Proceedings of the 2001 Winter Simulation Conference
B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds.

PANEL SESSION: THE FUTURE OF SIMULATION

Jerry Banks

1096 Tennyson Place
Atlanta, GA 30319, U.S.A.

ABSTRACT

Panelists representing seven areas of application give their views on the future of simulation. There is some consistency, but not a lot. Optimization, the web, training, supply chain management, graphics, and real time simulation received two mentions each. However, depending on how the counting is performed, there are another six areas with a single mention.

1 INTRODUCTION

This is the fifth year that a panel on the same topic has been convened. For the first two years, the panelists were all simulation software vendors. They discussed their forecasts for the technology in prescribed areas. In the third year, the panel was a mixture from academia, software vendors, consultants, and corporate simulationists. They discussed the needs of simulation in the future. Last year, the panelists were all simulation consultants. They used simulation every day. This year, the panelists were chosen to represent areas of use of simulation. These include manufacturing, healthcare, wafer fabrication, construction, consulting, logistics, and the military.

2 FARHAD AZADIVAR, UNIVERSITY OF MASSACHUSSETTS DARTMOUTH: MANUFACTURING

Computer simulation has enjoyed a great deal of success in performance evaluation of complex manufacturing systems. Another area where computer simulation has been used efficiently is comparing performance of systems under various operations policies. If there are a finite number of alternatives, manually building a simulation model for each alternative and comparing the results through a sound statistical process will provide the optimum solution. However, the optimum design may require evaluating a prohibitive number of alternatives that would make building all individual simulation models infeasible.

Several simulation optimization processes have been developed for systems where the simulation models for alternative manufacturing systems can be generated by changing the values of the quantitative variables of the system. Samples of these are given in (Azadivar and Lee 1988, Azadivar and Talavage 1980, Glynn, L'Ecuyer and Anes 1991, Morito and Lee 1994, Safizadeh 1984). In these cases the simulation model stays the same structurally and only its parameters are varied. In other words, the simulation model functions as an objective function of an optimization process. An example of this type of problems is optimization of the in-process inventory spaces for a complex and stochastic intelligent manufacturing system. Many of the methods used for optimizing these systems include adaptation of some of the search methods available in the literature. These include the stochastic approximation method, simulated annealing, response surface methodologies, simplex and complex searches, and several versions of gradient search methods.

Most realistic problems, however, consist of designing systems by evaluating many alternatives that are structurally different and cannot be represented by the same simulation model. For instance, in the same intelligent manufacturing system, alternatives may require considering different paths of material flow, different layout configurations, different priorities at different stations, different means of material handling systems, and utilizing different machines. Selecting one possible choice from each of the above factors will require a unique simulation model.

In most cases considering all possible combinations will be infeasible. Usual search methods cannot be applied here either, because most searches consider the feasible region as a geometric space and navigate through this space through geometrical means. In optimizing manufacturing systems with structural differences, possible settings of the decision factors do not have geometric relationships with each other. Besides, the objective function does not necessarily stay the same either, because the relationship between the variables and the performance of the system is defined by a different function each time the simulation model is changed.

In order to use computer simulation for optimal design of large and complex manufacturing systems with qualitative and policy variables, there seems to be a need for developing two distinctive tools that are able to interact with each other and result in an optimal setting for various design factors. These are:

a) An object oriented method for automatically generating and evaluating a simulation model for any given setting of decision factors of the given manufacturing systems such as combination of one set of machines, one particular routing scheme, one particular priority scheme, a different material handling system and a given layout.
b) Using a search method for systematically searching among possible alternatives and converging to an optimum solution by considering only a limited number of alternative configurations of the system.

