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SIMULATION PRACTICES IN MANUFACTURING

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ABSTRACT

Manufacturing companies are one of the major users of simulation. This panel will discuss the simulation process and practices typically found in manufacturing companies. The panelists will answer questions such as;

- How practitioners fit statistical distributions to their raw data?
- Are confidence intervals calculated for simulation results?
- What model verification techniques are employed?
- Do simulation models have an extended life span?

The panel will address practical approaches to problems relating to: data collection and input distribution definition, output analysis, management expectations, time constraints, and presentation of model results.

The following statements address the use of simulation at each of the panelists' respective companies and serve as a starting point for the discussion.

JAMES H. EMERY

Eaton-Kenway has been a major provider of automated storage material handling systems for more than twenty years. Since 1974, the company has been using simulation. I came to Eaton-Kenway in 1979 as a software engineer. In 1982, I moved to the simulation department where I have worked since. At that time, we had nine full-time analysts. We now have four full-time analysts with collective experience in statistics, industrial engineering, and computer science. We used GPSS/H until the mid-eighties when we switched to Auto Mod/AutoGram. In the first quarter of 1991, we completed a transition to AutoModII.

Our first products were the ASRS line of unit load cranes and mini load storage systems. We sold Digitron's automated guided vehicle (AGV), for which we designed custom systems. We also did the installation and implementation for the AGV systems. This was a very time-consuming process. One of my first jobs was for a John Deere hydraulics facility which took fourteen months to complete. A similar system with our present technology would now take about three months. We currently build several automated guided vehicles based on a standard chassis. Two of our latest products are the New Century Systems Crane and the ML1000 which can carry 1000 pound loads. A large portion of Eaton-Kenway's business has been, and continues to be, custom system design. We are also well known for our software expertise on controls and do a lot of integration.

The simulation department is involved in virtually every phase of product design. In the introductory phases, we try to determine design feasibility and system size. In project phases, which are usually under tight time constraints, we develop models for design validation. The model grows and evolves as the design is perfected. These models are utilized as a presentation tool for the proposal engineers. Because of this evolution process, the system which is implemented is often quite different from the original proposal. We are frequently able to provide better solutions than the initial concepts.

In a small percentage of the jobs, we participate in the acceptance testing. Our accuracy is plus or minus three percent. When there is a discrepancy, the problem is usually that the system is not being operated as it was designed. In the initial stages, the customer often doesn't have a precise idea of the requirements or changes them during the production and ends up trying to run it differently. We are continually working with this aspect of development. In many cases, after the system is installed, we don't get any feedback. I think this indicates that we did a good job.

With our models, we provide to our a software teams a set of ASCII files that provide the coordinates for all the AGV system control points. They are also able to extract from our model files the scheduling algorithms and park tables which drive the system. They take this information as a starting point for the actual tables that are used in the vehicle controls. Our simulations also allow us to generate what we call a load generated scenario which is essentially a script of the events that occurred in the model. It is in the form of a time-stamped ASCII file. We use this information as a driver for an emulator and to stress the control system software that will be delivered to the job site. In some cases, we are able to go on site and do set testing which gives us feedback on the validity of our models in the real world. On some jobs it would have been impossible to test the system for the customer's requirements without having the use of the simulation output for a driver.

The simulation lab is a standard stop for customers coming through the company to see our capabilities. 3D animation is a valuable sales tool. We usually make a five to ten minute video from a model of a proposed system. This serves as a starting point for establishing a discussion of a new project. We have been increasing our use of AutoModII business graphics in our simulation reports and are pleased with the results.

Simulation modeling has been beneficial to our company in many different ways. With the use of it, we are building models with greater accuracy and detail, using far fewer resources to produce them, and have drastically cut our lead time.

CHRISTOPHER C. FUNKE

Computer simulation has been in use at The Boeing Company for over two decades in support of both commercial and military airplane programs. This paper discusses issues related to the use of computer simulation in the Boeing manufacturing environment including the types of projects, how decisions are made, and the simulation process itself.

The Boeing Company has produced more commercial jetliners than any other company in the world, and in the last two decades has also become a leader in the missile, rocket, helicopter, space, electronics, and computer fields. The Boeing Company's Commercial Airplane Group operates major manufacturing facilities in locations throughout the United States.

