Simulation Aids Long-Term Capacity at a Sunglasses Manufacturing Plant

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ABSTRACT
Simulation has long been used as one of many powerful analytical tools to improve productivity and eliminate bottlenecks. Historically, the first major economic sector in which simulation was thus used was – and still often is – manufacturing. More recently, simulation analyses have expanded into logistics and transport, the entire supply chain, the health-care sector, call centers, and service industries. Equally significant, early uses of simulation were largely tactical and of short-term viewpoint – the pinpointing of and cost-effective eradication of an all-too-visible bottleneck. Recently, the applications of simulation have often become more strategic and of long-term viewpoint. The simulation application discussed in this paper is indeed strategic: industrial engineers and business strategic planners used it to advantage in the long-term (multiple-year) capacity planning of a factory manufacturing sunglasses.

Keywords: manufacturing, discrete-event process simulation, capacity planning
improvements to the current material flow and labor usage policies (phase and milestone #2) and with assessing potential operational changes such as varying conveyor speeds, scrap rates, and number of pieces of equipment (phase and milestone #3). Since the model is to be useful by many engineers and production managers over a six-year period, standards of documentation and ease of use (e.g., Microsoft Excel® input and output interfaces) were set to high standards.

3. OVERVIEW OF THE MANUFACTURING PROCESS
Sunglasses being manufactured travel almost exclusively in trays through the multi-phase process, which is shown in Figure 1 (Appendix). The product mix, based on type of lenses, does not affect the flow path, but does affect the time spent by each lens tray (sunglasses of different lens types are not intermixed within a tray) at many of the workstations. The manual stations adjacent to automatic stations are backup stations; trays of sunglasses are routed to these manual stations when and only when the automatic stations are full. Except for ovens, workstations can accommodate only one tray at a time. Trays are transferred between stations in groups of ten, either manually or via short conveyors. If, due to even one defective lens, a tray is rejected at any point, the lens is replaced and the tray re-enters the system at the original entry point. Until that tray again reaches the point of rejection (where the originally defective lens was noticed), it will have markedly lower cycle times at each workstation.

4. INPUT DATA AND ITS ANALYSIS
Much input data had to be collected by the analysts working in concert with the client’s process engineers and managers. These data included workstation process times (for both new and recirculated trays), scrap (rejection) rates at various workstations, downtimes and repair times, setup times, and tray transfer times. Inasmuch as there are two product families, required input also included their respective percentages, and for several workstations, changeover times. At the client’s request, these input data were provided to the model via a Microsoft Excel® workbook, in which various data related to the model (e.g., all cycle time data were on the same worksheet); hence, the data values could be changed quickly, conveniently, and with little likelihood of error.

Distribution fitters were used to help model data in the model (Leemis 2004). With the client’s concurrence, cycle times at workstations and travel times between workstations were assumed constant (i.e., using directly the value input from the Microsoft Excel® workbook), as were transfer times. Interarrival times of raw materials and times-to-failure of workstations were modeled as exponentially distributed. Durations of downtimes (i.e., time required to repair) were modeled as Erlang with \( k = 3 \).

5. MODEL CONSTRUCTION, VERIFICATION, AND VALIDATION
Discussions among client engineers and managers, and the simulation engineers reached the decision to use the modeling tool SIMUL8® (Hauge and Paige 2004) to build the model. This software is convenient to use; provides basic constructs such as workstations, work entry and exit points, simple conveyors, and resources (e.g., workers); and permits construction of a two-dimensional animation concurrently with the model.

Model verification used various methods such as desk checking of the model logic and the modeler’s comments embedded in the code (SIMUL8® contains its own internal coding language, “Visual Logic”), structured walkthroughs, and tracing the path of one entity (specifically, one tray of sunglasses containing one pair of sunglasses) through the model, and temporarily specifying all distributions in the model as having a constant value (Carson II 2001). The last two of these techniques ease the task of checking basic model results against spreadsheet computations. Model validation began by confirming carefully documented assumptions: E.g., raw material is always available, buffers use first-in-first-out (FIFO) discipline, and process flow, as mentioned above, is the same for all product types. Model validation included meetings with the clients, during which the model animation was run slowly and watched closely. Additional validation checks included degenerate tests, extreme condition tests (e.g., if number of input entities is steadily reduced to zero, equipment utilizations should approach zero), and, perhaps most convincingly, a Turing test of the base model against contemporary production records (Balci 1998). After correction of small and typical errors, the clients agreed in writing (i.e., as a project milestone), that the model was valid and had achieved credibility.

