arrays are used instead of entities.

4 MODEL VALIDATION

Three steps were taken to validate the simulation model. The first step was to collect time study data at the warehouse. Three weeks were spent at the facility observing the Stockpicker drivers, timing, and recording their actions as they performed their duties.

In the second step, the initial storage and retrieval strategies were coded in the simulation model and the outputs were compared with the time study data collected during the on-site study. A *t*-test showed that there was no significant difference between the means of the parameters analyzed. Among the parameters that were validated were pick time per box, store time per box, number of aisles visited per trip, and time for a Stockpicker to change aisles.

The last step was to analyze the direction of deviation from the time study data. This validation step determined whether or not the model tended to underestimate or overestimate the actuals. The data was normalized and another *t*-test was performed that showed that the direction of deviation of all parameters was not significantly different from zero. Once the team was confident that the model was valid, new strategies could be coded and analyzed.

5 SENSITIVITY ANALYSIS

The goal of sensitivity analysis was to identify the impact specific system parameters had on performance. Holding all but one parameter constant, two analyses were run on each system parameter. The first analysis increased the parameter by 50% and the second decreased the parameter by 50%. In both cases, the resulting change in throughput, or system performance, was recorded and is shown in Figure 3. One issue many team members raised with the operation was that the Stockpicker vehicles were “slow”. The sensitivity analysis helped settle this issue by showing that increasing Stockpicker speed by 50% would result in a minimal increase in throughput.

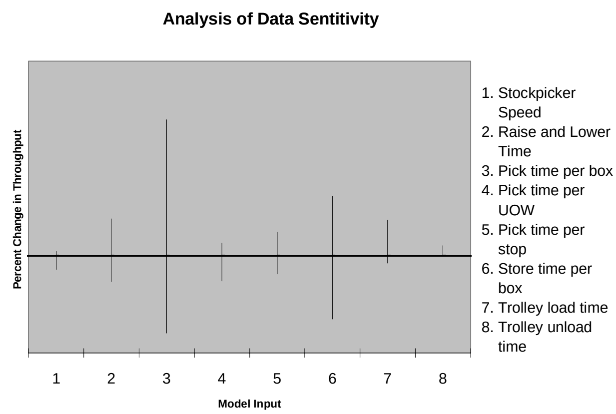

Figure 3: Sensitivity Analysis

6 STRATEGIES CONSIDERED

The following is a brief description of each strategy analyzed in the simulation model.

6.1 Storage Strategies

<u>Initial Storage Strategy</u>: Before the simulation model was constructed, the storage strategy in the WMS placed product at the box level. Beginning at the front of each aisle, open box locations were considered with no

algorithms in the WMS to minimize vehicle travel time or efficiently route vehicles through the aisles.

Search For An Empty Bin: Instead of searching for individual box locations to store product, this strategy first searched for empty bins in an effort to place more boxes in the same location and reduce vehicle travel. The model was run considering various numbers of empty bins at a time before searching for empty bins in the next aisle.

Placeman: The goal of this placement strategy was to efficiently route vehicles to available bin locations. The boxes to be stored on the trolley were logically sorted to minimize vehicle travel.

Pick After Store: In the Initial Strategy, once a trolley of boxes had been stored, the operator would return the empty trolley to the empty trolley staging area even though there were orders still to be picked. This strategy instructed an operator who just completed a storing operation to immediately start picking product to reduce the amount of time an operator traveled without a work assignment.

Dedicate Vehicles to an Aisle: This strategy assigned each vehicle to an aisle in an attempt to reduce the congestion in the system.

Place an Entire Trolley in One Aisle: This strategy stored all the product on a trolley within a single aisle to minimize the number of aisles traveled through.

6.2 Retrieval Strategies

Initial Retrieval Strategy: The retrieval strategy that was in the WMS before the simulation model was constructed divided orders into 3-box UOWs with no algorithms in the WMS to minimize vehicle travel time or efficiently route vehicles through the aisles.

Packman: The goal of this picking strategy was to efficiently route vehicles to the next box location. Stockpicker drivers received their next UOW assignment based on the proximity of all available UOWs.