The use of computer simulation at Boeing began in the 1960's with a small group of statisticians working on logistics management for selected military programs. In those days, GPSS on an IBM mainframe was one of the only commercially available simulation packages. During the late 1970's and early 1980's, Boeing began using simulation in the manufacturing arena. By 1992, over 40 simulation specialists supported manufacturing operations at various Boeing divisions. The simulation languages currently in use company-wide include AutoMod II, GPSS/H, ManuPlan, ProModel, Siman IV/Cinema IV, SIMSCRIPT, SLAM, and Witness. Personal computers, Macintoshes, engineering workstations, and mainframe computers are commonly used by Boeing simulation modelers.

Boeing fabrication facilities are responsible for part manufacturing to support both commercial and military production programs. A wide variety of manufacturing processes can be found in Boeing fabrication buildings. In most cases, these processes are organized by traditional machining functions. Processes include heavy machining, sheet metal forming, press work, painting, autoclave curing, shot peening, and composites routing. Simulation applications focus on material handling systems, machining centers, autoclave loading, transportation systems, chemical process lines, and shop load planning.

Boeing assembly facilities are responsible for final assembly of aircraft components. The work performed in these buildings involves the large scale integration of millions of detail parts from thousands of subcontractors into finished aircraft components. Typical processes include material handling, painting operations, wire bundle assembly, tube bending, Numerical Control (NC) riveting, and manual assembly. Simulation applications often focus on product lines, conveyor systems, NC riveting machines, automated storage/retrieval systems (AS/RS), material handling, distribution centers, inventory usage, and other related activities.

During the late 1980's and early 1990's, The Boeing Company expanded many of its production facilities to support increased requirements. The company has used computer simulation to evaluate the impact associated with making a variety of business decisions. Some examples include determining the number of docks at a new distribution center, evaluating the inventory holding costs for a specific vendor component, testing chemical process line recipes, experimenting with the number of computer workstations on the factory floor, and identifying the number of NC machines to purchase for a new airplane program. In many cases, simulation results have been used by Facilities, Industrial Engineering, Production Control, and Manufacturing management to help make capital acquisition decisions involving millions of dollars.

Most simulation projects begin with a management request to support a major operational decision or capital acquisition. A cross-functional team is usually formed. It is the team's responsibility to define the model objectives, operational rules, system constraints, and collect the required data. Team members are usually specialists in various manufacturing disciplines and have no formal training in computer simulation. The modeler must act as a facilitator in defining the requirements for most simulation projects. The requirements definition phase typically results in a document which defines the objectives, constraints, and assumptions for the project.

The development of simulation models is a dynamic process. Often, the design team for a new production facility or process will go through several iterations prior to agreeing on the final design. The challenge of the simulation modeler is to quickly respond to changes in the system or process under investigation and provide objective data to help make decisions.

As simulation practitioners in manufacturing environments, we must recognize that the level of detail required to evaluate most "real life" systems far surpasses that of academic examples and most software tutorials. A successful model design represents the best balance between functionality, level of detail, constraints, and flexibility to conduct experiments. Our philosophy is to include only the level of detail necessary to evaluate and make decisions about a system or process. In my opinion, this is still the "artistic" aspect of computer simulation. Given two competent modelers, each will have their own ideas on how to best represent the dynamics of a process.

Features in the simulation languages also influence the level of detail selected by the modeler. In the past, the level of detail sometimes hindered flexibility to conduct experiments. Due to the need for flexibility in conducting experiment runs, we place a high priority on selecting the appropriate level of detail to satisfy the project objectives.

Data collection is an important aspect of every simulation project. We strive for a data-driven design for many of the manufacturing simulation models we develop. This creates flexibility in conducting experiment runs and provides the capability to use data from Boeing production systems as inputs to the model. When production data are available, we use data modeling software such as UniFitII to fit probability distributions. Often, there is no data available for model inputs such as process times, failure rates, and part rejection events. In this case we must use the estimates of those who know most about the process and "engineer" an approximation such as a triangular distribution using the minimum, most likely, and maximum values. We try to avoid the use of "averages" as model inputs whenever possible.

In most projects we must depend on project team members to collect the data required to develop simulation models. The modeler's primary responsibility in this area is to define the required data, including specific methods to collect it.

Model verification is a critical phase of the simulation process. Verification ensures that the computer code represents the modeler's intent at defining the behavior of the system. Techniques that are typically used include a review of all assumptions used to develop a model, reviews of model animation with team members, design reviews with simulation staff members, test runs with trace files, and range tests for input variables.

