ANALYSIS OF CONVEYOR SYSTEMS WITHIN AUTOMOTIVE FINAL ASSEMBLY

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ABSTRACT

This study describes an application of discrete-process simulation to a final assembly process within the automotive industry. The study addressed the issues of whether the process design would meet production quotas, assessing the process flow times within the proposed system, verifying and improving the design of the conveyor system, and identifying and removing potential bottlenecks in the system. All these issues required resolution within a context more complex than that of a straightforward "single input – single output," inasmuch as the process required precise mating of components (engines with automotive bodies).

1. INTRODUCTION

Discrete-process simulation has a commendably long and successful track record in the improvement of manufacturing processes (Law and McComas 1997); its assistance is especially valuable when system operational complexities and stochastic variations prevent the profitable application of closed-form analytical solutions (Banks and Gibson 1997). Simulation renders this assistance via its abilities to predict overall system performance (e.g., throughput), identify bottlenecks, evaluate proposed alternatives for eliminating or ameliorating bottlenecks, and accurately attribute any deficiencies in overall system performance to specific problems such as over-used resources, inadequate or inappropriately placed in-process storage, or unduly long process flow times.

In this study, discrete-process simulation was applied to the improvement of an automotive final assembly process, with particular emphasis on material handling and transport via conveyors within that process. Engineers and managers not only needed to know whether the initially proposed process design would meet specified production levels, but also wished to assess variations of that design suggested as possible improvements. Additionally, the members of this plant production team wanted to locate and evaluate all bottlenecks, particularly those associated with the rigid requirement that a specified engine be mated with a specified vehicle body. Similar studies of analogous manufacturing systems are an evaluation of the feasibility of adding a new body style to a production line (Graehl 1992), assessment of rules for resolution of contention among pallets and fixtures in a flexible manufacturing system (Nisanci 1997), optimizing a large-scale transport system within a job shop (Angers, Gagnon, and Villeneuve 1995), and redesign of a process and consequent adjustments to a manufacturing line (Switek and Quiros 1996).

In this paper, we first provide an overview of the production system under study and then describe the development of the simulation model. We next describe the results of experimentation with the model. We conclude by describing "lessons learned" and indicating likely directions for future work.

