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SIMULATORS AS A TOOL FOR RAPID MANUFACTURING SIMULATION

Phillip A. Farrington
Bernard J. Schroer
James J. Swain

Department of Industrial and Systems Engineering
University of Alabama in Huntsville
Huntsville, Alabama 35899, U.S.A.

Yuncheng Feng

School of Management
Beijing University of Aeronautics and Astronautics
Beijing, P.R.C

ABSTRACT

This paper discusses the use of two simulators for the design and analysis of manufacturing modules. Included in the paper is a brief discussion of the simulators, the application of the simulators in solving a real world problem, and the lessons learned in using simulators.

1 INTRODUCTION

After developing a number of simulation models of manufacturing systems, it became obvious that a relatively simple simulator may satisfy the needs of many apparel manufacturing firms. Several reasons support the use of a simulator. First, many apparel firms lack sufficient data to adequately develop a detailed simulation model. As a result, the simulation model is greatly simplified. For example, the actual operation of a manufacturing module may not be thoroughly understood. It is not uncommon that the operation of the module has changed since the implementation. Therefore, the rules have changed for operator movement and the mean cycle times may have changed because of operator refinements.

Second, most apparel modular manufacturing systems contain a small number of stations and operators. As a result, the simulation model is not very complex. Consequently, the majority of the features in a commercial simulation language are not required in a modular manufacturing simulation model. Third, many firms lack the expertise to develop detailed simulation models. Furthermore, these firms have only minimal background in describing manufacturing systems and in analyzing simulation model results. Finally, many small and medium size manufacturing firms cannot afford the relatively high cost of commercially available simulation software.

Three simulators were developed for use with modular manufacturing systems (SSE3, SSE5, and SSE6). These simulators have been distributed since 1993. The next five sections illustrate how the simulator can be used for rapid evaluation of a production system. The final section reviews industrial response to the simulator as well as feedback on software use and effectiveness.

2 MODULAR MANUFACTURING

The apparel manufacturing industry in the United States is undergoing significant changes. This change in manufacturing is in response to market pressures for rapid style changes and quick response to customer orders. For years, the standard method of manufacturing has been the progressive bundle system (PBS). In the PBS, operators sit at the machines with each operator performing only one operation. As a result, large amounts of work-in-process (WIP) generally build up between the stations. Garments are generally inspected at the end of the line. Work is done in lots of several dozen. Operators are paid based on production or a piece rate.

Many firms are beginning to experiment with the concepts of modular manufacturing to improve the process, minimize system variability, improve quality, and reduce cost. Modular manufacturing has been defined as a contained, manageable work unit of five to 17 people performing a measurable task. The operators are interchangeable among tasks within the group to the extent practical, and incentive compensation is based upon the team's output of first quality product (Gilbert 1989). Some of the general characteristics of a modular manufacturing group are:

- Group members are cross-trained
- Group usually produces complete garments
- Each group member performs one or more sewing tasks
- Group chooses leader who interfaces with management
- Group given considerable latitude in performing tasks and in machine assignments
- Inspection done within group which corrects errors
- Group has regular meetings on company time and with access to management when required

- Group is paid a fixed salary, sometimes augmented by production bonuses
- Group members credited only with defect-free production

The advantages of modular manufacturing are:

- Reduced WIP and throughput time
- Reduced inspection and timekeeping
- Reduced supervision and bundle handling
- Reduced employee turnover and absenteeism
- Improved quality
- Increased worker and plant productivity

It would be unrealistic not to list some of the disadvantages of modular manufacturing as compared to the progressive bundle system. These disadvantages include:

- Increased number of machines
- Possible increase in floor space
- Plantwide training may be required before implementation
- Considerable supervisory planning is needed when changing modules for new products

