

## **SIMULATION IMPROVES END-OF-LINE SORTATION AND MATERIAL HANDLING PICKUP SCHEDULING AT APPLIANCE MANUFACTURER**

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### **ABSTRACT**

The most venerable and the most highly varied general application area in which simulation has frequently and repeatedly proved its economic value is the manufacturing sector of the economy. Manufacturing applications of simulation have included attention to complex issues of equipment and/or worker downtime, problems of facility layout, work and line balancing, bottleneck analysis, and material handling. Furthermore, simulation has proved itself capable of addressing productivity and efficiency improvement tasks in which these complexities overlap and interact. Historically, much of the success simulation has enjoyed in other economic sectors (e.g., service, transportation, and health care) has stemmed in large measure from the reputation it earned in the manufacturing sector. The manufacturing application described in this paper proved the cost-effective feasibility of designing sortation operations downstream of an assembly line, and scheduling SKU pickups there, with no risk of blockage of that line.

### **1 INTRODUCTION**

The earliest (dating back to at least the early 1960's) and for long the most conspicuous application successes of discrete-event process simulation have been the manufacturing sector of the economy (Law and McComas 1998). Numerous authors have described and documented the successful use of simulation to address a wide range of industrial-engineering problems arising in a likewise wide range of manufacturing contexts. For example, (Bandinelli, Iacono, and Orsoni 2004) describes the application of simulation to the remote scheduling of production of railway switch point assemblies. (Altinkilinc 2004) documents the use of simulation to undertake the layout planning and scheduling of a job-shop production plant. As a third of many possible examples, (Habenicht and Mönch) discusses the evaluation of batch production scheduling

strategies in a multi-product wafer fabrication unit via simulation.

In the present work, the production engineers and managers of a home-appliance manufacturing company undertook to improve the economy and reliability of sortation procedures and scheduling of material-handling movements downstream from the main assembly line. "Sortation" in this context refers to the proper arrangement of many different SKUs [stock-keeping units] for storage and/or for picking into individual customer orders (Tomkins et al. 2003). This sortation task and its associated material-handling tasks were of a complexity meriting discrete-event simulation analysis due to volatile product mix, the large number of SKUs, the high overhead costs (both equipment and personnel) to move and sort inherently heavy, bulky appliances, and the strict requirement that bottlenecks in sortation must never block the upstream assembly line.

### **2 OVERVIEW OF MANUFACTURING AND SORTATION OPERATIONS**

In the manufacturing and subsequent sortation processes considered in this study, large heavy unwieldy home appliances arrived from the final assembly line to the sortation area. The sortation area comprised six transit lines, each in turn comprising two equivalent spurs (hence twelve spurs in all). The appliances, of many different SKU varieties (during any one shift, up to 46 distinct SKUs could leave the assembly line), arrived at the sortation area approximately twice per minute. Sortation involved taking them to storage or to order-picking with proper attention to SKU. The transport to be scheduled required the use of manually operated "clamp trucks" – rather like conventional forklift trucks (Lane 2001), but retrofitted with special "upper arm grippers" to avoid damage to the appliances. A unit of an isolated SKU could be transported singly if necessary, although at lower efficiency of the clamp truck and its driver.

Preferably, if two or four appliances of identical SKU arrived in relatively close succession at the ends of the two spurs comprising one of the six lines, they could be scheduled for transport as a group. A pair of identical SKUs can be picked up together if they are adjacent side-to-side or front-to-back (but not diagonally), as shown in Figure 1 below.



Figure 1: Configurations allow pickup of two SKU#1

Due to the risks of cargo-load imbalance, it was unacceptable to transport *three* appliances on one foray, even if they were of identical SKU. The challenge confronting the engineers and the simulation study was to construct and validate a scheduling and operational procedure for routing various SKUs to the lines and spurs to forestall all risk of a sortation bottleneck blocking the assembly line, while using resources of clamp trucks and their drivers as thriftily and efficiently as possible.

### 3 DATA COLLECTION AND ANALYSIS

As up to 46 distinct SKUs could arrive at the sortation area in any one shift, the analysis team decided to collect product mix data from the production schedule for three months to estimate percentage quantity of each distinct SKU. The simulation analysts worked with the client's production planning and data control department to gather the most relevant and accurate data to estimate product mix. On request, the customer provided transport data such as pick up time for SKUs (1, 2, or 4 SKUs), travel time to warehouse, set down time for SKUs (1, 2, or 4 SKUs), and total number of clamp trucks and clamp truck uptime data.