Some work has been done in this area utilizing an object oriented simulation builder for several specific applications. These builders are then interfaced with a Genetic Algorithm (GA) for optimization. Representatives of these methods are given in (Azadivar and Wang 2000, Azadivar and Tompkins 1999, Azadivar and Zhang 1997, Cheng and Gen, 1996, Tam 1992, Tompkins and Azadivar 1995, Zhang 1997). The process is as follows:

- GA searches through the feasible region (all possible combinations) and selects a population of system configurations by providing a setting for each of the decision factors for each configuration and supplies the result to the simulation builder.
- The simulation builder builds a model for each of these configurations and evaluates the performance of the system. These values are supplied to The GA as the fitness values of the members of the population.
- Using these fitness values and common GA operators of *selection*, *crossover*, and *mutation* a new population is provided to the generator to build and evaluate fitness values for the next iteration.
- Iterations are terminated when an acceptable solution is achieved or computation budget is exhausted.

This process is just a sample of things that can be done in using simulation as a tool for design and optimization of complex manufacturing systems with qualitative and policy factors. Work needs to done to develop additional generic simulation model generators and more efficient search algorithms compatible with the nature of these problems.

3 DAVID M. FERRIN, ACCENTURE: HEALTHCARE

My comments will be regarding the “Future of Simulation” from the perspective of the users of simulation (clients or customers) rather than the perspective of the user of simulation tools. Characteristics of this group of users have been changing over the last several years. More importantly, the number of C-level customers have grown significantly in our practice. C-level customers are, for example, CFOs, CEOs, CIOs and so forth. I believe that these “C-level” customers are again realizing the power and strength of simulation as an aid to the decision-making processes. The rest of my comments will be centered on a few of the skills needed to work with this type of customer, specifically characteristics of these customers and marketing our technology to these customers since I believe that the needs of these customers will have a profound effect on the “future of simulation.”

It is essential to understand the characteristics of the requests of these customers in order to understand their needs. In relation to simulation, C-level customers desire more confidence, when available, in making complex, important decisions. This is possibly one of their most common needs as a group.

With respect to the future of simulation and this group of customers, the first step is for us as a group to understand their requirements, especially their business requirements. In fact, we need to learn to intuit their needs. To do this, we must become familiar with their industry, their personal business situation, know their goals and frame their questions in a manner so that we can be of service in providing the right (or even best) answers. If we are “selling” simulation, we are missing the boat. Instead, we should be answering very expensive questions, their most expensive questions.

The second step for us as a group is to provide high-quality graphic content. This content must be well customized to their needs as well as to the needs of the process owners. The validity of the simulation must be very high. When this is done well, the C-level customers will understand the model and its implications quickly and the simulation will serve as a discussion tool designed to meet their needs for a specific decision and situation. It is not unusual for a well constructed simulation to have significant impact on the politics surrounding the project. The reason is that management by facts becomes more predominant under these circumstances.

Marketing to C-level customers is a bit different than other customers. It is best done as “relationship selling” through an individual already in place. We add impeccable, previously established credentials that must be highly reinforced on the first project. Finally, follow-on opportunities come from good work.

4 JOHN W. FOWLER AND GERALD T. MACKULAK, ARIZONA STATE UNIVERSITY: WAFER FABRICATION

Most conventional simulation software packages used for modeling semiconductor fabrication are designed around a “job-driven” worldview. Entities (lots) are modeled as the items that traverse the various process constructs, while system resources (machines) are passive. Models are built by defining the sets of available resources that can limit entity flow at appropriate process steps, and then detailing the logic associated with step traversal. The simulation language must maintain unique entity identity, normally through the storage and manipulation of entity attributes.

Semiconductor fabrication facilities contain thousands of simultaneous production lots, resulting in a simulation model that may also contain thousands of entity records. The speed and space complexity of these simulations must be at least on the order of some polynomial of the number of lots in the factory and have been shown to increase exponentially in their execution time. Job-driven simulations are convenient for low-volume, high-mix manufacturing or when fast simulation execution speed is not as important as detailed information and/or system animation.

