SIMULATION IN SUPPORT OF ROBOTICALLY AUTOMATED VEHICLE SEAT TESTING

Edward J. Williams
Mark Hebert
Ryan Raftery
Industrial and Manufacturing Systems Engineering
2330 Engineering Complex
University of Michigan - Dearborn
4901 Evergreen Road
Dearborn, Michigan 48128 U.S.A.

KEYWORDS

Process simulation, automotive industry, manufacturing simulation

ABSTRACT

An international company with significant automotive-industry operations in the Detroit, Michigan, U.S.A. area wished to assess its current capacity to absorb a new influx of business from the Asian market. Discrete-event process simulation, a powerful tool for addressing such questions, proved its value in the hands of a team comprising students undertaking a senior-level class project in simulation and their instructor. This collaboration with industry is consistent with the university's traditions of furthering students' educational objectives via practical experience while increasing the competitiveness of local industry via infusion of analytical methods and techniques.

INTRODUCTION

A large international company with extensive operations in the Detroit, Michigan, U.S.A. area is a first-tier supplier of vehicle seats to multiple automotive manufacturers. Within the last year, this company has received an influx of new business from the Asian market. The company operates large testing facilities to evaluate the durability of seat backs and seat cushions. Corporate management requested a simulation study to determine what additional facilities (employees, equipment, etc.), if any, would have to be added to the testing laboratory to accommodate the increased seat-testing work. Since discrete-event process simulation can assess the performance of any work-flow system under varying hypothesized loads, it emerged as a natural choice of technology for corporate engineers (e.g., the student enrolled in the simulation course) and managers to enjoy the benefits of generous lead time to address any problems a simulation model predicted the test facility would have under increased load. Indeed, simulation has a long pedigree of successful results when used to address such questions, and some of its earliest and most unequivocal successes have been in manufacturing industries (Miller and Pegden 2000). At the University of Michigan – Dearborn, student teams are routinely required to undertake course projects involving immediate practical application of the analytical techniques being learned, since such projects improve students' understanding and retention of the techniques by demonstrating their contributions to a company's or organization's efficiency and competitiveness (Williams 2000).

MODEL CONSTRUCTION, VERIFICATION, AND VALIDATION

Since the simulation software used in the course (System Simulation 458, a senior-level class for industrial engineering majors and having calculus and statistics prerequisites) is Arena™ (Kelton, Sadowski, and Sturrock 2004), it was natural and convenient to use Arena™ for this project, because its standard constructs (such as *Create*, *Dispose*, *Process*, and *Assign* modules among which entities move, and *Resources*, scheduled by *Shifts*, which entities use to undertake various processes) readily sufficed to model the processes under study. The Arena™ concept of a *Station* as a generic area where an entity undergoes conveniently categorized operations facilitated the construction of a model whose overall organization was readily understandable to client managers with little or no experience as clients of a simulation study. Furthermore, Arena™ provides an environment wherein development of the model and its two-dimensional animation routinely proceed concurrently (Bapat and Sturrock 2003).

The base model was responsible for accurately representing current operations within robotic cells in the testing laboratory. These robots are used to perform "ingress/egress" tests (the industry-specific name for tests concerning a motorist's or passenger's entrance into or exit from a vehicle) to determine the life cycle of seat cushions and/or seat backs. As shown in Figures 1 and 2 four pages hence, the robots "torture test" seats by moving a "butt form" or a "butt and back form" (these terms are the industry-specific names for molded plastic forms shaped like a typical human posterior) in and out of the seat repeatedly, representing seat wear caused by a person entering and leaving the seat numerous times.

Proceedings 18th European Simulation Multiconference
Graham Horton (c) SCS Europe, 2004
ISBN 3-936150-35-4 (book) / ISBN 3-936150-36-2 (CD)

If a particular type or style of seat has never been tested before (2% of all entering seats), the program of testing motions must first be programmed into the robot assigned to the test. On a staggered schedule, the robots are taken out of service one day per month for preventive maintenance and calibration. The automotive manufacturer (customer for the seats within the supply chain) specifies whether the "butt form" or the "butt and back form" will be used. The three significant current customers are divided between usage of the two forms; the prospective new business will specify use of the "butt and back form." At the conclusion of these tests, engineers measure the wear to the seat trim and note any structural failures occurring within the cushion frame or pan. A seat found to have excessive wear and/or a suspected structural failure (25% of all seats) must undergo a jury review conducted by trim engineers from the customer involved.

