MODELING ISSUES IN A SHIPPING SYSTEM

Edward J. Williams

206-2 Engineering Computer Center
Mail Drop 3
Ford Motor Company
Dearborn, Michigan 48121-2053 U.S.A.

Susan Khoubyari

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

ABSTRACT

We describe the application of simulation and statistical analyses to the improvement of a shipping and distribution system supporting a component-fabrication plant and two automotive assembly plants interconnected by truck lines and railroads. These analyses enabled managers to determine the number and location of loading docks required, optimize the inventory level and distribution of racks (containers) circulating throughout this shipping system, determine the sizes of turnaround areas for truck and rail cargo at each plant, and predict annual truck and rail shipping volumes and costs.

1 INTRODUCTION

A simulation model is an alternative *realization* of a real-world system, such as a manufacturing, distribution, computer/communications, or service system, which permits timely, cost-effective experimentation directed toward improvement of the real-world system being modeled (Seila 1995). Such models provide strong advantages to the analyst responsible for design and implementation of a transportation, shipping, or distribution system, such as the abilities to evaluate flow of vehicles (in this context, trucks and trains) and trace entities (in this context, racks either empty or loaded with components) at minimal economic risk (Fishburn, Golkar, and Taaffe 1995). Simulation provides these advantages in situations where problem complexity and intractability frustrate use of queuing theory, linear and integer programming formulation and optimization (Subramanian et. al. 1994), or "closed-form" mathematical equations. Furthermore, simulation analyses provide these advantages irrespective of whether the shipping system is wholly contained in the production facility (Angers, Gagnon, and Villeneuve

1995) or, as in this study, physically external to it (Koh et al. 1994).

2 OVERVIEW OF SHIPPING SYSTEM

This shipping system supports three plants, a component-fabrication plant (Plant #1) in the United States, an automotive assembly plant (Plant #2) in the United States, and another automotive assembly plant (Plant #3) in Mexico. This system, comprising "northern" and "southern" truck routes and two railroad yards, one in the United States and one in Mexico, holds responsibility for transport of components from Plant #1 (an "upstream" plant) to Plant #2 and Plant #3 ("downstream" plants) in proper quantities and at proper times to meet production schedules set by management at Plant #2 and Plant #3.

The primary objective of this simulation study was to determine the minimum number of racks (these racks are expensive to purchase, transport, store, and maintain) required to meet these production schedules. Such racks are often a "workhorse" within a storage and/or distribution system, due to their abilities to both thrift floor space ("footprint") and provide precise access to either unit loads or large items (Kulwiec 1994). Related objectives were the confirmation of any increases in capacity needed at plant shipping and receiving docks or at cargo storage/transfer points, and increased accuracy and lead time relative to the prediction of annual shipment volumes and costs. Additionally, transportation and supply managers were keenly interested in the identification of methods of negotiating those costs (particularly via railroad) downward by decreasing variability of shipment volumes and dates within operational constraints of the system. Hence, migration from judgmental forecasting methods to analytical, quantitative ones (Sanders and Manrodt 1994) was already a management goal awaiting support from this simulation study.

3 INPUT DATA AND ASSUMPTIONS

Input data collection represented a significant portion (correctly estimated by the simulation project team, during preliminary project feasibility evaluation, estimation, and scheduling at 30% of the total project effort and time) (Williams 1996) due to the high complexity and broad scope of collecting data from multiple sources (three plants, two railroad yards, and trucking operations). Also, after initial data collection, these data required integration and cross-checking against both study objectives and intended simplifying modeling assumptions (Robinson and Bhatia 1995). To manage this complexity conveniently, the modeling team subdivided the data into three categories: general system input, plant-specific input, and railyard-specific input.

3.1 Input Data by Category

General system input answered these questions:
- initially, how many racks, truck trailers, and truck cabs were available?
- how many components does one rack carry?
- how many racks does one truck trailer (of each of two sizes) carry?
- how much time is required to attach a trailer to a cab, or detach it?
- how much time is required to load or unload a trailer?
- what are truck and train transit times, allowing for issues such as passing through customs, traveling across three time zones, and accommodating different holidays in the United States and Mexico?
- what are rates of damage and needed repair times to racks and to trailers, both of which must be returned to the United States for repair?

Plant-specific input answered these questions:
- what are the hours of operation at each plant?
- what is the production rate and schedule at each plant?
- what is the material-rejection rate at each plant?
- how many racks can the inbound and outbound storage areas accommodate at each plant?
- how many truck trailers can the staging areas at each plant accommodate?
- how many truck docks does each plant have, and what is their schedule of availability?
- at what times must trucks leave each plant to "catch" the next train departure at the local railroad yard?