An alternative methodology for simulating wafer fab operations, proposed by Professor Lee Schruben of the University of California-Berkeley, has shown promise in early evaluations. This alternative focuses on resource cycles as the active system component and the individual jobs as passive components, and has been named the "resource-driven" paradigm. Rather than maintaining a record of every job in the system, only integer counts of the numbers of jobs of particular types at different steps are necessary. The system's state is described by the status of resources (also integers) and these job counts. The speed and space complexity of resource-driven simulations is a function of the physical system characteristics rather than simultaneous entity tracking. This creates advantages for the resource-driven approach in large-scale models with high levels of tracked entities.

The hope is that resource-driven factory simulations can be developed that are able to provide much of the same information as job-driven simulators while executing many times faster. The expectation is that the two types of factory models can be used together. For example, high-speed, resource-driven factory simulators would be used for large-scale experiments that identify key opportunities for improvement. These can then be studied with detailed job-driven simulators.

At a low level, the dynamics of a queueing system can be viewed as the interactions among different job process steps. At a higher level, system dynamics can be modeled in terms of resources cycling through different states (busy, idle, broken, repaired, etc.). We anticipate that some mixture of job path and resource cycle modeling will be appropriate for many studies. Furthermore, the optimal mix might be dynamic, adapting to different experimental objectives or system conditions. Several ways of integrating job and resource modeling styles come to mind. Most obviously, it is probably always possible to create and maintain records for some individual jobs for data collection or routing logic during critical stages of processing without resorting to tracking all of the lots all of the time.

Another possible experimental strategy is to use fast resource-driven simulations to provide co-variates for reducing the variance of performance statistics estimated from slower but more detailed job-driven models. It may also be possible to develop procedures for determining a proper mix of job-driven and resource-driven simulation logic as well as methods for integrating the two modeling technologies.

Finally, an intriguing development is the recent discovery, documented in Schruben (2000), that the trajectories (WIP plots and cycle times) of some resource-driven models can be found analytically as solutions to linear or mixed-integer optimization programs. In addition to an academically interesting alternative to "running" a simulation, these optimization models may have practical value in schedule constraint generation and system sensitivity analysis. This, coupled with innovations in optimum-seeking experiments, documented in Hyden and Schruben (2000), have the potential to revolutionize simulation technology.

5 DANIEL W. HALPIN, PURDUE UNIVERSITY: CONSTRUCTION

Simulation is one of the cornerstones of business management and industrial planning. In contrast, to business and manufacturing sectors, the construction industry has been slow to accept "advanced" methods such as simulation. Although civil and construction engineers are trained to deal with complex calculations, the idea of using a quantitative approach to construction management and scheduling has been a hard sell.

This is changing slowly. A number of large civil engineering and construction firms have begun to realize that major productivity improvements can be achieved using simulation in the design of construction operations. Dragados y Construcciones, the largest construction firm in Spain, and one of the top 50 worldwide, has used simulation-based concepts over the past decade to achieve major savings. According to Ing. Edmundo Balbontin-Bravo, Chief of the Planning and Methods Unit, each work hour of analysis using simulation has yielded an average savings at the work site of $2000. In other words, 100 hours of analysis using simulation yields an average $200,000 of savings to Dragados.

As construction becomes more modularized and the benefits of standardization become more common, simulation will achieve more acceptance. At present, most construction practitioners view simulation as using a sledge hammer to kill a fly. Unless repetition can be exploited, simulation is often not viewed as effective in an industry in which "one-off" is the norm. However, in situations where repetition is typical, simulation can yield great benefits such as those realized by Dragados.

In the next 5 to 10 years, web-based simulation packages stylized to various applications in the construction area will become widely available. I think this availability together with the trend towards automation and design standardization will begin to change the industry's perception of simulation as too "advanced" for field application.

Simulation has great potential, as well, in supporting training of both managers and machine operators. These areas have gone largely untapped. 3- and 4-D modeling is an emerging area in which simulation is beginning to gain a "foot hold." Virtual reality modeling of the work site and its use for analysis of job site problems during the planning stages of a large and complex project offers great potential.

