PALLET OPTIMIZATION AND THROUGHPUT ESTIMATION VIA SIMULATION

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ABSTRACT

We describe a discrete-process simulation analysis of a production system at an automotive supply company. This simulation project was undertaken with the goals of demonstrating and confirming production rates of a manufacturing process based on a proposed design layout and operational data, and of identifying cost-effective ways of improving the design to increase those production rates.

1 INTRODUCTION

Simulation is a highly effective analytical tool for assessing the quality of design of a production system relative to its ability to meet production goals of quantity and quality within constraints of operational complexity and cost (Seila 1995). In view of the complexity of typical manufacturing systems and the high level of stochastic variability among their operations, analysis of manufacturing systems is among the most venerable and frequent of simulation application areas (Clark 1995).

In this paper, we first present an overview description of the manufacturing system under study and its operational flow. Next, we specify the project goals and performance metrics of the system, and review the data collection required to support these modeling objectives. We then describe the construction, verification, and validation of the simulation models. In conclusion, we present the results obtained from statistical analyses of model output, the use of these results in actual practice, and the indicated direction for further work directed to continuous improvement.

2 DESCRIPTION OF MANUFACTURING SYSTEM

The manufacturing system studied and improved with the help of this simulation model produces an automotive component.

Pallets, each responsible for carrying one component undergoing the operations to be described, enter one of eight serial manual build workstations; these workstations are collectively the "manual build loop." Each pallet experiences a discrete stop at each workstation, during which the par-t aboard it undergoes a required operation. Subsequently, the pallets convey the parts to further operations, some automatic and others manual, within a main processing loop. Conveyors extending between successive operation workstations hold pallets which travel adjacent to one another and carry the pallets at constant speed. Pallets enter workstations singly and likewise leave singly after the prescribed cycle time has elapsed.

After undergoing testing at one of two air test machines on the main line, a pallet receives a "good" or "reject" status based on the part it is carrying. "Good" pallets continue downstream along the main line to provide further processing and eventual unloading to their parts. The then empty pallet returns to the manual build loop for another build sequence at the first open station the pallet passes. "Reject" pallets bypass subsequent processing stations along the main line to be prepared for repair, and are then shunted to the particular manual build station that produced the reject part. Parts leave the system through one of two unload stations.

Figure 1, below, shows a diagram of these operations and their spatial interrelationships.

3 PROJECT GOALS AND PERFORMANCE METRICS

The goals of this project were the assessment of the system relative to performance metrics and the identification of the most cost-effective ways to improve system performance. The fundamental metric was throughput, measured in jobs per hour (JPH). For example, since the number of pallets in the system was readily adjustable, process engineers were keenly interested in examining the effect of that number on throughput. Palletization will support improvement of cycle times, reduction of setup time and cost, and increased agility in the face of demand-mix changes, all probable impending contingencies for this production system (Owen 1996). Throughput can be highly sensitive to the number of pallets on recirculating pallet loops, and too many pallets can be even more inefficient than too few (Williams, Jayaraman, and Khoubyari 1996), (Williams and Orlando 1996). Additionally, the concepts of gross throughput (that obtainable with no stochastic variations or equipment downtimes) and net throughput (throughput actually achieved in actual practice, hence reduced by variations and downtime) were used to define "overall system efficiency" as the quotient of net throughput divided by gross throughput. Hence, overall system efficiency became a dimensionless quantity constrained to be between zero and one.

4 COLLECTION OF DATA

Operation cycle times and conveyor transit times were readily available from equipment specifications, work standards within collective bargaining agreements (for manual operations), and direct time and motion studies (Mundel and Danner 1994).

However, the collection and analysis of downtime data, clearly important to this study, required more effort and time. Since "percent down" was inadequate to characterize the performance of various machines (Williams 1994), both mean time between failure (MTBF) and mean time to repair (MTTR) data were collected, both by observation and study of operating logbooks. These data were then graphed and quantitatively examined (chi-square, Kolmogorov-Smirnov, and Anderson-Darling tests) using the ExpertFit™ software tool (Vincent and Law 1995). The mean times between failures were typically Weibull; the mean times to repair, lognormal. These distributions held intuitive appeal inasmuch as their modes were less than their medians, which in turn were less than their means.