Railroad-yard specific input answered these questions:
- what are the hours of operation at each railyard?

- what are the inbound and outbound storage capacities at each railyard?
- how much time does loading or unloading a train require?
- what are the train schedules and cutoff times for train departures from each railyard?

3.2 Modeling Assumptions

With the customer's concurrence, the modeling team chose to assume that no plant shutdowns or major production blockages would occur, and that customs-clearance procedures and times would remain identical with historical observations. Additionally, the complete absence of cab, trailer, or railroad breakdowns, and of border-crossing delays, was assumed. This early agreement on documented assumptions, and establishment of a contingency plan for sensitivity analyses concerning them, removed the otherwise ominous danger of eventual users' misinterpretation or unfounded extrapolation of modeling results (Harrell and Tumay 1995). As trenchantly stated by (Musselman 1994), "It is easier to correct an expectation *now* than to change a belief *later*" (italics added).

4 BUILDING, VERIFYING, AND VALIDATING THE MODEL

4.1 Choice of Modeling Environment

Consistent with prior discussions between the simulation users and the model-building team, the simulation model was built using the SIMAN/ARENA analysis and animation tool. SIMAN is a general-purpose simulation language of high power, often used to model manufacturing, service, computer, and transportation systems (Profozich and Sturrock 1995). ARENA, an object-oriented simulation system, simplifies the building of complex SIMAN models and also provides animation capability (Hammann and Markovitch 1995).

4.2 Model Run Length, Time Unit, and Initialization

Since the variations in production schedules and the holiday breaks in both countries (United States and Mexico) both had yearly periodicities, the model run length was chosen to be one year. Accordingly, and in keeping with the consideration that the real system runs "around the clock, seven days a week," the simulation time increment was chosen to be one hour. Significant system activity durations, such as trip times, were then convenient multiples of one hour. The system being modeled is steady-state, not transient; therefore, removing the initial transient from model runs was

necessary. In view of the long, computationally intensive run times implied by the year of simulated time, the modeling team chose to initialize the simulation model to typical, actually observed, conditions (Banks, Carson, and Nelson 1996), rather than begin model runs "empty and idle" and discard data collected during a warm-up period.

4.3 Choices of Probability Densities

As noted in Section 3.2, damage to trailers was assumed rare enough to ignore.

Extensive empirical data available from the modeling clients were used to choose an appropriate probability density for the number of damaged racks per interval of time. Those data were analyzed via heuristic examination of histograms, the chi-square test, the Kolmogorov-Smirnov test, and the Anderson-Darling test (Law and Kelton 1991). The software tool UniFit [now ExpertFit] (Vincent and Law 1995) proved convenient for running these tests and assessing their results. The first three of these tests indicated normality of these data; the Anderson-Darling test demurred. Since the Anderson-Darling test emphasizes behavior in the tails, and since the users and modelers agreed that extreme values for the number of damaged racks were rare and hence unimportant, the normal distribution was selected to model the number of damaged racks.

Likewise, extensive empirical data were used to choose probability densities for the durations pertinent to loading and unloading of trailers, attaching truck cabs to and detaching them from trailers, loading and unloading of trains, and transit times of trucks and trains. The four density-fitting analyses mentioned above concurred on use of the uniform density to model these input data.

In accordance with user requests based on both contractual provisions related to the outsourcing of repair service for damaged racks and observed invariance of repair-time duration, the number of days required for rack repair was represented as a constant.

All parameters of these probability densities (including the constant value for rack repair time) were changeable directly by the users via the convenient SIMAN "Experiment Frame" interface.

4.4 Model Verification and Validation

To assist in verifying and validating the model, the modeling team began by building a model of the existing system, with the intention of incorporating proposed modifications subsequently. This "base case" model was verified by use of walkthroughs, use of animation as a verification aid, and extensive checking of entity traces (Pegden, Shannon, and Sadowski 1995).

Validation and establishment of model credibility, during which the modeling team worked closely with the model users, employed further use of animation while presenting the model to the users, removing all stochastic variation and arithmetically checking the results, varying the input data and confirming the model responded correctly to the change, and the use of Turing tests (Harrell et al. 1995). For example, model results pertinent to the use of two different sizes of truck trailers were compared to those obtained by analytical methods in (Bausch, Brown, and Ronen 1995), with close agreement achieved. These Turing tests, in which model predictions and actual system data agreed within 3½%, thus becoming well-high indistinguishable, established high credibility of and users' confidence in the model as a vehicle to explore alternative system configurations.