6 AVERILL M. LAW, AVERILL M. LAW AND ASSOCIATES: CONSULTING

We will discuss possible future directions for simulation technology and the factors that will motivate change. We will focus our attention on the following areas:

6.1 Simulation Software

Simulation-software vendors will continue to try to make their software easier to use to increase the size of the simulation market. One approach to accomplishing this goal may be an increased orientation of products toward particular applications, hopefully, to reduce the amount of programming required.

However, almost any real-world problem will have its own unique logic and require programming in some form. Furthermore, perhaps only 25 to 50 percent of the work required to perform a successful simulation study is actually the programming of the model. Also, current simulation software doesn't address critical and difficult issues such as problem formulation, what data are required, level of model detail, model validation, and design and analysis of the simulation experiments.

The availability of low-cost simulation software will make simulation accessible to more small- and medium-sized organizations, and will lower the cost of simulation software in general.

6.2 Application Areas

It is difficult to predict the specific application areas for simulation in the future. However, the following are some factors that will probably influence the areas:

- There will be more interest in performing enterprise-wide analyses of organizations (e.g., for a supply chain).
- Simulation capabilities will be embedded inside of other larger software applications (e.g., factory-floor scheduling systems).
- Simulation will be more widely used for real-time decision-making (e.g., for air-traffic control and combat decision-making).
- The explosion in the use of e-commerce will generate new opportunities for simulation.

6.3 Optimization

The integration of optimization modules into simulation software is arguably the "hottest" topic in simulation today. However, a major impediment to the use of this methodology on real-world problems is the execution time required to simulate a large number of system configurations. However, this difficulty will be lessened in the future by faster computers and the ability to make multiple replications of a simulation model on networked computers.

7 MANI MANIVANNAN, VECTOR SUPPLY CHAIN MANAGEMENT: LOGISTICS

Both new age and traditional players in logistics face a similar challenge – how to manage the flow of goods and expensive resources so as to optimize the supply chain performance. The logistics and supply chain industry is a huge market – estimated at $900 billion domestically in the U.S. and $2 trillion internationally. The market has been relatively untapped by logistics service providers, which have a meager penetration rate of 4.5%.

Today, depending upon the size and level of complexity, a handful of commercial software packages provide strong analytical modeling and distribution of information capability for effective management of supply chains. Such packages include *I2 Strategist, CAPS Supply Cchain Designer, Manugistics Supply Chain Suite of Tools, Superspin, Synquest IPE, Extend/SDI, and Insight*. These software packages mostly utilize optimization, heuristics, and genetic algorithms to capture the deterministic behavior of a supply chain. However, to a much lesser extent, they offer easy-to-use, built-in simulation/animation, and statistical tools to study the impact of the uncertainties and operational dynamics of the supply chain.

A simulation model of a supply chain is needed to investigate stochastic impact and the variability caused by production schedules, supplier problems, customer demand, transportation delays, and so on. A supply chain simulation model needs to combine the behavior of a physical logistic network depicting the complex activities and operations associated with external logistics entities and resources, e.g., trucks, airplanes, ships, and barges.

In addition, the supply chain simulation model needs to emphasize the internal logistics and operations of a warehouse, or the pickup and delivery of freight within a city or a zone, or the movement of physical goods across the interstate covering an entire country or even across continents. The supply chain simulation model may be built using any of the paradigms (process interaction, event scheduling, object-oriented, web-based, etc.). However, the unique processes and activities need special attention to ensure that they adequately represent the inter-dependencies of a supply chain.

A supply chain simulation model needs to work with a geographic map showing physical relationships among plants, terminals and hubs, warehouses, and/or distribution centers, and customers. The activities at the plants, warehouses and distribution centers, and customer sites should be modeled at appropriate levels of detail. Such individual sub-models should be preferably integrated with the underlying supply chain network, super-imposed on a geographic map.

Often, a hierarchic modeling paradigm is preferred to represent the supply chain network as well as the operations at the individual nodes (a node may refer to a plant, a customer, or a warehouse). In this way, the logistics user/designer can visualize the movement of transportation entities at the map level as well as the operations at the plant level or at the warehouse and distribution center level.