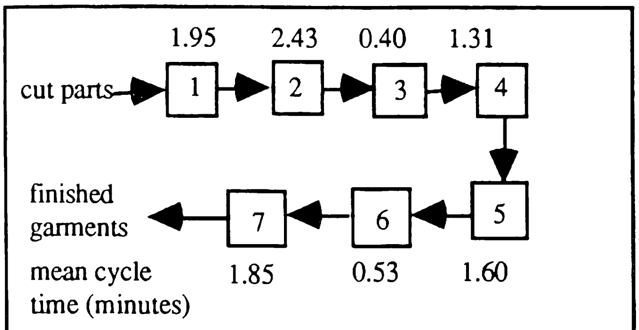
3 APPAREL MANUFACTURING MODULE

Figure 1 shows the process flow for making a garment at Hilton Apparel. The line consists of seven stations with multiple machines at each station. The exception is Station 3 which is a manual operation not requiring a machine. The line has six operators. The maximum output achievable from this system can be realized if it is assumed that all operators can move to any machine in any order and extra machines are at each station. In that case:

- Sum of operation times = 10.07 minutes
- Average cycle time = 10.07 min/6 operators = 1.68 min.
- Maximum production per day = 480/1.68 = 286 garments

A realization of this line with seven stations utilizing ten machines and six operators is illustrated in Figure 2. There are no constraints on operator movement between stations. The SSE3 (Schroer, Wang 1993a) simulator was used to model this system using the mean cycle times given in Figure 2. A production of 286 is consistent with the calculations shown previously.

This model is grossly simplified and may employ unrealistic assumptions. For instance, operators are 100% utilized. In the next two sections, more realistic models and configurations are developed to achieve maximum throughput at minimum cost.



Station	Description	Machine
1	set pocket	single needle lockstitch
2	front merrow, close shoulder, & side seam	top feed safety stitch
3	mark for collar	no machine
4	set collar	top feed safety stitch
5	topstitch fronts	single needle lockstitch
6	tail merrow	top feed safety stitch
7	hem sleeve & tail	single needle lockstitch

Figure 1: Existing Progressive Bundle Line

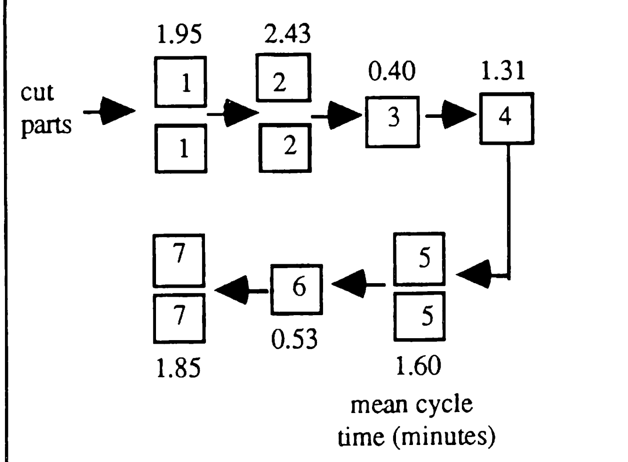


Figure 2: Modular Manufacturing Design Using SSE3

4 TSS MANUFACTURING MODULE DESIGN

One common method of module operation is the Toyota Sewn System (TSS). The operator movement rules for the TSS are listed in Figure 3. The simulator SSE6 has been written specifically for evaluating TSS modules (Schroer and Wang 1992a)

This configuration is based on seven stations with six machines, as illustrated in Figure 1. In order to optimize system configuration, the number of operators is varied from three to six. (Runs 1 to 4).

SSE6 operator movement rules:

- Items move forward in the manufacturing module. Operators move forward with the item and also move backwards for additional work.
- An operator performs an operation at a station and will move forward with the item to the next station and performs the operation until the operator reaches an operator at a station. The item is then placed in front of the station, or passed directly to the operator, if the operator if free.
- If an operator is not busy, the operator will move backwards until there is an available part. If there is no item waiting, the operator will interrupt the first operator reached. The interrupted operator will then move backwards to either find an available item or another busy operator to interrupt. The interrupting operator will then complete the interrupted operation.

Figure 3: SSE6 Operator Movement Rules

Figure 4 shows the SSE6 simulator results as a function of the number of operators with only one machine at each station (except station 3, which has no machine. Note that the production did not increase above 169 by adding a fifth or sixth operator. WIP remained around 95 garments. Also, by adding a fifth operator, one operator was idle 100 percent of the time. By adding a sixth operator, two operators were idle 100 percent of the time.