2. OVERVIEW OF THE PRODUCTION SYSTEM

The production system under study comprises chassis, engine decking, and frame line operations within an automotive assembly plant. These operations are responsible for adding the engine, plus the powertrain and chassis components, to the vehicle body. These operations must be performed on behalf of three different vehicles, denoted "A," "B," and "C" in this paper, whose production is intermixed in proportions ultimately specified by marketplace demands. Hence, a typical "product mix" defines the long-range proportions in which batches of similar vehicles enters the system. The production system extends "floor to ceiling" within a large facility and includes extensive material handling and transport, supported by both overhead and inverted power-and-free conveyors, plus chain conveyors. This complex mix of conveyor types is typical of vehicle assembly plants, especially since widespread use of chain conveyors, despite their high initial cost, is often required to support high-volume vehicle production in contexts where slight job-per-hour loss might equate to six-figures-per-day financial
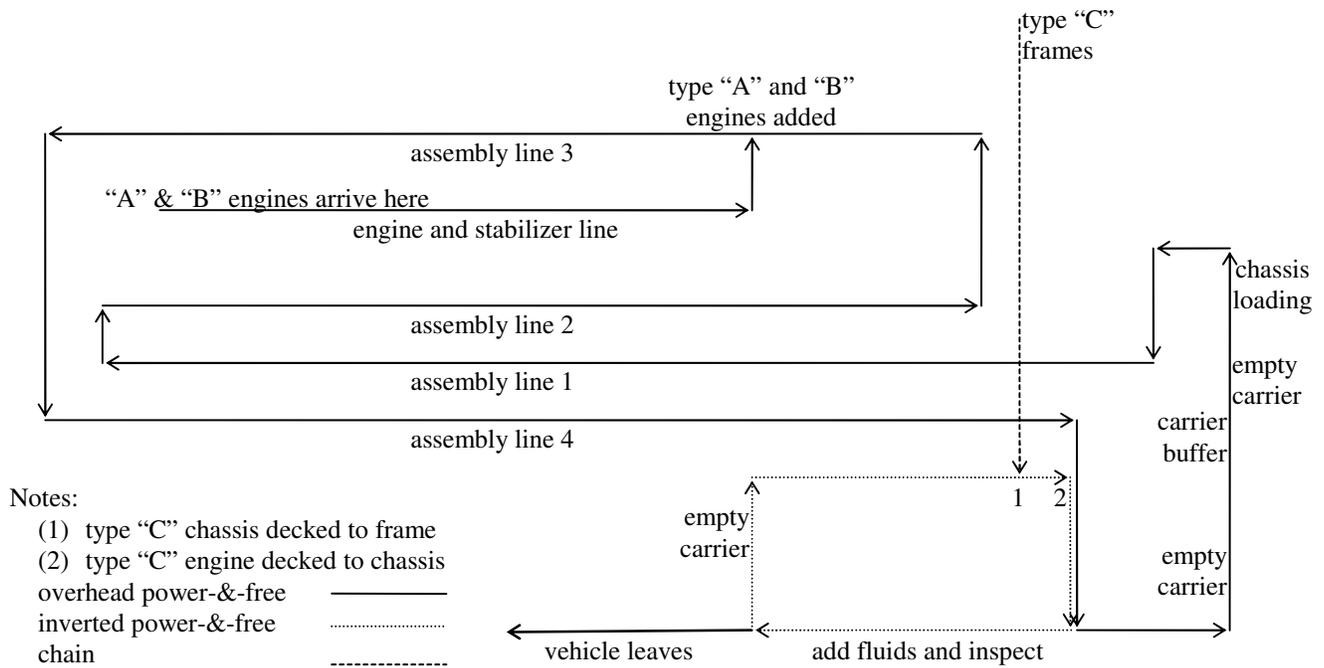
Figure 1: Schematic of chassis, engine decking, and frame operations

losses (Gunal, Sadakane, and Williams 1996). Simulation is particularly well suited to the fine-tuning of complex yet important material-handling details prevalent in manufacturing systems such as this (Langnau 1997).

A chassis enters the system by being loaded aboard a carrier. If the chassis is of vehicle type "A" or "B," its frame accompanies it. The chassis then travels along a series of overhead power-&-free assembly lines where a variety of vehicle components such as brake and fuel lines, an exhaust heat shield, the muffler, and front and rear bumpers, are attached to it in sequential operations. Most significantly, if the chassis is of vehicle type "A" or "B," the engine (plus stabilizer) is decked (attached) during these operations. The chassis eventually reaches an unloading station where it is detached from its carrier. The chassis then travels along an inverted power-&-free conveyor (i.e. the powered chain is at floor level, not ceiling level) through final operations such as addition of fluids (gasoline, oil, water) and inspections before leaving the system. Meanwhile, the now-empty carrier travels around a loop to the loading station where it will receive another chassis.

For vehicles of type "C," an empty carrier travels along the inverted power-&-free line until it receives a type "C" frame. This frame subsequently receives a type "C" engine; next, a type "C" chassis, which previously traveled along the overhead power-&-free conveyor without a frame, is attached. The type "C" vehicle then travels through the same final operations and inspections as did the type "A" and type "B" vehicles.

A schematic of these operations appears in Figure 1.

3. DEVELOPMENT OF THE SIMULATION MODEL

The engineers, analysts, and managers on the project team agreed that significant broad-based goals were evaluation of the throughput capabilities and process flow times of the proposed system, verification of the conveyor system design, and identification of all potential bottlenecks in the system. More detailed goals were determining the appropriate number of pallets in the system, comparing alternative layouts (for example, extending or eliminating curves in conveyors), and discovering the length of time an upstream station could be down before affecting the operation of a station downstream from itself. Knowledge of these tolerable downtime durations represents valuable information relative to establishing levels of and allocation rules for repair resources. Early specification of simulation project goals, as done here, is essential to the definition of model scope and to project success achieved by solving the right problems (Banks and Gibson 1996).

