Proceedings of the 1997 Winter Simulation Conference
ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson

PALLET OPTIMIZATION AND THROUGHPUT ESTIMATION VIA SIMULATION

Edward J. Williams

A-73 Adv. Manufacturing Technology Development
24500 Glendale Drive
Ford Motor Company
Redford, Michigan 48239-2698, U.S.A.

Andrew Gevaert

Production Modeling Corporation
Suite 910 West
Three Parklane Boulevard
Dearborn, Michigan 48126, U.S.A.

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 1996).

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. Key steps undertaken to achieve success in this study, such as problem definition and goal setting, attainment of management support, specification of input data and assumptions, and determination of output required to solve the stated problems, parallel those advocated by (Banks and Gibson 1996).

2 DESCRIPTION OF MANUFACTURING SYSTEM

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

Empty pallets, each responsible for carrying one component undergoing the operations to be described, circulate within the manual build loop (eight identical stations of operation 10) until admitted to a vacant station. There, the pallet receives a component to be carried to the series of stations constituting the main line. Along the main line (but not the manual build loop), each pallet experiences a discrete stop at each workstation, during which the part 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. A “reject” pallet broadcasts a signal to the manual build station where it originated and continues to travel along the main line, bypassing all subsequent processing stations. Subsequently, the reject is readmitted to its manual build station of origin. This readmission has higher priority than any new work: that build station can accept no new work until the reject arrives. Parts leave the system through one of two unload stations. Figure 1, on the next page, shows a diagram of these operations.

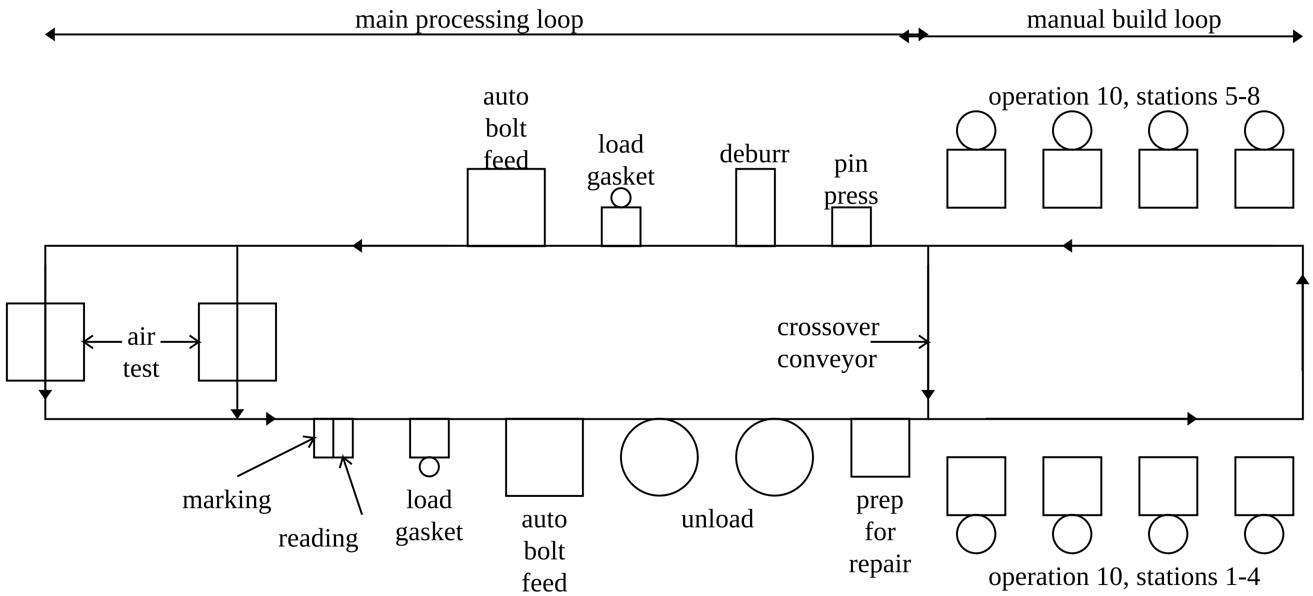

Figure 1: Diagram of process operations and flow

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 AND ANALYSIS OF SYSTEM OPERATIONAL 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). Cross-checks among these data sources guarded against the Hawthorne effect (Thurkow 1996).

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 best-fit calculations from an engineering reliability handbook (Kececioglu 1991), implemented in Excel™ spreadsheets. 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. An additional intuitive motivation for using these distributions was their occasional generation of a markedly lengthy downtime.

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 one four-spot manual build buffer for each of the eight manual-build workstations. 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, consisting of rejection probabilities and unscheduled downtime occurrences, 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 1996) 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, on the next page, presents simulation results from the second and third models of the study. 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). Our methods for planning and designing these experiments drew ideas and plans from (Özdemirel, Yurttas, and Köksal 1996). For ease of interpretation of results by client engineers, simultaneous acceptance and confidence ellipses (Hocking 1996) were included in the output reports.

