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WAREHOUSE DESIGN THROUGH DYNAMIC SIMULATION

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ABSTRACT

Intel's new processors in mid-1997 were a dramatic increased in speed *and size* over their ancestors. The increased size caused box volume to increase beyond the capacity of the existing warehouses. New warehouses are under construction, among them an overseas facility. This warehouse is scheduled to be completed soon and will be the first site to implement a new warehouse management system. A simulation model was constructed to identify the labor and equipment required to support warehouse operations. With both the warehouse and warehouse management system still under construction when the simulation analysis was performed, model validation became extremely difficult. Regardless, partial model validation was possible given data from current operations. An in-depth look at how simulation modeling was used to aid in the design of a new warehouse is presented.

1 INTRODUCTION

Although Intel's microprocessors have changed dramatically over the years, the Logistics department saw relatively little change in its warehousing operations. There were the same number of units per box, stored in either tubes or trays. The new processor posed a threat to existing warehouse operations in mid-1997. It was not a single chip, but a product comparable in size to the cartridges used in many of today's game systems. This meant that at the product's introduction, the volume of boxes had increased beyond the capacity of the current warehouses. New warehouses were scheduled to be constructed and simulation modeling was used to validate each warehouse design.

An insight into the simulation model for one of the warehouses built recently, the Integrated Warehouse (IW), is provided. The objective of this simulation model was to recommend both headcount and equipment required to support warehouse operations. The data collection, modeling assumptions, analysis methods, and results using simulation to aid the design of this warehouse will be explored.

2 DATA COLLECTION

There are three items that make the IW simulation effort unique. First, the analysis is performed on a strategic level *before* the warehouse is built. Second, a new warehouse management system will be installed creating new operator jobs and eliminating some as Intel's warehouses move from batch processing to parallel processing of orders. Third, new battery operated vehicles (BOVs) and conveyor lines are purchased to support operations.

2.1 Data Sources

The data used in the IW model came from three main sources. The first source was time study data gathered on today's processes that will be similar in the IW. Time studies on such activities as scanning a box, relabeling a box, and loading a truck are independent of the warehousing system and were gathered on existing operations. The second source of data came from the equipment specification sheets for the new equipment. This allowed the velocity, acceleration, lift speeds, lower speeds, and other data about the new equipment to be inputted into the model. The third data source was assumptions from knowledgeable warehouse persons used to fill in the gaps not captured by the previous two sources. Consolidating an order of boxes from different processing lines is a function that does not take place under a today's batch processing system, but will occur in the IW.

2.2 Warehouse Design Targets

Before the number of operators and equipment required could be determined, the target throughput out of the warehouse had to be defined. This throughput is composed of two pieces: the product plan and the surge rate. The product plan is the forecasted volume of each product type stored in the IW. Whereas the product plan looks forward, the surge rate is calculated by looking backward at historical shipping volumes and is defined as:

$$\frac{\text{end of quarter shipouts per day}}{\text{average shipouts per day}}$$

Since shipouts increase dramatically at the end of a quarter, the new warehouse must be designed to handle this end-of-quarter surge in customer shipments.

3 MODEL ASSUMPTIONS

3.1 Model Starting Point

As a starting point for the simulation model, static calculations were performed in a spreadsheet model to identify the number of operators and equipment by type with which to begin the simulation analysis. More operators and pieces of equipment were then built into the simulation model to allow analysis on varying combinations of operators and equipment.

3.2 Modeling Timeframe

With the operations in transition to a new building, a new warehousing system, and new equipment, one of the key assumptions in the simulation is that all data were assumed to be for maturity. In other words, warehouse start-up is not modeled and time study data are not increased in an attempt to model an operator's first day in the warehouse. This is not to say that the times would not be different for this operator, but this is a very subjective matter and one best left for post-analysis discussion.

3.3 Customer Order Sizes for a New Product

Given that the IW would be storing a new product, a database of customer order sizes is not available. Because of this, the database of customer orders for the current processor is used to create various order sizes for the new processor in the simulation. This is in line with the assumption of modeling maturity since it is expected that the order profile for the new processor will eventually resemble that of the current processor.

4 MODELING METHODS

Two different methods are used in conjunction to determine if a given combination of headcount and equipment is able to meet a simulated volume of orders, or throughput.

4.1 Analyzing the Buildup of WIP

For a high level view of the system, the model is run for two days and the work in process (WIP) is recorded at equal time intervals. This analysis is conducted at various order volumes and the data is then plotted as WIP versus time (see Figure 1). If the WIP increases over time, then the system is unstable, meaning that more volume is sent to the warehouse than can be processed.