Model validation substantiates that the computer simulation represents, for a predetermined level of confidence, the response characteristics of the real or proposed system. In other words, is the behavior demonstrated by the model adequate to warrant its use in decision making? Subjective validation techniques are typically used for most manufacturing based simulation projects with which I have been involved. Some of these include even validation using animation, graphical comparisons, and sensitivity analysis. The time required and accuracy of input data seem to be the two largest obstacles to model validation.

The analysis of simulation output data can take on a number of flavors. Most simulation practitioners at Boeing prefer to run multiple experiment runs each with different random number seeds while removing the warm-up period. However, there is also a contingent at Boeing that favors using one very long model run, then removing the warm-up period. At this point the jury is still out. Time permitting, design of experiment techniques are used to determine which, if any, input variables affect the behavior of the system. Modeler knowledge and experience is a large factor. Short project schedules often impact our ability to calculate confidence intervals about key performance measures. This is an area in which we hope to improve.

We rely heavily on user-defined output trace files from specific model events or performance measures. We often develop custom UNIX shell scripts using AWK, Sed, or Grep to format output data into statistical reports. Frequently, PC charting software along with business graphics tools are used to develop graphs of performance measures. Time line plots are helpful in both analyzing warm-up periods and detecting logic errors with long model runs.

The presentation of model results requires the ability to convey complex concepts and results to personnel with no formal training in simulation. We have noticed that simulation models with animation are more likely to develop a sense of ownership in project team members. The 3D animation with the AutoMod II simulation language facilitates discussions with shop personnel, managers, and project team members on aspects of a system's operation. 3D animation also enables modelers to efficiently identify and correct logic errors during model verification. As a communication tool, we have come to depend on visual images as much as written reports and memos.

The management support of the simulation community within Boeing has grown over the past five years. Five years ago, it was a struggle to get management to include simulation personnel on project teams. Now, management routinely requests the involvement of simulation specialists on process design teams.

Throughout The Boeing Company, millions of dollars have been saved from improved process designs and avoided costs as a direct result of simulation efforts. However, the intangible savings often go unobserved. Simulation has been an excellent tool to improve communication among project team members about the operation of a process or system. In developing models, the simulation specialists must ask questions that might otherwise have slipped through the cracks, resulting in the entire project team learning more about their process. Simulation has also provided a forum for the collection of process operating rules and assumptions in one medium as a basis to develop the model. The use of simulation at The Boeing Company has proved to be one of the most successful tools for continuous process improvement.

FRANK GUDAN

Simulation models have been used at General Motors since the late sixties. We started using simulation to evaluate systems that could not be solved mathematically and thus had estimated solutions (Ex: line rates and buffer sizes). Eventually, the industrial engineers saw the value for computer simulation for capacity studies and layouts, and included them in the manufacturing methods analysis procedure. The major stumbling point at this time was trying to explain to manufacturing personnel how the numeric results were generated in the computer and the accuracy of the model. By the mid eighties, animated graphics were introduced and it became the communications tool between the modeler and the user.

At General Motors, process simulation is used for all types of manufacturing systems. Model usage can occur when the initial concept for a manufacturing system is proposed and continues as the system is designed, installed, and operational. Simulation models are typically used to study the production flow to evaluate investment cost, labor requirements, marketing plans, and a host of other items depending on the scope of the project. In addition to determining major equipment requirements, simulation models are also used to study operating strategies for a proposed system and the interaction of support functions such as material control, etc. Excluding operational activities and pertinent support functions can result in congested and inefficient operations for the production life cycle of the product.

Data requirements for simulation models vary according to usage. If the model represents a system that is operational, then current data is required. However, future planning proposals usually only need benchmark data from current operation plus expert advice from production and the process engineers. Other production delays such as quality problems and tool changes need to be considered in the data for future planning models.

In addition to following basic mathematical procedures in validating a model, I also recommend working with the users of the model. This should be done on a one-on-one basis, not in a major presentation. Animation is also a useful validation tool to demonstrate the model design. It helps the user to understand the model and communicate with the modeler. Periodic reviews should be held with the users throughout the model development process. A successful simulation project depends on the users understanding and involvement in the model development.

Simulation modeling is used throughout General Motors to study manufacturing systems. In many cases the simulation activity is an integral function of a major product development program. Major factors for the wide acceptance have been animated graphics, language enhancements, and reduction in model development time.