5 CONSTRUCTION, VERIFICATION, AND VALIDATION OF MODELS

Before the actual construction of simulation models, all assumptions were explicitly listed, and the plant engineers and simulation analysts agreed upon them. Such documentation of and concurrence on underlying assumptions is critical to simulation project success (Musselman 1994). In this project, these assumptions were:

- one pallet type flows through the system, with one associated part type
- conveyor speed is 45 feet per minute; all conveyors are accumulating and have no downtime
- no extra time is spent shifting the direction of pallets
- each operation holds one part per cycle
- raw material is infinitely available (no starvation at the upstream system-environment interface point)
- finished parts always leave the main line without blockages
- labor is always available, without reference to shift patterns.

Three models were developed, two base models and one alternate model. The first base model depicted a system without variation and with a four spot manual build buffer. Omission of variation from this first model permitted direct closed-form analytical validation (Schriber 1974), thereby increasing model credibility. The second base model added stochastic variation to the first. The alternative model, representing a potential system modification the users were eager to assess, retained variation and reduced the number of off-line positions for pallet visitation during build or repair situations from four to one. The single position then accepts empty pallets on a first come, first serve [FCFS] basis, but will prioritize reject pallets to their correct manual build stations. WITNESS™ was chosen as the modeling tool in view of its support of concurrent model-building and animation construction (Thompson 1995) and familiarity with it among the industrial and process engineers at the client site. Integer subscripting proved a convenient approach to the explicit representation of the eight identical workstations in the manual build loop.

Major logic issues incorporated in these models included:

- location of a broadcast signal to alert a manual build station that a specific pallet is returning for repair, and ensuring that pallets designated to return to a particular station indeed do so
- assigning probabilities for pallet rejection
- assessing the potential for scrapping the pallet at a manual build station
- ensuring single or consecutive pallets move through a connecting dual platform between two adjacent machines (operation 60) such that the lift operates for both machines every cycle

- specifying proper buffer sizes immediately upstream from the air test machines (in parallel) and from the unload stations (in series).

The formal modeling technique advocated by (Dindeleux and Haurat 1996) was useful in specifying and confirming the proper conceptual communication between broadcast signals and pallets bearing defective parts en route to repair.

Several techniques were used to verify these models (confirm their execution matches the analysts' intentions) and validate them (confirm their output is believable and representative of the real system being studied) (Barth and Algee 1996). These techniques included partitioning and progressive refinement of the models, structured walkthroughs of model logic, use of stepwise execution and traces, and extensive interviews among the model builders and the production and process engineers most familiar with the real system (Harrell and Tumay 1995). Specifically, these interviews included Turing tests (Law and Kelton 1991). These verification and validation techniques are a necessary component of high-quality manufacturing simulation practice (Norman et. al. 1992).

6 ANALYSIS OF RESULTS

Since this manufacturing system is a steady-state system, a warm-up period, chosen to be eight hours and twenty minutes, was necessary to eliminate initial bias (Banks, Carson, and Nelson 1996). Following this warm-up period, all replications were run for an equivalent of 500 hours of production. Antithetic variates were used to reduce variance of results (Bratley, Fox, and Schrage 1983).

Table 1 presents simulation results from the second and third models of the study.

Table 1: Average Jobs per Hour and System Efficiency

number of pallets	# of off-line positions	average JPH	system efficiency
40	4		
45	4		
50	4		
55	4		
60	4		
65	4		
40	1	154.30	0.8036
45	1	156.09	0.8129
50	1	157.65	0.8210
55	1	158.83	0.8272
60	1	159.67	0.8316
65	1	29.37	0.1529

The abrupt drop in productivity and efficiency caused by oversupply of pallets was especially conspicuous in these results.

These and other results were analyzed statistically, using techniques such as construction of confidence intervals, linear regression, and design of experiments (DOE)/analysis of variance (Porcaro 1996).