5 STUDY RESULTS AND CONCLUSIONS

Four scenarios, a base case and three competing methods of shipping deployment, were analyzed in detail, beginning, as indicated above, with model validation via the base case. In all four scenarios, certain parameters were fixed, namely: each rack held eight components, each 40-foot truck trailer carried fourteen racks, and each 53-foot truck trailer carried eighteen racks. Also, all trains were "unit trains." Traditionally, shipments had always been made in lot sizes filling at least one railroad freight car; such shipments avoid the time and cost overhead of processing within railroad freight terminals (Van Metre 1939). Unit trains naturally extend these economies of time and cost by their complete dedication to moving the goods of *one* shipper from *one* loading point to *one* unloading point (Alexander 1967).

To provide for the construction of confidence intervals, five replications of each scenario were run. Intuition (the appeal of testing "competing proposals under equal loads") suggested the use of common random numbers (CRN) as a variance reduction technique (VRT) among the four scenarios. Reexamination of test runs verified the monotonicity of system performance metrics as functions of uniform random variates. These monotonicities confirmed the modelers' expectation that CRN would indeed reduce variance, as formally proved in (Bratley, Fox, and Schrage 1983). Specific results were:

Table 1: Starvation Results of Four Scenarios

Scenario	# racks in system	# docks at Plant #1	# instances starvation/year
Base	1699	1	21
1	1299	2	0
2	1055	2	0
3	1030	2	10

Highlights of these results presented to management were that dedication of an additional dock at Plant #1 to these shipments was urgently needed, and, given that dedication, the initial estimate of 1699 racks required could be safely thrifted to 1055 racks, a savings of three-eighths the initial estimate and translatable to significant reductions in capital investment, storage, and maintenance costs. Using Scenario 2, the model further predicted:

- average utilization of 40-foot trailers is 20; of 53-foot trailers, 5
- plant #1 requires yard space to hold 13 trailers loaded with empty racks and 19 trailers loaded with full racks
- plant #2 requires yard space to hold 2 trailers loaded with empty racks and 5 trailers loaded with full racks
- plant #3 requires yard space to hold 2 trailers loaded with empty racks and 17 trailers loaded with full racks
- the average number of trailers per train is 4; the maximum, 6.

Management implemented Scenario 2 on the bases of no instances of starvation coupled with a highly thrifted number of racks in the system. After eighteen months of actual operation under Scenario 2, all predictions held to within 4%.

6 DIRECTIONS FOR FURTHER WORK

The successful predictions described in the previous section have spawned significant customer interest in further work. Sensitivity analyses will be undertaken to determine:

- the number of truck trailers required to maintain continuous production at each plant during a year
- the impact of damaged trailers on those trailer requirements
- the number of truck cabs required to maintain production in the total system
- the impact on container requirements of various percentages (e.g., 5%, 10%, 15%) of racks damaged per year.

Interest in these system parameters is especially high due to changes in the trucking industry spawned by federal deregulation, ongoing North American Free Trade Agreement [NAFTA] negotiations on border crossings, and the increasing tendency of buyers to ask freight carriers to provide value-added services incremental to freight movement (Minahan 1996a). Similarly, ongoing development and use of the model will help assess economic and timing opportunities available through increased use of intermodal transport service providers (Minahan 1996b). Further, management is eager to

extend improvements conceived and implemented through this study to shrinking the time lapse between vehicle-order placement and delivery within the retail distribution system (Keller 1996).

Additionally, the users have requested modeling of scenarios involving presumably rare but surely high-impact events, such as plant shutdowns or strikes, train wrecks blocking rail traffic, or temporary but dramatic increases in border inspection and crossing times. Analysis of such rare yet highly significant events will be undertaken using the "external unknown unknowns" methods explained in (Okashah and Goldwater 1994), in view of the mathematical intractability of the "rare event problem" acknowledged there and in, for example, (van Moorsel, Kant, and Sanders 1996).

ACKNOWLEDGMENTS

APPENDIX: TRADEMARKS

SIMAN/CINENIA and ARENA are trademarks of Systems Modeling Corporation.

REFERENCES

Alexander, Robert E. 1967, The Shipper Views the Unit Train. In *Unit Train Operations,* 81-85. Chicago, Illinois: Railway Systems and Management Association.

Angers, Pierre-E., Gaétan Gagnon, and Laurent Villeneuve.   1995. An Analogical Approach to Optimize a Large Scale Job Shop Transportation System. In *Proceedings of the 1995 Summer Computer Simulation Conference,* eds. Tuncer I. Ören and Louis G. Birta, 396-399.