Actual construction of the base model was relatively straightforward, using fundamental modules of Arena™ such as those mentioned above. For example, the *Create* modules on the left-hand side of Figure 3 (last page) represent work samples arriving from various current customers whose test requests involve the same equipment to be used for the expected new tests, plus expected samples from the new Asian customers. After assignment (*Assignment* modules) of graphic icons and priorities, the samples are batched into groups of five, corresponding to standard scheduling policy of the robots. Next, after assignment of cycle times from the client's database, the work samples undergo preparation, including the work of obtaining required signatures. Times needed for sample preparation were obtained from a previous 6-sigma (Harry and Schroeder 2000) project; indeed, some client managers viewed this study as a natural extension of that project. Next, the samples undergo testing; two percent of these samples (representing previously untested types of seats) required preparatory programming of the robot. One-quarter of the samples suffer extensive material wear and/or structural damage during the test; those samples must then receive a jury review performed by trim engineers. Arena's™ diamond-shaped *Decide* blocks randomly direct 2% of the samples to robot reprogramming or jury review. All samples, after collection of performance metrics such as time-in-system, then exit the model via the shipping dock, represented by a *Dispose* block.

After this model construction, the simulation analysts then decided to run the Arena™ model on the presumption that five seats – the maximum possible – would be run through each of the two robotic cells during each test cycle, even though the current average production is less. This decision accommodated the principal goal of the simulation: to assess the ability of the current system to absorb the new business without expensive investment in new personnel and/or equipment. For example, adding a robot would cost approximately $97,000; adding a programmer or test engineer, $60,000 annually or slightly more.

The most significant problems in model construction were those of data collection. Most data, such as percentage of new seat types, arrival rates of seats from various customers, and length of robotic test sequences, were routinely obtainable from managers and engineers. However, under current operational policy, line supervisors forbade direct observational data collection of the times spent by technicians moving seat samples from one test station to another. To circumvent this problem, one of the analysts unearthed data used in a Six Sigma project the previous calendar year whose original objective was to explore ways of decreasing downtime among the robots. Meanwhile, model construction continued expeditiously with data collection, a concurrency strongly advocated by (Johansson and Grünberg 2001) to reduce calendar project time elapsed – important here due to both the inevitable academic-calendar constraints and the eagerness of client management to receive guidance relative to potentially needed capital investments.

Model verification and validation (Balci 1998) were achieved by various traditional methods, including traces and step-by-step observation of the animation, structured walkthroughs (Weinberg 1971) of the model and its data, extreme-value testing (typically blending with sensitivity analysis and involving the most uncertain input data values), and direct comparison of the base model output with observations in the test facility. These last were accurate within 4% after verification and validation, incorporating correction of various problems, was deemed sufficient. As a typical example of a problem needing attention, the original travel time to a holding area was specified as NORM(1.0, 0.25) (the Arena™ notation for a random variate normally distributed with mean 1.0 and standard deviation 0.25). However, the standard deviation is dangerously large compared to the mean – in a large group of long replications, this sampled value may be expected to be negative fully 37 times in 10^6.

RESULTS OF THE STUDY

After verification and validation were completed relative to the current system, the simulation team and the client investigated the following scenarios:

1. Add the anticipated new business to the system load without adding any resources.
2. Add the anticipated new business and add an engineer to the second shift.
3. Add the anticipated new business and add an eighth robot.
4. Add the anticipated new business and add a programmer.