Table 1: Average Jobs per Hour and System Efficiency

number of pallets	# of off-line positions	average JPH	overall system efficiency
40	4	150.00	0.7813
45	4	158.97	0.8279
50	4	168.17	0.8758
55	4	169.39	0.8822
60	4	171.84	0.8950
65	4	170.49	0.8879
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

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 (just 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.

Client engineers and managers decided, on the basis of these simulation results, to refuse the capital investment necessary to implement four (versus one) off-line positions. The additional three off-line positions never achieved a 10% increase in average jobs per hour (except for the anomalous case of dramatically overloading the single-position scenario with 65 pallets – itself a valuable contribution to problem avoidance).

Another unexpected result of interest was the occasional passage of pallets carrying rejected parts on the crossover conveyor (see Figure 1). This conveyor had been designed to carry only empty, recirculating pallets. However, occasional rejections originating from the same manual build station in quick succession caused a second reject to return from the main line while the previous reject was still in service at the manual build station. On these occasions, which arose on average twice per hour, the pallet carrying the second reject had to recirculate and hence travel along the crossover conveyor.

After engineering management implemented the recommendations spawned by this study, model predictions were confirmed within 3½%. Accordingly, future investigations planned using extensions of this model include:

- assessing the merit of providing manual backup stations to the automatic bolt feed stations (operations 50 and 130)
- checking the feasibility of manning the eight manual build loop stations (operation 10) with seven, not eight, workers
- evaluating methods of decoupling the unload stations (operation 140) from the main line via various material-handling methods; this operation has higher environmental cleanliness requirements than the others.

These planned extensions and uses of the model certainly match predictions of the increasing importance of simulation in business process re-engineering and production scheduling (Pegden 1997).

ACKNOWLEDGMENT

Dr. Onur M. Ülgen, president, Production Modeling Corporation, and professor of industrial and manufacturing systems engineering, University of Michigan – Dearborn, and John M. Dennis, simulation analyst, Ford Motor Company, both made valuable suggestions to improve the clarity and organization of this paper.

APPENDIX: TRADEMARKS

Excel is a trademark of Microsoft Corporation.
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.

Banks, Jerry, and Randall R. Gibson. 1996. Getting started in simulation modeling. *Industrial Engineering Solutions* 28(11):34-39.

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.

Clark, Gordon M. 1996. Introduction to manufacturing applications. In *Proceedings of the 1996 Winter Simulation Conference*, eds. John M. Charnes, Douglas J. Morrice, Daniel T. Brunner, and James J. Swain, 85-92.

Dindeleux, Régis, and Alain Haurat. 1996. Formal modelling 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.

Hocking, Ronald R. 1996. *Methods and applications of linear models: Regression and the analysis of variance*. New York, New York: John Wiley & Sons, Incorporated.

Kececioglu, Dimitri. 1991. *Reliability engineering handbook, volume 1*. Englewood Cliffs, New Jersey: Prentice-Hall, Incorporated.

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* 116(1):33-42.

Özdemirel, Nur E., Gazanfer Y. Yurttas, and Gülser Köksal. 1996. Computer-aided planning and design of manufacturing simulation experiments. *Simulation* 67(3):171-191.

Pegden, C. Dennis. 1997. Simulation: A look to the future. In *Proceedings of the 11th European Simulation Multiconference*, eds. Ali Riza Kaylan and Axel Lehmann, K-17—K21.

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, 7-15.

Thompson, W. Bruce. 1996. Introduction to the WITNESS visual interactive simulator and OLEII automation. In *Proceedings of the 1996 Winter Simulation Conference*, eds. John M. Charnes, Douglas J. Morrice, Daniel T. Brunner, and James J. Swain, 547-550.

Thurkow, Niki M. 1996. The use of security video film in video work sampling. In *Proceedings of the 1st Annual International Conference on Industrial Engineering Applications and Practice*, eds. Jacob Jen-Gwo Chen and Anil Mital, 1145-1149.

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, 16-22.

AUTHOR BIOGRAPHIES

EDWARD J. 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 in 1972, where he works as a computer software analyst supporting statistical and simulation software. Since 1980, he has taught evening classes at the University of Michigan, including undergraduate and graduate statistics classes and undergraduate and graduate simulation classes using GPSS/H, SLAM II, or SIMAN. He is a member of the Association for Computing Machinery [ACM] and its Special Interest Group in Simulation [SIGSIM], the Institute of Electrical and

Electronics Engineers [IEEE], the Institute of Industrial Engineers [IIE], the Society for Computer Simulation [SCS], the Society of Manufacturing Engineers [SME], and the American Statistical Association [ASA]. He serves on the editorial board of the *International Journal of Industrial Engineering – Applications and Practice*.

ANDREW GEVAERT holds a B.Sc. in Industrial and Manufacturing Systems Engineering from The University of Windsor, Ontario. He worked inside Chrysler - Windsor Assembly Plant #6 (full size van assembly) during 1995 as part of an engineering team, developing a plant wide quality improvement project. Employed at Production Modeling Corporation (Dearborn, Michigan) since January 1996, he has worked in the field of Applications Engineering, primarily focused on discrete-event simulation, chiefly involving automotive-industry manufacturing.