Banks, Jerry, John S. Carson, II, and Barry Nelson. 1996. *Discrete-Event System Simulation.* Englewood Cliffs, New Jersey: Prentice-Hall, Incorporated.

Bausch, Dan O., Gerald G. Brown, and David Ronen. 1995.   Consolidating and Dispatching Truck Shipments of Mobil Heavy Petroleum Products. *Interfaces* 25(2):1-17.

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

Fishburn, Paul T., Javad Golkar, and Kevin M. Taafte. 1995. Simulation of Transportation Systems. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom

Kang, William R. Lilegdon, and David Goldsman, 51-54.

Hammann, John E., and Nancy A. Markovitch. 1995. Introduction to ARENA. In *Proceedings* of *the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 519-523.

Harrell, Charles R., Robert E. Bateman, Thomas J. Gogg, and Jack R. A. Mott. 1995. *System Improvement Using Simulation,* 3d ed. Palos Verdes, California: JMI Consulting Group.

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

Keller, Maryann. 1996. Distribution: the Next Battle Ground. *Automotive Industries* 176(2):17.

Koh, Peng-Hong, Hak-Soon Ng, Hwei-Chiat Ng, and Jimmy L. K. Goh. 1994. Using Simulation to Preview Plans of a Container Port Operations. In *Proceedings* of *the 1994 Winter Simulation Conference,* eds. Jeffrey D. Tew, Mani S. Manivannan, Deborah A. Sadowski, and Andrew F. Seila, 1109-1115.

Kulwiec, Ray. 1994. Storage Rack Selection Guide. *Modern Materials Handling* 49(5):49-50.

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

Minahan, Tim. 1996a. The New Face of Trucking. *Purchasing* 120(4):38-43.

Minahan, Tim. 1996b. The Little Engine That Will. *Purchasing* 120(4):46-49.

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.

Okashah, Lobna A., and Paul M. Goldwater. 1994. Unknown Unknowns: Modeling Unanticipated Events. In *Proceedings of the 1994 Winter Simulation Conference,* eds. Jeffrey D. Tew, Mani S. Manivannan, Deborah A. Sadowski, and Andrew F. Seila, 689-694.

Pegden, C. Dennis, Robert E. Shannon, and Randall P. Sadowski. 1995. *Introduction to Simulation Using SIMAN,* 2d ed. New York, New York: McGraw-Hill, Incorporated.

Profozich, David M., and David T. Sturrock. 1995. Introduction to SIMAN/CINEMA. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 515-518.

Robinson, Stewart, and Vinod Bhatia. 1995. Secrets of Successful Simulation Projects. In *Proceedings of the 1995 Winter Simulation Conference,* eds. Christos Alexopoulos, Keebom Kang, William R. Lilegdon, and David Goldsman, 61-67.

Sanders, Nada R., and Karl B. Manrodt. 1994. Forecasting Practices in US Corporations: Survey Results. *Interfaces* 24(2):92-100.

Selia, 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.

Subramanian, Radhika, Richard P. Scheff, Jr., John D. Quillinan, D. Steve Wiper, and Roy E. Marsten. 1994. Coldstart: Fleet Assignment at Delta Air Lines. *Interfaces* 24(l):104-120.

Van Metre, T. W. 1939. *Trains, Tracks, and Travel,* 5th ed. New York, New York: Simmons-Boardman Publishing Corporation.

van Moorsel, Aad P. A., Latha A. Kant, and William H. Sanders. 1996. Computation of the Asymptotic Bias and Variance for Simulation of Markov Reward Models. In *Proceedings of the 29th Annual Simulation Symposium,* 173-182.

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. 1996. Making Simulation a Corporate Norm. In *Proceedings of the 1996 Summer Computer Simulation Conference,* eds. V. Wayne Ingalls, Joseph Cynamon, and Annie Saylor, 627-632.

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 both 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 Society for Computer Simulation [SCS], and the Society of Manufacturing

Engineers [SME]. He serves on the editorial board of the *International Journal of Industrial Engineering - Applications and Practice.*

SUSAN KHOUBYARI is a Systems Consultant at Production Modeling Corporation, Dearborn, Michigan. She holds B.S. and M.S. degrees in Industrial Engineering from the State University of New York at Buffalo. She has been working at PMC for five years, where she is responsible for managing discrete event simulation projects and finite-capacity scheduling systems, as well as training in project management concepts and software packages. She is a senior member of the Society of Manufacturing Engineers [SME].