Comparison of the last three scenarios with the first proved disappointing. These comparisons were undertaken using a warm-up time of one month, a run time of one year, and ten replications to build confidence intervals, using the Student-*t* distribution, at the 95% level for performance metrics. These confidence intervals bracketed either a performance metric for one scenario, or the difference between performance metric values for two scenarios. As a precaution against non-normality severe enough to undermine use of the Student-*t* distribution, replication results were checked for normality using the Kolmogorov-Smirnov test (Law and Kelton 2000), which failed to reject the null hypothesis of normality at $\alpha = 0.10$. Additionally, since some significance levels for rejection of normality did approach 0.10, those confidence levels were recalculated using the distribution-free method of Tukey based on Wilcoxon's signed rank test (Hollander and Wolfe 1999). These confidence intervals were in excellent agreement with those calculated from the Student-*t* distribution. Results of scenario #1 demonstrated that the system could handle the increased load in terms of throughput, but with longer time-in-system than hoped. Relative to scenario #1, the remaining scenarios provided negligible increases in throughput. Scenarios #2 and #4 provided slight reductions (about 5%) in time-in-system *for current customers* relative to scenario #1. Scenario #3 provided a moderate reduction (about 10%) in time-in-system *for current customers* relative to scenario #1. In each scenario, current customers' work was assumed of higher priority than the new work. However, management deemed none of these improvements sufficient cost justification for the (expensive) investment inherent in acquisition of another engineer, another robot, or another programmer, especially since predicted times-in-service for the new business were unduly long. Additionally, sensitivity analysis demonstrated that even these modest improvements were strongly dependent on the presumed amount of new business to be provided by the new customer – and both the amount of new business and the rate of increase from current to expected load on the system (i.e., rate of introduction of the new business) were naturally uncertain in an economic sense. Therefore, client management's response to the results of the study was to reject the three proposed investments (and any possible additive combination thereof) in favor of developing contingency plans for outsourcing of work during periods of sufficiently heavy and/or unexpected customer demand. A summary of the quantitative results is presented in Table 1 below, in which the new work is prioritized

Scenario	Throughput	*New Work* Time in System
Current	218	Not applicable
New work	326	684 hours
+Engineer	329	685 hours
+8th robot	332	812 hours
+Programmer	327	714 hours

Table 1. Summary of Scenario Comparisons

Results in the third column of this table clearly warned management that adding a resource (an engineer, a robot, or a programmer) without careful attention to revamping service priority policies would indeed improve overall service and particularly service to current customers – but provide such slow service to the new business that it "might well not linger long." This warning was deemed one of the most valuable results of the study.

SUMMARY AND CONCLUSIONS

The most significant aftermaths of this project were the client's desire to use this model (to be revised) further, treating it as a "living document," and indeed to use simulation in a variety of new situations. Significantly, this simulation study was the first ever undertaken by this client relative to the Ingress/Egress testing division of the business, notwithstanding that this work contributes about $700,000 annually to the corporation's annual income. Therefore, the project team wrote extensive documentation, both internal and external to the model itself, to facilitate its ongoing use and modification, and make simulation, as an analytical technique, more accessible to client engineers and managers, as advocated by (Seila, Ceric, and Tadikamalla 2003). For example, the client plans to use the model to assess possible improvements achievable by changing the test batch size from its current value of five; the batch size might plausibly be dynamically determined by current system conditions instead of being fixed. Client management has now embraced the philosophy "If at first you don't succeed, you probably should have simulated it" (harrell, Ghosh, and Bowden 2004).

ACKNOWLEDGMENTS

The assistance of Professor Roger Klungle, a valued colleague and statistician, is gratefully acknowledged. Colleague Rohit Trividi provided assistance in the formatting and layout of the figures within this paper. Additionally, two anonymous referees have provided helpful criticisms and suggestions after a careful reading of the paper.

REFERENCES

Balci, Osman. 1998. Verification, Validation, and Accreditation. In *Proceedings of the 1998 Winter Simulation Conference*, Volume 1, eds. D. J. Medeiros, Edward F. Watson, John S. Carson, and Mani S. Manivannan, 41-48.

Bapat, Vivek, and David T. Sturrock. 2003. The Arena Product Family: Enterprise Modeling Solutions. In *Proceedings of the 2003 Winter Simulation Conference*, Volume 1, eds. Stephen E. Chick, Paul J. Sánchez, David Ferrin, and Douglas J. Morrice, 210-217.

Harrell, Charles, Biman K. Ghosh, and Royce O. Bowden. 2004. *Simulation Using ProModel*, 2nd edition. New York, New York: The McGraw-Hill Companies, Incorporated.