The future is bright for simulation-based decision-support software and ASP type e-solution providers, giving new revenue opportunities for those software vendors that deliver value-added supply chain solutions. The simulation software should be capable of supporting both planning and execution of the supply chain. It should be (a) web-enabled, (b) able to interface with existing commercial supply chain software, (c) able to work with the real-time supply chain visibility data, (d) able to provide rapid modeling and decision-making tools, and (e) able to offer built-in tools to simulate/animate end-to-end visibility to materials flow combined with supply chain inventory, replenishment plans, part buffering and distribution systems.

In the years to come, we will witness significant work in simulation research and software in supply chain simulation. This is evidenced by a strong desire to perform (a) front-end strategic modeling and design, and (b) back-end operational control that would improve the efficiency and reduce costs of large supply chains.

8 WILLIAM S. MURPHY, Jr., DEFENSE INFORMATION SYSTEMS AGENCY: MILITARY

The military's desire to effectively simulate warfare has historically been a significant driving force behind the invention and evolution of the principles and practices of simulation science. The military was quick to recognize when new scientific discoveries provided technologies that could be used to enhance its ability to simulate warfare; and then eagerly used their investment dollars to fund the research needed to incorporate those technologies into military simulations. The military's influence was especially strong in the early days when the existence and use of non-military simulation applications was limited.

The military incorporated the new technologies into simulation science by introducing conceptual framework components that provided techniques, tools, and procedures that made it easier and more economical to construct and use more powerful and more functional simulations. These enhanced capabilities have enabled a significant number of non-military domains to outgrow the obsolete, or possibly misguided, notion that simulations should only be used to scientifically examine the characteristics of systems whose models are too complex to be solved by analytical, heuristic, optimization, or other simplistic closed form solution procedures. These enhanced capabilities facilitated the widespread popularity and use of simulations in a wide variety of non-military applications and domains.

The popularity and widespread use of simulations outside the military domain and the accompanying advent of the recent technological revolution are among the factors that have slowly eroded the military's influence on simulation science. Although the military still plays a significant role in the advancement of simulation technology, it is no longer "the" driving force. Instead, the military domain, along with the gaming, entertainment, medical, industry, and several other domains are among the many driving forces behind the advancement of the principles and practices of simulation science.

Legacy military simulation programs and initiatives are characterized as non-standard stove-pipe applications that are not interoperable with each other. The Department of Defense (DoD) recognized the inefficiency associated with this disjoint approach, and responded by establishing the Defense Modeling and Simulation Office (DMSO) which is responsible for coordinating simulation policy, establishing interoperability standards and protocols, promoting simulation within the military departments, and establishing guidelines and objectives for coordination of simulation, war-gaming, and training (Undersecretary of Defense for Acquisition and Technology 1995).

The DMSO recently developed the High Level Architecture (HLA) (Defense Modeling and Simulation Office 1996) to provide an architecture-based distributed simulation interoperability support environment that enables modular distributed component models and simulations to interact with each other in an indirect manner by exchanging information with a separate, centralized, content neutral, domain independent infrastructure software process in accordance with a well-defined interface specification. The HLA is designed to promote component interoperability and reuse by enabling simulations to be composed from reusable components.

The DMSO also recognized that the emergence of the large population of non-military simulation users could potentially lead to a fragmentation of simulation theory that would result in barriers to simulation interoperability and increased costs. They sought to avert this potential fragmentation by actively encouraging non-military participation in the development of the standards that support the HLA. The military appears to have been successful in these efforts. This well orchestrated, well funded, high priority military effort is having an unprecedented effect on the speed at which the simulation community moves in arriving at a consensus on a new world view of the principles and practices of simulation science.

The HLA is emerging as the consensus distributed simulation architecture in the current simulation era, having been adopted as an Institute for Electrical and Electronic Engineers (IEEE) standard and as the Object Management Group's (OMG) distributed simulation specification. The enhanced architecture based distributed simulation support environment provided by the HLA is a key enabling technology for future military simulation initiatives.