The analysis started with the construction of a "base case" simulation model for the current sortation area with current total number of clamp trucks and current product mix. Subsequent scenarios were developed to change the product mix production schedule in accordance with the client's marketing predictions, and to maximize the number of SKUs per pickup while also leading to efficient use of clamp trucks via more nearly optimal scheduling of pickups.

In the proposed scenario #1, clamp trucks were used to pick up two SKUs all the time irrespective of SKU type. This scenario caused extra travel for trucks in the storage area. More specifically, scenario #2 was then developed using logic to sending an SKU to the spur having the same SKU type in its last occupied position. If there was no matching SKU in any of the spurs then the SKU was sent to the spur having the smallest current contents. Clamp

trucks were utilized to pick up only two or four appliances at a time. Scenario #3 was an extended version of scenario #2 wherein, instead of six sorting lines (twelve spurs), up to ten sorting lines (twenty spurs) were analyzed. Any sorting line after number six would be used only if all of the first six lines were full.

The strategy used in the analysis was further changed to study sortation behavior in scenarios #4 and #5. According to the proportions of various SKUs in the product mix, each SKU was assigned to a sorting line. Hence, to balance usage of the six sortation lines, each should carry approximately 16% of the total number of SKUs. Product mix data were used to group SKUs to be routed to certain sorting lines. As a specific example, this logic stated that SKU types 1, 2, 3, and 5 would be routed only to line 1 because product mix for these SKU types summed to very nearly 16%. Scenario #5 was run with ten sorting lines. As the number of sorting lines changed, SKU assignments for each line changed. In this case each line was allocated to carry 10% of total number of SKUs. Clamp trucks were then logically directed to pick up 1, 2, or 4 SKUs only, depending on the SKU type available at the end of a line. These scenarios gave scheduling priority preference to two or four SKU pick ups (instead of only one) in the interests of servicing as many SKUs as possible per trip and efficiently utilizing all available clamp trucks.

The scenarios #6 and #7 were extensions of scenarios #4 and #5 respectively. They differed only in that clamp trucks always picked up two or more SKUs per trip irrespective of SKU type.

### 4 CONSTRUCTION, VERIFICATION, AND VALIDATION OF THE SIMULATION MODEL

In accordance with client preference and the strength of the simulation software tool ProModel® for detailed material-handling modeling, the client and consultant engineers jointly elected to use this tool. ProModel®, like other modern simulation software tools, provides concurrent construction of the model and its animation, constructs such as *Entities* which move through the model, *Locations* to which they go, *Resources* which they use, plus powerful and intuitive constructs for modeling material-handling equipment and the network(s) within which such equipment operates (Harrell and Price 2003). A screen shot of the running simulation model appears as Figure 2. In this figure, the maze of blue lines represents travel routes and times between the warehouse (long rectangle at bottom of figure) and the twelve sortation lines shown. The performance metrics gathered dynamically during the run (right-hand side of figure) provide statistics on the number of pickups, and classify these pickups as of one, two, or four items. The number in the yellow rectangle should remain zero – that is the number of blockages (an SKU tried and

failed to enter the overcrowded sortation system) attributable to overly slow pickup service by the clamp trucks.

Verification methods applied to this model included modular development of the simulation model (to its credit, the ProModel® user interface encourages such development and makes it convenient), running the model with all randomness temporarily removed for ease of desk-checking results, running the model with only one entity, examination of the animation, use of directional analysis (e.g., verifying that if arrival rates increase and other input data remain unchanged, queue lengths should increase), and structured walkthroughs of the code segments within the model (Carson 2002).

Validation included running the model under current operating conditions and noting that the model predicted the necessity of three clamp truck trucks to avoid blockage of the assembly line. This threshold of three matched the client’s experience and consequent current practice. Early

in validation, a Turing test (Schruben 1980) exposed, and aided the correction of, an error relative to clamp-truck routing within the model network of paths. Also, the model prediction for “number of SKUs per pickup” slightly exceeded one, also matching current practice in which a clamp truck only rarely picked up more than one appliance per pickup. As an example of “extreme value validation,” (Sargent 2004), the model was run under the unrealistic assumption that breakdowns never slowed or halted appliance flow from the main assembly line to the downstream sortation line. Under this hypothetical condition, model analysis showed that seven clamp trucks are needed to run the sortation area without blocking the assembly line. The prediction “seven clamp trucks needed” matched approximate spreadsheet calculations and the client’s experience-based intuition.