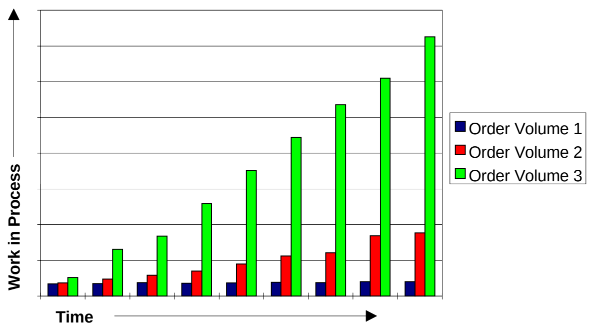

Figure 1: Work in Process vs. Time

From Figure 1, the WIP for Order Volume 1 remains relatively flat signifying a stable system. This is in contrast to Order Volumes 2 and 3 which both show increasing WIP over time signifying an unstable system. Also note that with this analysis it is possible to tell *how* unstable a system is by analyzing the rate at which WIP builds up in the warehouse. This comparison is useful if different product lines peak at different points in time or at different surge rates. Unfortunately, this analysis does not tell us *where* the bottleneck is in the system, simply that there is one.

4.2 Identifying the Source of the Bottleneck

The second analysis method will identify *where* the bottleneck is in the system. The model is run at various order volumes and the utilization of each operator and equipment type is recorded. The utilization as a function of volume is then plotted (see Figure 2). Figure 2 shows that as order volume increases, so does the utilization of each operator and equipment type. The key to this method is to define the utilization cutoff point above which an operator or piece of equipment is overutilized, or a bottleneck. For example, if the utilization cutoff point is 80%, then the operator or piece of equipment that crosses 80% first is the bottleneck in the system.

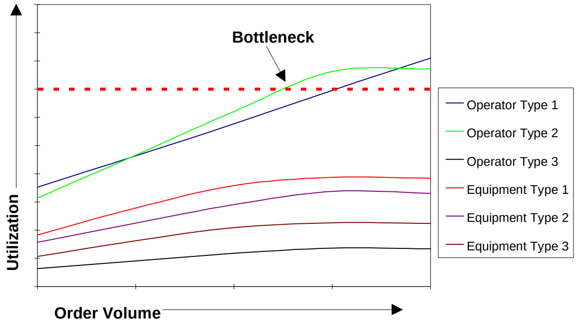

Figure 2: Utilization vs. Order Volume

Using this technique, the modeling team is able to identify the source of the bottleneck that caused the buildup of WIP in the first analysis. If the order volume at which WIP accumulates is unacceptable, or does not meet the warehouse design targets, then resources must be added to the bottleneck operation. For example, if the Processors cross 80% first, then resources could be added to processing in the form of another operator, or another processing workstation, or another operator cross-trained to processes when idle, etc. Adding another Packing operator, for instance, will not increase the capacity of the warehouse. Rather, it will simply reduce the utilization of already underutilized Packing operators at the bottleneck volume.

4.3 Analysis Methods Summarized

To summarize the modeling methods discussed here, first track the WIP in the system over time at various order volumes. If the system is unstable below the target order volume, plot the utilization of each operator and equipment type versus order volume. Identify the operator or equipment type that crosses the utilization cutoff point first. Add resources to this bottleneck and rerun the model. Repeat these steps until the system is stable at or beyond the target order volume.

5 ANALYSIS RESULTS

The analysis was begun by simulating the quantities of operators and equipment suggested by the spreadsheet calculations. Operators and/or equipment were then added one at a time to the bottleneck operation, and the model was rerun with the new combination of operators and equipment. This was repeated until the system was stable at an order volume greater than the warehouse's target order volume.

5.1 Simulation Run Length and Warm-up

To achieve statistically significant results, confidence intervals were computed on all operator and equipment utilizations and a half-width of 2% or less was targeted. In order to meet this target, twenty simulation runs at the lower order volumes and thirty simulation runs at the higher order volumes were required. More replications were required at the higher order volumes because of the high degree of variability in customer order sizes. The simulation also needed a warm-up length of twelve hours. This was determined by examining the warehouse queues and noting that they required about twelve hours to reach steady state. After a twelve hour warm-up period, the model was then run for three days. Run lengths longer than three days were performed, but the results did not differ from the models with three day run lengths.

For each operator and equipment type, the number required at the end of the quarter was identified through the simulation analysis. The critical and non-critical areas in the new IW were highlighted for management and solutions for handling the critical areas were explored. Recommendations to combine the job functions of some underutilized operators were also made to the IW management team.

5.2 Warehouse Queue Analyses

In addition to analyzing the WIP and utilizations for each operator and equipment type, two side analyses impacting the layout and design were also performed. Both were analyses on queue capacities required in the warehouse, calculations difficult with a spreadsheet model. The first analysis was performed on the queues located immediately after Picking (see Figure 3) and the second analysis was performed on the Consolidation Area located immediately after the Processing Workstations.