Harry, Mikel, and Richard Schroeder. 2000. *Six Sigma*. New York, New York: Random House, Incorporated.

Hollander, Myles, and Douglas A. Wolfe. 1999. *Nonparametric Statistical Methods*, 2nd edition. New York, New York: John Wiley & Sons, Incorporated.

Johansson, Björn, and Thomas Grünberg. 2001. An Enhanced Methodology for Reducing Time Consumption in Discrete Event Simulation Projects. In *Proceedings of the 13th European Simulation Symposium*, eds. Norbert Giambiasi and Claudia Frydman, 61-64.

Kelton, W. David, Randall P. Sadowski, and David T. Sturrock. 2004. *Simulation with Arena*, 3rd edition. New York, New York: The McGraw-Hill Companies, Incorporated.

Law, Averill M. and W. David Kelton. *Simulation Modeling and Analysis*, 3rd edition. Boston, Massachusetts: The McGraw-Hill Companies, Incorporated.

Miller, Scott, and Dennis Pegden. 2000. Introduction to Manufacturing Simulation. In *Proceedings of the 2000 Winter Simulation Conference*, Volume 1, eds. Jeffrey A. Joines, Russell R. Barton, Keebom Kang, and Paul A. Fishwick, 63-66.

Seila, Andrew F., Vlatko Ceric, and Pandu Tadikamalla. 2003. *Applied Simulation Modeling*. Belmont, California: Thomson Learning, Incorporated.

Weinberg, Gerald M. 1971. *The Psychology of Computer Programming*, New York, New York: Van Nostrand Reinhold Company.

Williams, Edward J. 2000. Enhancing Collaboration Among Operations Research and Simulation Educators and Practitioners. In *Proceedings of the 2nd International Conference on Simulation, Gaming, Training and Business Process Reengineering in Operations*, eds. Yuri Merkuryev, Birger Rapp, and Galina Merkuryeva, 22-26.

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 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 Production Modeling Corporation, Dearborn, Michigan, as a senior simulation analyst. Also, since 1980, he has taught evening 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; İstanbul, Turkey; Genova, Italy; and Rīga, Latvia. His e-mail address is: williame@umdsun2.umd.umich.edu and his university Web-page can be found at http://www-personal.umd.umich.edu/~williame.

RYAN P. RAFTERY is an undergraduate student at the University of Michigan – Dearborn pursuing his bachelor's in Industrial and Manufacturing Systems Engineering with a concentration in manufacturing. Throughout his undergraduate tenure at the university, he has participated in cooperative education programs with companies such as Johnson Controls, Incorporated and Lear Corporation. During these work-study programs, he has worked within a range of engineering departments, such as Advanced Manufacturing and Product Design. As a graduate of the university's Honor's College, his coursework has ranged from Bible study and World War II to manufacturing processes and facilities design. Prior to his enrollment as an undergraduate student at the University of Michigan – Dearborn, Ryan attended Dearborn High School, where he was graduated in June of 2000 with honors while serving as student council vice-president and as a two-year starter on the varsity football team. He is a current member of the International MODAPTS Association [IMA], where he is a certified practitioner of the time-study methodology, and a member of the Society of Manufacturing Engineers [SME], where he serves as the Student Chair of the University of Michigan – Dearborn chapter S126. Ryan is a senior and his future intentions include being graduated in December of 2004 and attending graduate school to earn his master's degree in business. His email address is rraftery@umd.umich.edu.

MARK HEBERT is a senior at the University of Michigan – Dearborn majoring in Industrial and Manufacturing Systems Engineering with an individualized concentration, and is a member of Alpha Pi Mu (Industrial Engineering Honor Society). He will be graduated in May of 2004 and begin work on his Master's degrees in Business Administration and in Industrial Engineering. Mark is currently employed at a major automotive seating supplier in the Detroit Michigan area. His position is currently in product validation while focusing on the aspects of Six Sigma. He has earned his Design For Six Sigma Certification and is finishing his Six Sigma Green Belt training. Upon graduation, Mark will be participating in an operations rotation for his current employer, focusing on all aspects of the industry. His email address is mhebert88@yahoo.com.