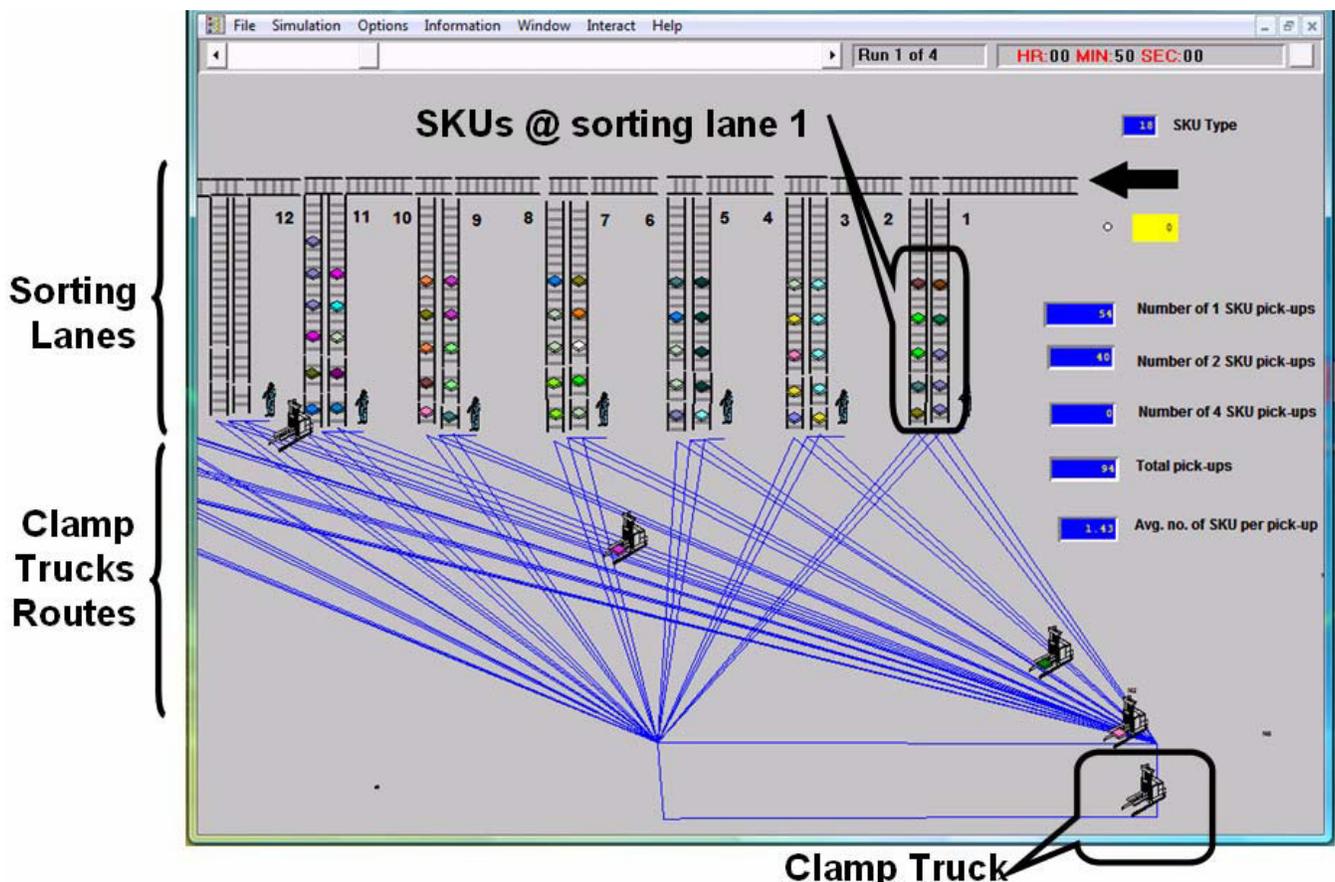


Figure 2. Annotated screen shot of ProModel® model during simulation run

**5 RESULTS AND INDICATED FURTHER WORK**

Simulation runs for the various scenarios were made as steady-state runs with a warm-up period of five production day and a data collection period of twenty production days (in practice, representing about one calendar month). To obtain sufficiently narrow confidence intervals (uncertainty for key performance metrics < 5%), twelve replications of each scenario were made.

The key performance metric “percentage blockage for the upstream assembly line” was collected for each scenario with a varying number of clamp trucks, showing how many clamp trucks would be needed to minimize or eliminate assembly line blockage in each pickup-scheduling scenario.