Dr. Deleores Etter, the Deputy Undersecretary of Defense for Science and Technology, presented a briefing titled "Future of Modeling and Simulation" to the Executive Council on Modeling and Simulation (EXCIMS) in February 2001 (Etter 2001). The following discussion of her presentation materials includes my interpretation of her vision. Dr. Etter's briefing slides indicated that the DoD appetite for modeling and simulation tools will not be satisfied soon. An example that illustrates the need for future enhancements in simulation technology is the fact that live training with real soldiers and real equipment is still easier to do in a real world environment than it is to do in a simulated environment.

The DoD is making strides in this area but simulation and technology requirements currently outstrip capabilities. Today's attempts to simulate live training of real soldiers and equipment are not cost effective, efficient, or sufficiently high fidelity for the intended training audience. Dr. Etter's presentation materials indicated the driving forces behind current DoD initiatives are the desire to have better human behavior representations and integrated natural environments to support course of action analysis and mission rehearsal in near real time and to support warfighter requirements associated with a digital force. Her briefing slides acknowledged the influence of non-military domains on future military simulations and underscored the importance of developing and maintaining a strong partnership between the military, the gaming industry, the Hollywood entertainment industry, and other domains. Entertainment and gaming partnerships are essential because those industries have the ability to create and tell stories, and to expertly employ computer-generated effects.

Dr. Etter's briefing further indicated that the military is committed to the immersion of virtual reality technologies that will make a Star Trek like holodeck a future reality. In the short-term a CyberSphere has been proposed that would project a virtual reality environment around a person or a military unit to support training. The CyberSphere would be designed as a movable training environment that will in essence untether the modern-day "cave" environments from their fixed-facilities while providing them with enhanced efficiency, fidelity, and the ability to rapidly create virtual environments. These future simulation capability requirements will need to be supported with a significant number of enhanced infrastructure capabilities in network capacity, wireless network technology, batteries, power generation, and other technologies. The DoD will rely heavily on future commercial off the shelf technologies to obtain many of these future capabilities.

The military's commitment to and investment in modeling and simulation initiatives will continue to grow in the future. However, the military's success in achieving its goals will depend on its ability to partner with other simulation domains and its ability to effectively integrate and employ emerging technologies.

[The views expressed are the author's and not those of the Department of Defense.]

9 SUMMARY

Seven different areas were represented by this panel. There is some agreement on the future of simulation, but not a lot of agreement, at least from the contributions that were submitted.

Azadivar indicates that development efforts are needed for additional generic simulation model generators and more efficient search algorithms. Ferrin's comments were from the perspective of the user of simulation, rather than from the users of the tools. He said that we should understand the user's requirements and provide high quality graphics to them.

Fowler and Mackulak discussed the speed of simulation and described an alternative methodology for simulating wafer fab operations. They called it a resource driven paradigm. Halpin discussed the hard sell that has been required for the construction industry to adopt simulation. He looks forward to the potential of web-based simulation packages and in using simulation in training.

Law discusses the need for easier-to-use simulation software. He addresses four potential application areas; supply chain management, embedded simulation, real-time decision making, and e-commerce. He also discusses optimization as a hot topic.

Manivannan describes the need for a simulation model of a supply chain. This model needs to consider both the physical logistic network and the internal logistics and operations of the warehouse or other distribution point. He sees a bright future for simulation-based decision-support and ASP type e-solution providers.

Murphy describes the long-time involvement of the military in the area of simulation. He discusses the role that the military played in the emergence of HLA for non-military purposes. He issues a challenge for better human behavior representations and integrated natural environments to support course of action analysis and mission rehearsal in near real time and to support warfighter requirements associated with a digital force.

REFERENCES

Azadivar, F. and Y. Lee. 1988. Optimization of Discrete Variable Stochastic Systems by Computer Simulation. *Mathematics and Computers in Simulation*, 30, 331-345.