One approach to increase module production is to add duplicate machines at selected stations. The stations with long cycle times are logical selections. In this case, these are Stations 1 and 2. Table 1 shows the simulator results after adding more machines. Run 5 consisted of four operators and two machines at Station 2. This change increased production to 190 garments per day. Run 6 consisted of four operators and two machines at both Stations 1 and 2. In this case, the production remained at 190 garments per day. Run 7 consisted of adding a fifth operator and a second machine at Station 2. Production increased to 234 garments per day.

Run 8 consisted of five operators and two machines at both Stations 1 and 2. Production increased slightly to 238 garments per day. Note that adding additional machines not only increased production, but also reduced the WIP to less than five garments. Also, average operator utilization was 92 percent for Run 8 (Reference Table 2). Table 3 gives the percentages each operator spent at each station for Run 8. Note that the operators worked in zones. For example, Operators 1 and 2 worked at Station 1 and 2. Operator 3 worked at Station 2, 3, and 4. Operator worked at Station 4, 5, and 6. Operator worked at Station 6 and 7.

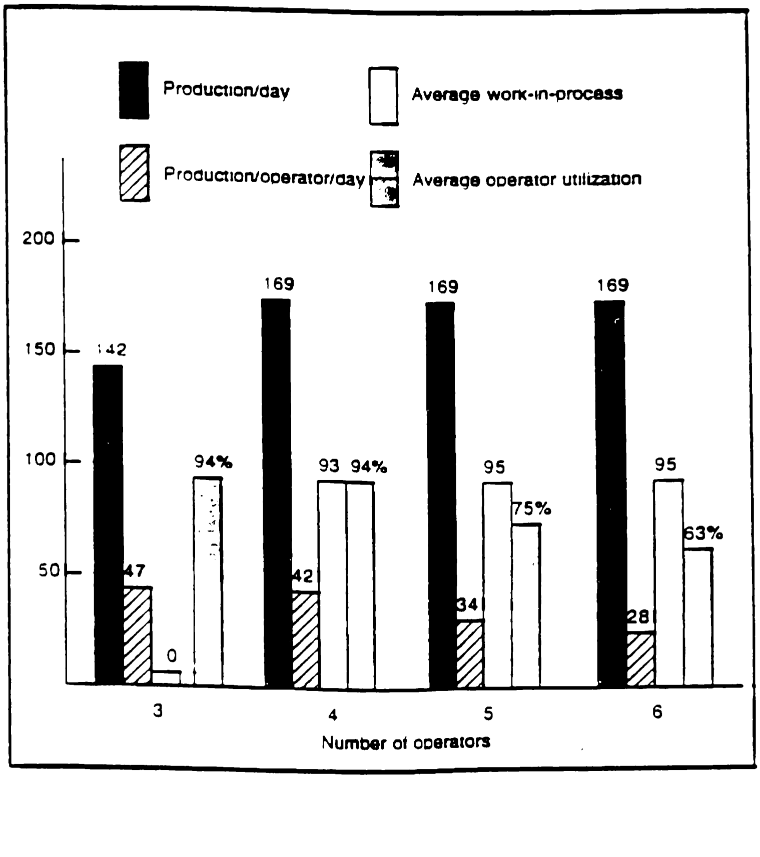


Figure 4: Simulator SSE6 Results

Run	Station 1	2	3	4	5	6	7	Operators	Production per day	Module WIP after 1 week
5	1	2	*	1	1	1	1	4	190	0
6	2	2	*	1	1	1	1	4	190	2
7	1	2	*	1	1	1	1	5	234	0
8	2	2	*	1	1	1	1	5	238	4

Table 1 Machines at Each Station

Run	Operator 1	2	3	4	5	Average operator utilization
5	81	85	87	100	—	88
6	92	93	87	100	—	93
7	69	72	84	88	100	83
8	94	96	84	84	100	92

Table 2 Operator Utilization for Run 8

Station	Machines	Operator 1	2	3	4	5
1	2	75	22	0	0	0
2	2	19	65	27	0	0
3	*	0	9	10	0	0
4	1	0	0	59	5	0
5	1	0	0	0	74	1
6	1	0	0	0	5	7
7	1	0	0	0	0	92
idle		6	4	4	16	0

Table 3 Percent Time Operator Worked at Each Station for Run 8

5 MIXED MANUFACTURING MODULE DESIGN

It is generally impossible in most real world systems to have the operator move freely as in the TSS module. Instead, some operators are fixed at machines while others are cross-trained and work on several machines. The SSE5 simulator can be used to evaluate various operator assignments (Schroer and Wang 1992b). The operator movement rules are listed in Figure 5.