5.2.1 Post-Picking Queues

Product is placed in queues at the end of each storage aisle after it is picked, and waits in this queue until a Processing Workstation is available. It was observed in the simulation model that when the number of queue locations at the end of each aisle were reduced, there was a significant increase in the waiting time of the Picking BOVs (see Figure 4). Therefore, to keep the BOVs picking instead of waiting, various queue sizes were analyzed and the average BOV waiting time (due to a full queue) was recorded. From Figure 4, five queue locations at the end of each aisle were recommended through simulation to minimize BOV wait time.

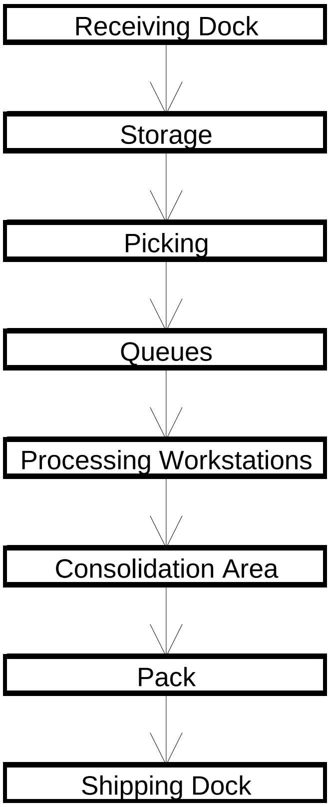

Figure 3: Warehouse Product Flow

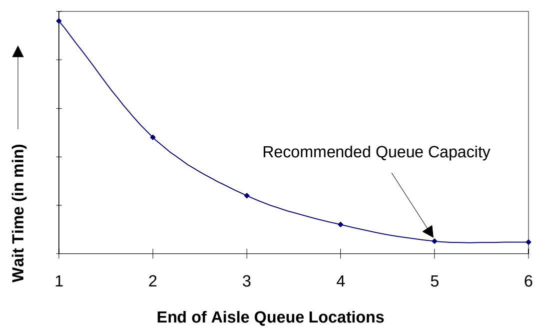

Figure 4: Vehicle Wait Time vs. End of Aisle Queues

5.2.2 Consolidation Area Queue

The second queue analysis was performed on the consolidation area located immediately after the Processing Workstations. This was an extremely difficult calculation to perform on a spreadsheet model, since it was unable to capture the dynamics of multiple-sized orders coming off different processing lines at various points in time. In contrast to the post-Picking queue, the consolidation queue was modeled as an infinite queue since it was assumed that the product would be unloaded from the Processing Workstations and put *somewhere* to allow another order to be processed.

The industrial engineers laying out the warehouse wanted to design this area large enough to handle the volume in the consolidation area 90% of the time, assuming operations would use work-arounds to accommodate the other 10% of the time. Rather than track statistics for 1 box, 2 boxes, 3 boxes, and so on, ranges of boxes were summarized, such as 1-100 boxes, and displayed in a pie chart (see Figure 5).

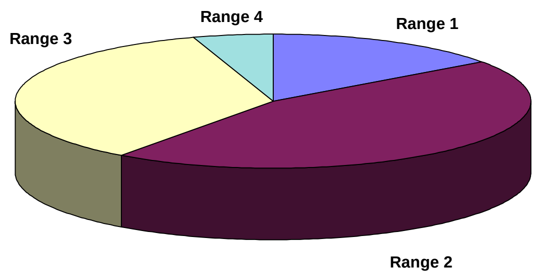

Figure 5: Boxes in Consolidation by Percent of Time

From Figure 5, the consolidation area will contain boxes in Range 1 a small percent of the time. But, the consolidation area will contain boxes from Range 2 through Range 3 the majority of the time. Realizing that boxes in Range 4 would be present in the consolidation area less than 10% of the time, 90% coverage was achieved by designing the consolidation area large enough to handle the upper limit of boxes in Range 3. So, if Range 3 was 201-300 boxes, then it can be seen from Figure 5 that there would be 300 boxes or less in the consolidation area 90% of the time. Thus, the area would be designed to accommodate 300 boxes.

6 FUTURE PLANS

The IW simulation model will be a “living” model, updated and analyzed regularly as the warehouse changes. In fact, once the IW is fully operational, time study data will be gathered on the new warehousing system and operations, and replace the existing time estimates used in the model. This will improve the accuracy and help validate the simulation model.

7 SUMMARY

The simulation analysis of the IW proved very beneficial for both management and the Logistics industrial engineers. Management’s uncertainty about the new warehouse and warehouse management system was reduced after the model results showed the warehouse would be able to meet the target throughput. In addition, not only did the results highlight the most critical areas in the IW, but allowed management to concentrate training efforts on these operations. Furthermore, the new warehousing equipment could be purchased with confidence that the quantities would support the end-of-quarter surge.

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