3.1 Establishment of Modeling Assumptions

The project team then reached consensus on explicit modeling assumptions. These assumptions specified, for example, that operators would always be available during scheduled production time and that all manual operations would be completed within the nominal cycle time

specified within the operation definitions. Additionally, the engineers agreed to assume that needed materials (e.g., parts, subassemblies) would always be available in needed quantities and that stations would generate no scrap. In lieu of extensive details in modeling machine downtimes and worker break times in the initial model, net throughput actually to be expected was modeled as a fraction of the gross, conceptually possible throughput. Explicit acknowledgment of modeling assumptions contributes to project success by simplifying the initial model (thereby enhancing its credibility and the ease of understanding it), indicating profitable paths of evolution toward models of successively greater complexity, forestalling mis-interpretation or misapplication of model results, and increasing the ability of the project team to present valid, useful results to management early relative to the overall project timetable (Musselman 1994). All project team members not only agreed on the reasonableness of these assumptions, but also specified sensitivity analyses to assess the extent of system performance degradation associated with the hypothetical failure of each assumption.

3.2 Data Collection

Essential data included operation cycle times for both automated and manual operations, plus loading and unloading times; conveyor types, lengths, and speeds; dog, moving, and stopping spacing of all power-&-free conveyors; and current and possible future production mixes by vehicle type. The plant engineers also provided "maximum float numbers" between all successive pairs of control points on the power-and-free conveyors; those numbers specified the maximum number of carriers able to occupy the conveyor between those control points simultaneously. For the base model, no downtime data were included. Most of these data were directly available via operation or equipment specification documents. As needed, the plant engineers undertook traditional time-and-motion studies (Mundel and Danner 1994). Based on experience of industrial engineers and examination of histograms, cycle, load, and unload times were modeled as normally distributed, using observed means and standard deviations as distribution parameters.

3.3 Model Development, Verification, and Validation

A prototype submodel of the engine and stabilizer preparation subsidiary line was first built using the WITNESS™ simulation software package, which combines ease of use with two-dimensional animation within an integrated suite of simulation and analytical tools (Markt and Mayer 1997). Outputs of this prototype submodel, particularly the numbers of pallets in the engine and suspension loading systems, and appropriate conveyor speeds in these systems, proved valuable during development of subsequent models. These models, more detailed especially with respect to material handling considerations, were built using the AutoMod™ simulation modeling package, which provides extensive modeling constructs to represent details of conveyors, three-dimensional animation, and a post-processor animation package (Rohrer 1997). Since both these tools provide the capability of importing AutoCAD™ drawings, animations acquired additional realism and ease of interpretation.

Aside from the animation, other techniques provided assistance to the verification and validation processes. For example, the lead model developer explained details of his modeling work to colleagues in structured walkthroughs. The analytically critical but nonjudgmental milieu of these walkthroughs exposed a variety of subtle errors for early correction. Examination of model execution traces subsequently provided additional assurance that the model was faithfully imitating the operational procedures of the actual system. For example, the engineers had provided not only the maximum float numbers between conveyor control points, as described in Section 3.2, but also the "expected float numbers." The expected float numbers represented observed average numbers of carriers expected between control points. Model validation included achieving close agreement between "average contents" of conveyor segments during simulation and the expected float numbers. Numeric results from deliberately over-simplified scenarios, such as a hypothetical "mix" of only one vehicle type, were readily checked to add additional assurance to validity of model output. Collectively, these techniques co-operated to not only provide high assurance of successful model verification and validation, but also to increase the confidence of client engineers and managers in the predictions of the model (Robinson 1997). Existence of and adherence to a simulation project discipline specifying performance of these tasks characterize high Capability Maturing Model [CMM] levels (Allenbach and Huffman 1998).

4. RESULTS OF MODEL EXPERIMENTATION

The model was first and foremost used to investigate whether the system would meet production quotas for various plausible production mixes. Additionally, many of the most pressing questions, for which managers and engineers looked to the simulation model for answers, were of the following two types:
1. How long can an upstream operation be down before a downstream operation stops for want of input?
2. How soon can a downstream operation, having been thus starved, restart subsequent to the resumption of operations at an upstream operation?