Figure 1. Robot, “Butt and Back Ford,” and Seat Under Test

Figure 2. “Butt Form,” Close-Up

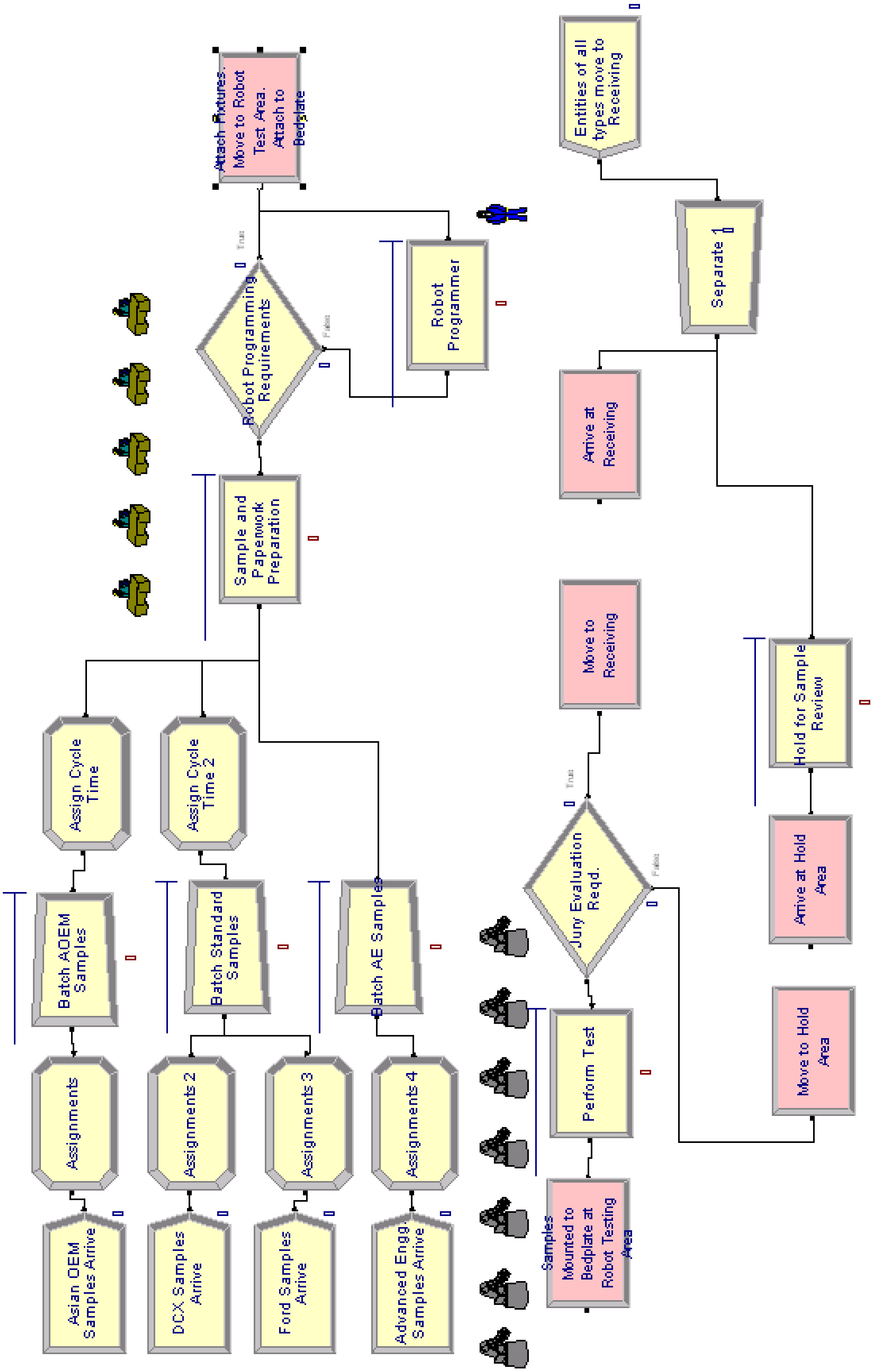

Figure 3. Screen Shot of Arena® Model