Various UOW Sizes: This strategy analyzed the impact of increasing the UOW size in an attempt to reduce the number of bins visited and stops made in the storage area.

Resort the UOW to Reduce Deadheading: Prior to entering the storage area, this strategy sorted the boxes in each UOW based on minimizing the distance vehicles would travel through the storage area.

Dedicate Vehicles to an Aisle: Each Stockpicker was assigned to an aisle and given UOWs that originated within its assigned aisle.

Limit the Number of Aisles a UOW Comes From: In an attempt to limit the number of aisles a vehicle would travel before completing a UOW, this strategy placed a limit on the number of aisles a UOW would come from.

Route Stockpickers to the Least Congested Aisle: This strategy attempted to minimize the congestion within an aisle. Two methods for calculating congestion were analyzed. One method computed congestion based on the number of Stockpickers in each aisle. The other method measured congestion based on the number of boxes to pick and store in each aisle.

7 IMPACT OF THE STRATEGIES

All of the above strategies were analyzed in the simulation model to determine their impact on system performance. The final result showed that not one strategy, but a combination of strategies (two storage and three picking) built upon each other to achieve the target throughput. Figure 4 summarizes the benefits of the strategies which are explained in detail in the following sections.

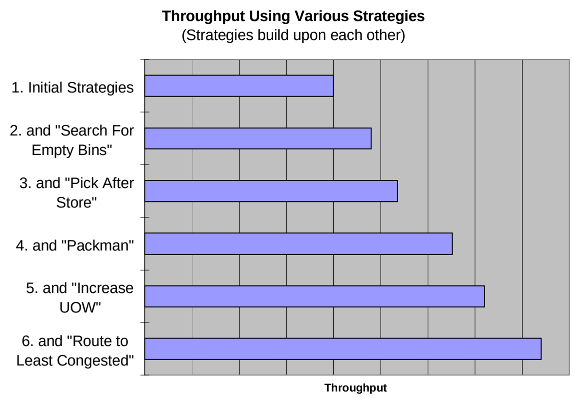

Figure 4: Summary of Successful Strategies

7.1 Successful Storage Strategies

The "Search for Empty Bins" strategy increased throughput by 20%. Instead of placing boxes in the next available box location, empty bins were found where twelve boxes could be stored at once. After analyzing various numbers of bins to consider in an aisle before searching in the next aisle, it was discovered that considering six bins at a time would maximize throughput. Throughput was maximized at six bins because searching more bins at one time increased congestion, and searching less increased vehicle travel.

Fortunately, this strategy was identified early in the study and required only slight changes to the WMS. This allowed the strategy to be implemented before the analysis was complete. After implementation, throughput increased by about 24% which strengthened the team's confidence in the validity of the simulation model.

The second storage strategy that proved successful was a change in the operational method termed "Pick After Store" which increased throughput by about 14%. Instead of returning the empty trolley to the common load and unload point after storage was complete, Stockpicker drivers were instructed to begin retrieval immediately after they finished storage. Using this strategy, Stockpickers would leave the load/unload point with a full trolley of boxes to be stored, then return to this point with a full trolley of boxes that had been picked.

7.2 Successful Retrieval Strategies

Along with the two storage strategies, there were three retrieval strategies that worked well. The first strategy, “Packman”, increased throughput by 29%. Originally, UOWs at the front of each aisle had the highest priority, which caused excessive travel to the front of the aisles. This strategy comprehended the vehicle’s location in the storage area and gave the closest boxes the highest priority which reduced travel between UOWs.

The second retrieval strategy increased the UOW size which resulted in a 17% increase in throughput. UOW sizes of 3, 6, 12, and 18 boxes were all analyzed. Results showed no difference in throughput between 12-box and 18-box UOW sizes, but these were a dramatic improvement over 3-box and 6-box UOW sizes.

The “Route Stockpickers to the Least Congested Aisle” strategy increased throughput by 29%. Rather than computing aisle congestion based on the number of Stockpickers in each aisle, using the number of boxes to pick and store in each aisle to compute congestion proved to be more successful for two reasons. First, simply considering the number of vehicles in each aisle did not provide visibility to *how long* each vehicle would be in the aisle. Knowing the number of boxes that must be stored or retrieved by each vehicle provides a reasonable estimate of the amount of time the vehicle will spend in the aisle. Second, this strategy considers not only the boxes currently being stored and retrieved, but also those that will be stored and retrieved in the near future. Therefore, this strategy understands that an aisle empty now, may actually be congested shortly.