7 CONCLUSIONS AND INDICATIONS FOR FURTHER WORK

The following conclusions emerged as consequences of this project:

- variations caused by unscheduled downtimes and rejects decrease production significantly
- throughput is highly sensitive to the number of pallets in the system
- the location of a broadcast signal Oust downstream from the air test machines or just downstream from operation 180) is immaterial
- off-loading parts between the two unload stations after repairing the first unload station creates a "bubble" necessary to utilize both unload stations effectively
- logic is required to sequence pallets and hence to ensure proper buffering upstream from testing and unload stations.

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APPENDIX: TRADEMARKS

ExpertFit is a trademark of Averill M. Law & Associates. WITNESS is a trademark of the Lanner Group.

REFERENCES

Banks, Jerry, John S. Carson, II, and Barry L. Nelson. 1996. *Discrete-Event System Simulation*, 2nd edition. Upper Saddle River, New Jersey: Prentice-Hall, Incorporated.

Barth, Tom, and Jane Algee. 1996. Proving and Improving Your Process with Simulation. In *Proceedings of the 1996 International Industrial Engineering Conference*, 522-525.

Bratley, Paul, Bennett L. Fox, and Linus E. Schrage. 1983. A *Guide to Simulation.* New York, New York: Springer-Verlag New York Incorporated.

Clark, Gordon M. 1995. Introduction to Manufacturing Applications. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 39-45.

Dindeleux, Regis, and Alain Haurat. 1996. Formal Modeling of Manufacturing Processes in Order to Simulate and to Analyse the Impact of the Control Process on the System. In *Proceedings of the 1996 European Simulation Multiconference,* eds. Andras Javor, Axel Lehmann, and Istvan Molnar, 188-192.

Harrell, Charles R., and Kerim Tumay. 1995. *Simulation Made Easy: a Manager's Guide.* Norcross, Georgia: Industrial Engineering and Management Press.

Law, Averill M., and W. David Kelton. 1991. *Simulation Modeling and Analysis,* 2nd edition. New York, New York: McGraw-Hill, Incorporated.

Mundel, Marvin E., and David L. Danner. 1994. *Motion and Time Study: Improving Productivity,* 7th edition. Englewood Cliffs, New Jersey: Prentice--Hall, Incorporated.

Musselman, Kenneth J. 1994. Guidelines for Simulation Project Success. In *Proceedings of the 1994 Winter Simulation Conference,* eds. Jeffrey D. Tew, Mani S. Manivannan, Deborah A. Sadowski, and Andrew F. Seila, 88-95.

Norman, Van B., James H. Emery, Christopher C_ Funke, Frank Gudan, Kenneth Main, and David Rucker. 1992. Simulation Practices in Manufacturing. In *Proceedings of the 1992 Winter Simulation Conference,* eds. James J. Swain, David Goldsman, Robert C. Crain, and James R. Wilson, 1004-1010.

Owen, Jean V. 1996. Profits Through Pallets. *Manufacturing Engineering 1* 16(l):33-42.

Porcaro, Dino. 1996. Simulation Modeling and Design of Experiments. *Industrial Engineering Solutions* 28(9):24-30.

Schriber, Thomas J. 1974. *Simulation Using GPSS.* New York, New York: John Wiley & Sons, Incorporated

Seila, Andrew F. 1995. Introduction to Simulation. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 715.

Thompson, W. Bruce. 1995. Introduction to WITNESS and Linking to Process Mapping Tools. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 462-466.

Vincent, Stephen, and Averill M. Law. 1995. ExpertFit: Total Support for Simulation Input Modeling. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 395-400.

Williams, Edward J. 1994. Downtime Data -- its Collection, Analysis, and Importance. In *Proceedings of the 1994 Winter Simulation Conference,* eds. Jeffrey D. Tew, Mani S. Manivannan, Deborah A. Sadowski, and Andrew F. Seila, 1040-1043.

Williams, Edward J., Arun Jayaraman, and Susan Khoubyari. 1996. Optimization of Palletization in a Production Job Shop. In *Simulation for Manufacturing Improvement Conference and Exposition.* Dearborn, Michigan: Society of Manufacturing Engineers.

Williams, Edward J., and Dean E. Orlando. 1996. Simulation Applied to Engine Upper Intake Manifold Assembly. In *Proceedings of the Southeastern Simulation Conference,* ed. Joseph S. Gauthier, xx-*yy.*

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