6. RESULTS OF THE SIMULATION MODEL
In keeping with the objectives of analyzing long-term performance of the system, and because the system itself does not “empty out” at the end of a work-shift, nor at the end of a calendar day or week, the model was always run as a “steady-state” model. Typical warm-up times were 14,000 minutes (30 work shifts of 8 hours each) and periods for results collection were twice that (60 work shifts). The laboratory actually runs two such shifts per day, five days a week. At minimum, five independent replications were run, with the option of increasing this number whenever 95% confidence intervals for performance metrics were uncomfortably wide.

Since the model and its analysis are primarily responsible for evaluating plans to increase production over a six-year planning horizon (“Throughput
Improvement Road Map” or “TIRM”), key performance indicators examined included throughput (measured in trays of sunglasses per hour), equipment utilization, and work-in-process levels at various production stations.

By prior agreement with client management, the analysis proceeded in five steps:

1. Current system with only setup times included (“gross model.”)
2. Gross model #1 plus downtimes.
3. Gross model #2 plus lens breakages.
4. Summarized “net model” (setup times, downtimes, and breakages all included).
5. TIRM analysis based on #4 net model and increased requirement predictions.

As indicated in the previous section, steps 1 through 4 were all validated against current production. Analysis steps #1 and #2 agreed that the Blocking workstation was a severe bottleneck. In steps #3 and #4, after the inclusion of lens breakages, the automatic Generator workstation, even though backstopped by a manual one, became a bottleneck of approximately equal severity. Then, the TIRM was completed for the next planning year (details shown in Table 1, Appendix). Similar plans, and indeed, detailed action tables, were constructed for the next five years. By the end of implementation of these six plans, throughput was predicted to increase by a factor of 2.5, empowering the client company to comfortably meet expected demand over the multi-year planning horizon.

7. CONCLUSIONS AND FURTHER WORK

This extensive simulation project has provided a solid six-year expansion plan to the client manufacturing company. Its predictions have been vindicated during the first ¾ of the first plan year implementation.

The next phase of this study is already being carried out in much more detail, devoting attention to the schedule of incoming orders, shipping schedules, cycle time as determined on the basis of different lens attributes, number of workers, shifts, and holidays. Essentially, operational strategies will be provided to the laboratory to meet the six years’ target throughput via optimized, incremental, and cost-effective changes to the existing system.

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REFERENCES


AUTHORS BIOGRAPHIES

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EDWARD WILLIAMS holds bachelor's and master's degrees in mathematics (Michigan State University, 1967; University of Wisconsin, 1968). From 1969 to 1971, he did statistical programming and analysis of biomedical data at Walter Reed Army Hospital, Washington, D.C. He joined Ford Motor Company in 1972, where he worked until retirement in December 2001 as a computer software analyst supporting statistical and simulation software. After retirement from Ford, he joined PMC, Dearborn, Michigan, as a senior simulation analyst. Also, since 1980, he has taught classes at the University of Michigan, including both undergraduate and graduate simulation classes using GPSS/H®, SLAM II®, SIMAN®, ProModel®, SIMUL8®, or Arena®. He is a member of the Institute of Industrial Engineers [IIE], the Society for Computer Simulation International [SCS], and the Michigan Simulation Users Group [MSUG]. He serves on the editorial board of the International Journal of Industrial Engineering – Applications and Practice. During the last several years, he has given invited plenary addresses on simulation and statistics at conferences in Monterrey, México; Istanbul, Turkey; Genova, Italy; Riga, Latvia; and Jyväskylä, Finland. He served as a co-editor of Proceedings of the International Workshop on Harbour, Maritime and Multimodal Logistics Modelling.
### Table 1. TRIM First Year Plan

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Action to Raise Capacity</th>
<th>JPH Rating</th>
<th>Incremental Improvement</th>
<th>% Absolute Throughput</th>
<th>Next Bottleneck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline #4</td>
<td>Begin analysis</td>
<td>68.5</td>
<td></td>
<td>68%</td>
<td>Generator</td>
</tr>
<tr>
<td>2</td>
<td>Generator ↑46%</td>
<td>70.1</td>
<td>2%</td>
<td>70%</td>
<td>Finish Block</td>
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<td>6%</td>
<td>76%</td>
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<tr>
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<td>1%</td>
<td>77%</td>
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<td>88%</td>
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</tr>
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<td>Washing ↑13% Final Insp. ↑13%</td>
<td>95%</td>
<td>6%</td>
<td>95%</td>
<td>First Inspection</td>
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<tr>
<td>7</td>
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<td>99%</td>
<td>4%</td>
<td>99%</td>
<td>Coaters</td>
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