Table 1: Comparison of base case and Scenario #1

Number of clamp trucks	Assembly line AVG % Blocked (Baseline)	Assembly line AVG % Blocked (Scenario #1)
3	100.0%	100.0%
4	-	55.1%
5	100.0%	2.6%
6	25.2%	0.0%
7	0.8%	0.0%
8	0.0%	0.0%

Proposed scenario #1 predicted the need for least six clamp trucks to have no blockage of assembly.

Table 2: Comparison of Scenarios #2 and #3

Number of clamp trucks	Assembly line AVG % Blocked (Scenario #2)	Assembly line AVG % Blocked (Scenario #3)
3	100.0%	100.0%
5	100.0%	52.8%
6	10.7%	0.0%
7	0.0%	0.0%

Proposed scenarios #2 and #3 likewise indicated that at least six clamp trucks would be needed to keep the assembly running without blockage.

Table 3: Comparison of Scenarios #4 and #5

Number of clamp trucks	Assembly line AVG % Blocked (Scenario #4)	Assembly line AVG % Blocked (Scenario #5)
3	100.0%	100.0%
4	-	7.3%
5	12.4%	2.0%
6	1.3%	0.0%
7	0.0%	0.0%

Proposed scenarios #4 and #5 again showed that at least six clamp trucks would be needed to keep the assembly running without blockage.

Table 4: Comparison of Scenarios #4 and #6

Number of clamp trucks	Assembly line AVG % Blocked (Scenario #4)	Assembly line AVG % Blocked (Scenario #6)
3	100.00%	100.00%
5	12.35%	0.82%
6	1.25%	0.00%
7	0.00%	0.00%

Table 5 indicated that the change from scenario #4 to scenario #6 (recall that this change entails *only* the scheduling of a clamp truck to pick up at least two SKUs per trip irrespective of SKU types) would allow reduction of the clamp truck fleet from six to five. Since the change from Scenario #5 to Scenario #7 was analogous, these two scenarios were compared next.

Table 5: Comparison of Scenarios #5 and #7

Number of clamp trucks	Assembly line AVG % Blocked (Scenario #5)	Assembly line AVG % Blocked (Scenario #7)
3	100.00%	100.00%
4	7.28%	8.88%
5	2.04%	0.80%
6	0.00%	0.00%

The comparison between proposed scenario #5 and #7 again showed that the required number of clamp trucks could be reduced from six to five, here producing an acceptably small (less than 1%) blockage, although not zero blockage. In both these scenarios, four clamp trucks prove inadequate, with the difference in percent blocked time (7.28% versus 8.88%) insignificant at the 5% significance level. Five clamp trucks perform noticeably better, especially in scenario 7, which is now superior to scenario 5 at the 5% significance level (2.04% versus 0.80%). The dramatic drop in blockage attainable by adding one or two more clamp trucks (typical of operations research results concerning congestion (Thomas and Wilson 2001)) was documented for the clients using graphs such as Figure 3. The client management became more comfortable with these results upon being provided this analogy from everyday experience: “Recall how the waiting line in a bank or post office can suddenly shrink if one more service window opens, or lengthen if one currently open service window closes.”

The summarized results are shown in Table 6.

Table 6: Summarized results: # clamp trucks needed

Scenario Description	Required number of clamp trucks
Baseline scenario	8
Proposed Scenario 1 (Pick 2)	6
Proposed Scenario 2 (Last position)	7
Proposed Scenario 3 (20 sorting lines)	6
Proposed Scenario 4 (SKU assignment)	7
Proposed Scenario 5 (20 Sorting lines)	6
Proposed Scenario 6 (Pick 2, SKU assignment)	5
Proposed Scenario 7 (Pick 2, 20 sorting lines)	5

Effect of the Number of Clamp Trucks (Prop Scen #5 vs. #7)

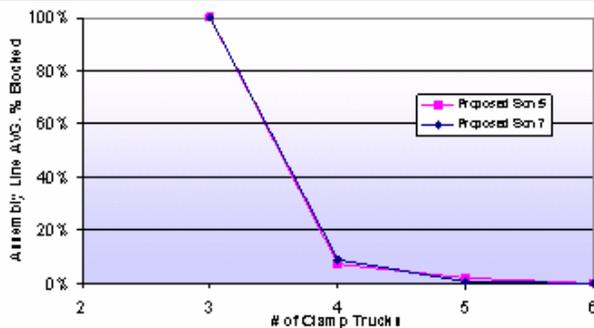


Figure 3: Graph showing dramatic drop in %blockage when sufficient clamp trucks available

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