Azadivar, F. and J. Talavage. 1980. Optimization of Stochastic Simulation Models. *Mathematics and Computers in Simulation*, 22, 3, 31-241.

Azadivar, F., G. Tompkins. 1999. Simulation Optimization with quantitative variables and Structural model changes: A Genetic Algorithm Approach. *European Journal of Operational Research*, 113, 169-182.

Azadivar, F., Wang, J. 2000. Facilities layout optimization using simulation and genetic algorithms. *International Journal of Production Research*, Vol 38, No. 17, 4369-4383.

Azadivar, F., J. Zhang. 1997. Automatic generation of simulation Models for optimum design of manufacturing systems. *Proceedings of the 14th International Conference on Production Research*.

Cheng R. and M. Gen. 1996, Genetic search for facility layout design under interflows uncertainty. *Japanese Journal of Fuzzy Theory and Systems*, vol 8, no. 2, pp 335-346.

Defense Modeling and Simulation Office. 1996. *Department of Defense high level architecture interface specification version 1.0.* Washington, DC: Department of Defense.

Etter, D. 2001. Future of Modeling and Simulation, Presentation to the Executive Council on Modeling and Simulation (EXCIMS). Washington, DC: Deputy Undersecretary of Defense for Science and Technology.

Glynn, P., P. L'Ecuyer, and M. Anes. 1991. Gradient sstimation for ratios. *Proceedings of the 1991 Winter Simulation Conference*, ed. B. L. Nelson, W. D. Kelton, and G.M. Clark, 986-993.

Hyden, P. and L. Schruben. 2000. Improved decision processes through simultaneous simulation and time dilation. *Proceedings of the 2000 Winter Simulation Conference*, ed. J.A. Joines, R.R. Barton, K. Kang, and P.A. Fishwick, 743-748.

Morito, S and K. H. Lee. 1994. An application of simulated annealing for an FMS dispatching priority problem. *New Direction in Simulation for Manufacturing and Communications,* 197-203.

Safizadeh, M. H. 1984. Optimization in simulation experiments using response surface methodology. *Computers and Industrial Engineering*, 8, 1, 11-27.

Schruben, L. 2000. Mathematical programming models of discrete event system dynamics. *Proceedings of the 2000 Winter Simulation Conference*, ed. J.A. Joines, R.R. Barton, K. Kang, and P.A. Fishwick, 381-385.

Tam, K.Y. 1992. Genetic algorithms, function optimization, and facility layout design. *European Journal of Operational Research*, Vol. 63, pp. 322-346.

Tompkins, G., F. Azadivar. 1995. Genetic algorithms in optimizing simulated systems. *Proceedings of the 1995 Winter Simulation Conference*, ed. C. Alexopoulos, K.Kang D. Goldsman, and W. Lilegdon, 757-762.

Undersecretary of Defense for Acquisition and Technology. 1995. *Department of Defense modeling and simulation (M&S) master plan*. Washington, DC: Department of Defense.

Zhang, J. 1997. *Genetic Algorithm Based Simulation Optimization of Flexible Manufacturing Systems*, Kansas State University. Ph. D. Dissertation.

AUTHOR BIOGRAPHIES

FARHAD AZADIVAR is the Dean of College of Engineering at University of Massachusetts, Dartmouth. He received his Ph.D. from Purdue University in 1980. His areas of research interest are in design and optimization of manufacturing and other complex stochastic systems. His e-mail address is <`fazadivar@umassd.edu.`>

JERRY BANKS is an independent consultant. He retired from the School of Industrial and Systems Engineering at Georgia Tech in 1999 then worked for Brooks Automation-AutoMod for two years as Senior Simulation Technology Advisor. He is the recipient of the 1999 Distinguished Service Award from INFORMS-CS. His e-mail address is <`atljerry@earthlink.net`>.