KENNETH G. MAIN

The ALCOA Tennessee Operations is composed of two major plants. The south plant is the smelting and casting facility, the north is the fabrication rolling division. The main product is aluminum can sheet which is sold to manufacturers for the production of beverage containers. Computer simulation was first used at ALCOA in the industrial engineering department. The first models were for local area capacity analysis. These were time-consuming to develop and most were applicable only to the original situation. When engineers went back to analyze the same areas, they found that the models had to be re-written. In the early eighties, the facility had to be modernized in order to stay in business. One of the additions was a material handling system in the fabrication division. I was the head of the control project portion and was required to verify the design of the system using simulation. This was my first experience with simulation modeling and it turned out to be a very positive one. We found that our first model was adaptive to the ever-changing design of the system during its development. As the system design evolved, new questions would arise about equipment capability and capacity. We found that, with a few alterations, our model could answer the new questions. We probably used that first model at least six times.

During the modernization process, I investigated the possibility of increased capaities in our various production areas. The management department wanted to know if we could get a certain percent more capacity without any major capital expenditures. We went back to the material handling model and tried to generate an incremental step increase. Our initial thinking was that we needed more storage space and furnaces to achieve the increased capacity. We added a lot of detail to the model in order to discern the difference in capacity that we were expecting. We took the data from the model run and ran it through a screening analysis of the statistical processes we were using. We discovered that we didn't need any more capital improvements to achieve the increased capacity. This resulted in a savings of several million dollars. Because of these impressive results, the simulation modeling process was implemented in several other areas of production. The simulation teams were, again, trying to minimize capital expenditures by achieving increased capacity through small, incremental changes. Over the last year and a half, we have spent a lot of time fine-tuning this process. We use a multi-disciplined team of industrial engineers, electrical engineers, mechanical engineers, production operators, supervisors, and maintenance personnel. The team focuses on root causes, through root cause analysis, to develop potential change factors. In parallel, a sub-team builds a model that represents the area. Then the model is validated against actual production runs and run through various change scenarios which are outlined by a well-defined design of experiments. The data from the simulation is put into a multiple regression analysis of the design of experiments. From the results, we can see how to improve the various production areas and minimize capital expenditures. This process is now being used in a plant-wide integration model which we are studying to determine how to reduce the flow time of our product from when it is cast until it is delivered out the back door.

Our main simulation process is having a sub-team build a model simultaneously to the main team analyzing root causes. Their main emphasis is getting the model to work correctly. We work with the industrial engineering department to gather data from the plant. Because our data does not usually fit normal, gamma, exponential, etc. curves, we create continuous distribution functions as model inputs to provide the variability to our simulation models. We compare the outputs of the models to actual raw data and then do statistical analysis using non-parametric methods, because, like with the input data, our output does not fit normal distributions. When the model is validated, we are then ready to run the design of experiments.

Simulation and tools for statistical analysis are extremely useful in combination. Over the last several years, ALCOA employees have been trained to do statistical analysis and it is becoming commonplace. When we make presentations to management teams, we routinely use statistical displays of the data generated from a model. Most of our presentations are focused on the output of the multiple regression analysis of the design of experiments using contour plots. This provides a multi-dimension view and shows how to get capacity through various levels of input change factors.

Animation and business graphics are used during the actual model design, de-bugging and verification stages. They are especially helpful to engineers and maintenance people for determining if systems are functioning properly. They promote a hands-on kind of confidence in the people who will be using the output of the model before it is run to generate useful data for our statistical packages.

DAVID RUCKER

GE Aircraft Engines (GEAE), a component of the General Electric Company, began using discrete event computer simulation in the early 1980's to test new concepts for automated manufacturing. Initially, the company contracted this work to outside firms specializing in simulation services. But the need for in-house simulation services quickly became apparent.

Early success with flexible manufacturing systems led to rapid growth of the company's Advanced Manufacturing Engineering group. As the group developed and implemented a wide range of automated systems for GEAE's plants in the U.S., Canada, and France, the need for simulation grew accordingly. Thus the groups' charter was expanded to include in-house simulation capabilities.

Established in 1985, the AME simulation team performs simulation analyses for systems ranging from single-process machines to totally integrated factories. Over one hundred simulation models have been completed in-house of both existing and planned manufacturing systems.

Simulation modeling provides managers and designers with the data they need to make a wide variety of decisions at different stages of a manufacturing system design project. Early in the project, simulation is used as a capacity analysis tool, to determine the quantity and type of equipment required to achieve a production target. This makes it easier to develop basic project parameters for space and capital investment, and it gives management an early look at a project's capital economic benefits.