The following tables present illustrative results concerning these sensitivities for stations downstream from the chassis decking operation for three different carrier distributions.

Downstream Station	Time Interval Before Shut Down (minutes)	Time Interval After Bring Up (minutes)
body load	30.0	8.5
frame load	2.0	3.0
final line	2.0	2.5
A/B engine load	16.0	5.5

Table 1: Body Decking Sensitivity with Carrier Slack on Empty Side of Body Pickup

Downstream Station	Time Interval Before Shut Down (minutes)	Time Interval After Bring Up (minutes)
body load	8.5	7.5
frame load	2.0	3.0
final line	2.0	2.0
A/B engine load	5.0	5.0

Table 2: Body Decking Sensitivity with Carrier Slack on Loaded Side of Body Pickup

Downstream Station	Time Interval Before Shut Down (minutes)	Time Interval After Bring Up (minutes)
body load	19.0	8.0
frame load	2.0	3.0
final line	2.0	3.0
A/B engine load	5.5	5.0

Table 3: Body Decking Sensitivity with Carrier Slack Spread Evenly on Both Sides of Body Pickup

Broadly valid and applicable conclusions drawn from study of these and many similar tables obtained under a variety of assumptions about product mix were:

1. If the chassis unload station is more critical (less reliable) than the chassis load station, then carriers should by default be kept on the empty side of the system (the right-hand portion of Figure 1). If the chassis unload station goes down, there are still carriers in the carrier buffer to run the production line.

2. If the chassis load station is more critical (less reliable) than the chassis unload station, then carriers should by default be kept on the loaded side of the system (the left-hand portion of Figure 1). If the chassis load station goes down, production lines can still run to fill the carrier buffer.

The model provided explicit throughput (total production) figures for all scenarios. Comparisons, using paired *t*-tests, made by the analysis team and plant management confirmed that, under the most attractive system configurations suggested by experimentation with the model, the variation of throughput attributable to product mix change was reassuringly small. Specifically, the simulation analysis told engineers and managers how to configure the system such that no product mix scenario resulted in throughput less than 97% or greater than 103% of the average throughput among all plausible product mix scenarios.

After confirming the ability of the system to meet production quotas under a wide range of production mixes, members of the project team sought further improvements by redesigning the carrier buffer. This buffer had always consisted of three spurs, traditionally indistinguishable in usage. The center spur had a capacity of five carriers; each outer spur had a capacity of six. The base model was revised to specify that each individual carrier was explicitly assigned to transport *one* chassis type ("A," "B," or "C") and that each of the three spurs in the carrier buffer was explicitly assigned to hold only carriers of like assignment. The plant engineers had hesitated to undertake this change in operational procedure due to apprehensions that it would require a costly and disruptive lengthening of the spurs. However, extensive experimentation with the revised model proved that the capacities of five and six would remain adequate under all of the eight production scenarios run. Given this reassurance, plant management approved the proposed revision to operational procedure. This revision enabled process designers to eliminate a manual switching operation at the spurs, which in turn permitted reassignment of that worker to an understaffed area elsewhere in the plant.

5. LESSONS LEARNED AND FUTURE WORK

Throughout this project, engineers from the automotive manufacturer, the supplier of conveyors and material-handling equipment, and external simulation consultants worked in close co-operation. All members of this project quickly realized that open, unfettered communication across both horizontal and vertical organizational boundaries was essential to the free flow of information and ideas required for success (Williams, Edward 1997).

A significant trend in material-handling technology is that away from fixed, inflexible conveyor systems and toward flexible, modular, reconfigurable, and reusable solutions supporting agile manufacturing (Williams, Thomas 1997). As more new and competing alternatives for continuous improvement become available to the plant engineering team via rapid advances in material-handling technology, their relative merits will be assessed by ongoing modification and use of the simulation model already developed for this study. These assessments will be aided by increased use of cost analyses within the model (Strugalla 1996).

criticisms of an anonymous referee were also valuable and appreciated.

APPENDIX: TRADEMARKS

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