DAVID M. FERRIN is an Associate Partner with Accenture in the Customer Relationship Management, Decision Integration, Capability Modeling and Simulation practice in Northbrook, Illinois where he serves as the Lead in the America's practice. David is an Assistant Professor in the Health Systems Management Department at Rush University, Chicago, Illinois and is an Adjunct Professor in the Health Records Administration Department at York College, York, Pennsylvania. He is a Senior Member and past chapter president of IIE and a Fellow Member and past chapter president of HIMSS. David has served/serves on WSC committees from 1997 until 2003 when he will be the general chair. He is a frequent speaker on simulation and quality in health care and has 15-20 years experience in those areas. David holds a BSIE degree from the University of Utah and an MHA degree from Brigham Young University. His e-mail address is <`david.m.ferrin@accenture.com`>.

JOHN W. FOWLER is an Associate Professor in the Department of Industrial Engineering at Arizona State University. He received his Ph.D. from Texas A&M University. His research interests are in manufacturing systems analysis, discrete event simulation and applied operations research. His email address is <`john.fowler@asu.edu`>.

DANIEL W. HALPIN is Professor and Head of the Division of Construction Engineering and Management at Purdue University in West Lafayette, Indiana. He received a B.S. degree from the U.S. Military Academy at West Point in 1961. He received M.S. and Ph.D. degrees in Civil Engineering from the University of Illinois in Champaign in 1969 and 1973, respectively. He was on the faculty at Georgia Tech (1973-1985), and held the A. J. Clark Chair Professor Position at the University of Maryland (1985-1987). He developed the CYCLONE methodology for construction simulation. He has received many awards, including the Huber and Peurifoy Awards, for his contributions to computer applications in civil and construction engineering. His email address is <halpin@ecn.purdue.edu>.

AVERILL M. LAW is President of Averill M. Law & Associates, a company specializing in simulation consulting, training, and software. He has been a simulation consultant to numerous organizations including Accenture, ARCO, Boeing, Compaq, Defense Modeling and Simulation Office, Kimberly-Clark, M&M/Mars, 3M, U.S. Air Force, and U.S. Army. He has presented more than 335 simulation short courses in 17 countries. He has written or co-authored numerous papers and books on simulation, operations research, statistics, and manufacturing including the book *Simulation Modeling and Analysis* that has been used by more than 75,000 people. He developed the ExpertFit distribution-fitting software and also several videotapes on simulation modeling. He has been the keynote speaker at simulation conferences worldwide. He wrote a regular column on simulation for *IIE Solutions*. He has been a tenured faculty member at the University of Wisconsin-Madison and the University of Arizona. He has a Ph.D. in industrial engineering and operations research from the University of California at Berkeley. His E-mail address is <averill@ix.netcom.com>.

GERALD T. MACKULAK is an Associate Professor in the Department of Industrial Engineering at Arizona State University. He received his Ph.D. from Purdue University. His research interests are in simulation, applied operations research to manufacturing systems, and artificial intelligence for virtual manufacturing and production control. His email address is <mackulak@asu.edu >.

MANI MANIVANNAN received his Ph.D. from the Pennsylvania State University in 1988. He specializes in modeling and analysis of logistics and supply chain networks, artificial intelligence, and large database design. Since 1993, he held many positions in CNF Transportation Company. Prior to coming to CNF, Dr. Manivannan worked as an Assistant Professor in the School of Industrial and Systems Engineering at Georgia Tech. He is a recipient of the 1991 Outstanding Young Manufacturing Engineer of the Year Award from SME. He received the 1996 Raymond F. O'Brien Award of Excellence from the CNF Board of Directors. He served as the Program Chair for WSC'98 Conference. His e-mail address is <manivannan.mani@vectorscm.com>.

WILLIAM S. MURPHY, Jr. is a Major in the U.S. Army Corps of Engineers with 19 years of commissioned service. He graduated with a B.S. from the United States Military Academy in 1982 and with a M.S. in Mathematics and Computer Science from the Colorado School of Mines in 1992. Major Murphy is a licensed Professional Engineer (PE) in Virginia. He is currently a command, control, communications, computers (C4) analyst in the Defense Information Systems Agency (DISA). His e-mail address is <murphyw@ncr.disa.mil>.