Once the basic information is in place, simulation analyses become increasingly specific and precise. Support processes and material handling systems are added to the simulation model. Sensitivity analyses are performed to determine which operating parameters are critical to the system's overall success. As simulation evolves, it becomes a tool through which specialized subsystem design teams can interact.

The process of developing a simulation model is flowcharted in figure 1. Note that over half of the tasks occur before any code is written. One key to making this process successful is customer buy-in. Customer buy-in consists of having the right people on the customer's staff involved, and educating the customer to a basic level of understanding of simulation technology. Having the "right" people involved means people knowledgeable of the process being modeled, and capable of making higher-level decisions on model scope and model assumptions.

To develop models of exisisting manufacturing systems we define what data needs to be collected and then rely on the customer to collect the data. Current, actual process times, rework rates and scrap factors are usually available from manufacturing databases. Typically, only data from the past quarter is used, since processes are continually changing on the shop floor. Equipment MTBF and MTTR are the hardest pieces of data to compile. If equipment downtime is collected, it is usually in an unusable format, such as cost to repair a machine, or total maintenance hours charged to a machine. Typically the equipment downtime input data is verbally estimated by manufacturing engineers with statements such as, "it goes down for about two shifts every three weeks", or, 'its down about 5% of the time". Based on the readings of equipment downtime studies presented at various simulation conferences, we default to the exponential distribution for MTBF and MTTR.

Presentation of model results consists of developing graphs and tables of the output data. These can be displayed on the simulation workstation or printed on hardcopy or vugraph media. Simulation animations are developed for automated manufacturing systems or, if the model is being used as part of a presentation package, to upper management for project justification.

The benefits of simulation analysis can be summed up in two words: better decisions. Simulation gives GEAE designers access to more information than ever before, and does it fast. It provides the freedom to explore more possibilites—to be more creative. Designers can try things on the model they could never afford to try on the shop floor. They can generate and process information faster, so their decisions can be based on reliable data rather than guesswork or the need to play it safe. The result is more productive systems that come on line faster.