7.3 Poor Strategies

Not all the strategies that were analyzed increased throughput. Some had no impact and others had a negative impact on system performance. One strategy of note is “Dedicate Vehicles to an Aisle”. Before constructing the model, many team members thought this strategy would be the most efficient since it appeared to reduce vehicle congestion to zero. In fact, the simulation analysis showed that instead of increasing throughput, dedicating vehicles to an aisle actually *reduced* throughput. The primary reason was that the WMS had no control over which boxes were allocated to an order. Therefore, there was no guarantee that an order, or entire UOW for that matter, would come from one aisle. Thus, Stockpickers were required to leave their assigned aisles in order to pick the remaining boxes in a UOW, then were routed back to their assigned aisle to begin the next UOW. This resulted in excessive travel and congestion as Stockpickers ventured from their assigned aisles to complete a UOW.

8 FURTHER ANALYSIS

As was stated earlier, successful strategies complemented each other to achieve the targeted throughput. Since coding strategies into the WMS was not a cost free procedure, an additional analysis was performed on any strategy or combination of strategies that showed a positive benefit. This analysis identified the additional equipment that would need to be purchased to achieve the same throughput instead of changing the WMS logic. Cost numbers could then be applied to both the WMS changes and the additional equipment and a decision made based on the cost associated with each alternative. Figure 5 shows how the number of vehicles needed decreased as the WMS storage and retrieval strategies improved.

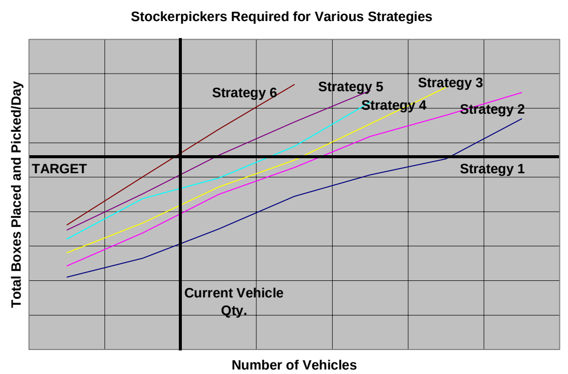

Figure 5: Vehicles Needed to Meet Production

To help management understand why the recommended strategies improved system performance, the statistics shown in Figure 6 were captured from the model.

Percent Improvement in Metrics

	Retrieval	Storage
Throughput	110%	constant
Time per box	38%	76%
Time per trolley	56%	74%
# Aisles visited per trolley	69%	83%
# Bins visited per trolley	34%	12%
# of Stops	36%	96%

Figure 6: Overall Improvement in Metrics

These same metrics were compiled after every strategy was modeled and analyzed and helped define the next strategy to be evaluated.

9 CONCLUSION

Initial efforts by the improvement team proved to have limited success. Only when a discrete event simulation model was developed, were strategies able to be analyzed. In the absence of a simulation model, the “Dedicate Vehicles to an Aisle” strategy probably would have been implemented in the WMS and created a negative impact on system performance.

A key learning from this study was that the method used to perform the analysis enhanced the likelihood for success. First, an improvement team was formed to investigate possible system alternatives. When it was determined that simple engineering practices could not solve the problem, discrete event simulation was employed. Actual system data was collected by visiting the site and talking with those who were operating the facility. Then, a high-level model was quickly developed to judge if the system had a chance of meeting the target production level. Once it was determined that the system could support production, a detailed model was constructed. The initial strategies were coded in the detailed model and the results from this model were compared with the information collected during the on-site visit. Finally, strategies were modeled and metrics were gathered that directed the simulation efforts towards beneficial strategies.

During the modeling effort, one recommended strategy was implemented in the WMS with measurable system improvements similar to simulation results. The outcome of the analysis revealed that a combination of strategies was required to achieve the target throughput.

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