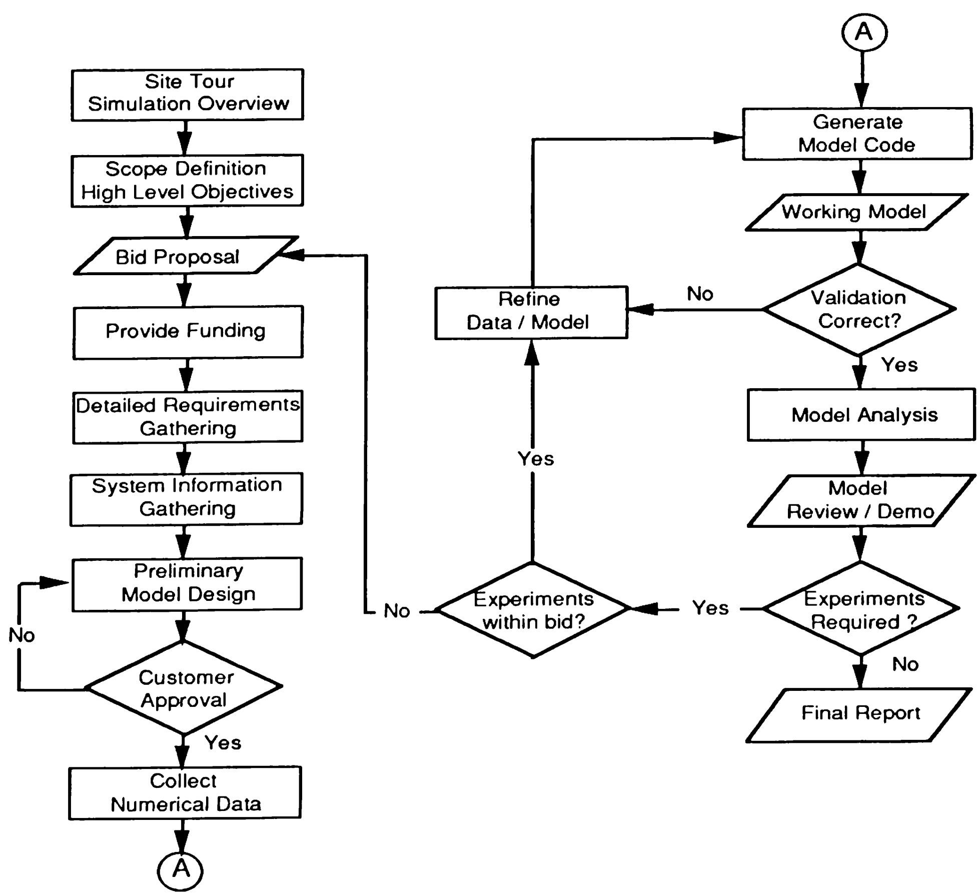

Figure 1: The Process of developing a simulation model at GEAircraft Engines

AUTHOR BIOGRAPHIES

VAN B. NORMAN, President of autoSimulations, Inc. received a B.S. in mathmatics at the University of Utah in 1969. He spent six years at Eaton-Kenway, where he implemented the first simulation animator. In 1982, using his experience in factory automation and simulation, he co-founded AutoSimulations, Inc., where he co-authhored AutoMod, AutoSimulation's first graphic simulation software. He has authored papers on the application and future of simulation in manufacturing. His interests are in world-class manufacturing operations and simulation research.

JAMES H. EMERY is a Principal Simulation Engineer currently managing the Simulation Engineering department at Eaton-Kenway, Inc. in Salt Lake City, Utah. Employed by Eaton-Kenway for the past thirteen years, he has spent the last nine years simulating material handling systems using GPSS/H, AutoMod/AutoGram, and AutoModII. Mr. Emery has also worked as a Software Engineer and has experience in the coding and implementation of custom material handling control and inventory systems. Mr. Emery graduated from Ricks College in 1975 with an associate degree in Electronic Engineering.

CHRISTOPHER C. FUNKE is supervisor of the Operations Computing Simulation Group responible for operational analysis for The Boeing Company's Everett, WA. Division. He has been involved in the design and analysis of complex aircraft manufacturing systems for The Boeing Company for the past five years. Mr. Funke has participated in a variety of simulation projects including distribution centers, warehousing, automated material handling, chemical process lines, overhead crane systems, automated fastening, and product lines. He also worked as a Manufacturing Methods Engineer for McDonnell Douglas Corp for three years. He has served as the National Membership Chairman for the AutoMod Users Association, is a Senior Member of IIE, and has been a member of CASA/SME. He has also served as Chairman, Vice-Chairman for the Boeing Simulation Technology Forum 1990-1992, Mr. Funke received a B.S. in Industrial Engineering from the University of Arizona in 1985.

FRANK GUDAN is a senior project engineer at the General Motors Technical Center. He has a B.S. degree in Industrial Engineering from the University of Michigan. Mr. Gudan has extensive experience in manufacturing systems and simulation. In his current position, he is a project leader for modeling new car platforms and provides consulting support in simulation methodology and usage. Mr. Gudan is also a simulation representative on corporate committees.

KENNETH G. MAIN, P.E., is a Senior Staff Electrical Engineer with Tennessee Operations, Aluminum Company of America, where he is currently assigned to manufacturing simulation modeling and statistical analysis of the plant and major individual production centers. His major emphasis is to provide information on capacity, throughput and system capabilities on the heavy industrial manufacturing processes for determining the most economical and practical solutions to meet the plant's continued improvement growth objectives. His twenty-two years of engineering experience include machine tool, furnace combustion and rolling milling electrical and electronic control systems. He was the electrical and control systems project manager for Alcoa's 30-ton, fully automated material handling system, integrating the three largest production centers of the plant. Mr. Main is a registered Professional Engineer in three states. He is a member of SME and currently is vice-chairman of the AutoMod Users Association. He holds a B.S. degree in Electrical Engineering from Purdue University.

DAVID M. RUCKER, P.E., is a Senior Automation Engineer for the Advanced Manufacturing Engineering group at GE Aircraft Engines, Evendale, Ohio. He is the leader of a Simulation Technology Center, a group of simulation engineers responsible for developing and maintaining computer simulation models of manufacturing systems. The Simulation Technology Center employs a number of simulation studies and has developed over sixty computer simulation of manufacturing systems. He has published several papers on computer simulation of manufacturing systems. Mr. Rucker has a Bachelor of Science degree in Industrial Engineering, a Masters of Science in Operations Research, and is currently working part-time on a Doctorate in Industrial Engineering at the University of Cincinnati. He is a Registered Professional Engineer in the State of Ohio and a senior member of the Institute of Industrial Engineers.