Figure 6 shows the layout of the modified module. Two machines were placed at Station 2 because of the large cycle time. All cycle times are normally distributed with the standard deviations set at ten percent of the means.

The input parameters for a fixed operator are:

- Priority = 1
- Operator efficiency (%) = value 1 to 150
- Other parameters - unused

The input parameters for a moveable operator are:

- Priority = 1, 2, 3, ... (1 = home station)
- Operator efficiency (%) = value 1 to 150
- Lower WIP limit at this station = 0, 1, 2, 3, ... lots
- Upper WIP limit at this station = 0, 1, 2, 3, ... lots
- Bundle limit at this station = 0, 1, 2, 3, ... lots
- Time limit operator spends at this station = any positive number

The rules for the movement of a moveable operator are:

Rule 1: Operator will attempt to move to another station in the priority list when the operator has worked more than the "Time Limit" at the current station, or when the operator has completed, or exceeded, the "Bundle Limit" at the current station and the operator has completed a lot of garments.

Rule 2: If Rule 1 is satisfied, the operator will move from the current station to the first station in the priority list when one of the following conditions is satisfied:

Rule 2a: WIP at current station is LESS than the upper WIP limit and the WIP at a station in the priority list is GREATER than the upper WIP limit.

Rule 2b: WIP at current station is LESS than the lower WIP limit and the WIP at a station in the priority is GREATER than the lower WIP limit.

If Rule 1 is satisfied and both Rules 2a and 2b are not satisfied, then the operator will stay at the current station and do another lot. After each lot the operator will try to move depending on Rules 2a or 2b.

When the operator can no longer do work at the current station because there is no WIP and Rules 2a and 2b are not satisfied, the operator will attempt to go to the first station in the priority list that has WIP greater than zero., rather than remain idle at the current station. However, if the operator still cannot move, the operator will remain at the current station and be idle. Note that the operator will attempt to move every time the system changes state.

The above rules always check the parameters in the assigned priority sequence. For example, if the operator is at Station 4 and the priority sequence is Station 2, Station 3, Station 4, and Station 5, the rules are always fired starting with Station 2, then Station 3 and then Station 5.

It should be noted that some of the parameters may be set to zero. For example, if the "Time Limit" and "Bundle Limit" are zero, then Rule 1 is always true and Rules 2a and 2b are tested after the operator has completed every lot.

Figure 5: Operator Movement Rules for SSE5

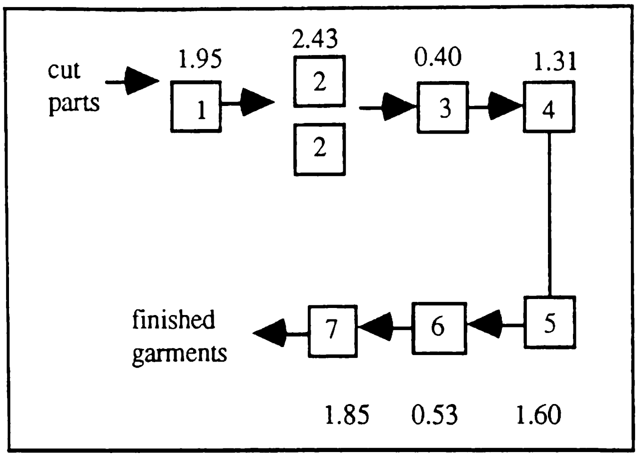


Figure 6: Manufacturing Module Design Using SSE5

The following operator assignments were made:

Run 9

Operator	Assignment
1	fixed at STA1
2	moves between STA2, 3, and 4
3	moves between STA4, 3, and 2
4	moves between STA5 and 6
5	moves between STA7 and 6

Run 10

Operator	Assignment
1	fixed at STA1
2	moves between STA2 and 3
3	moves between STA2 and 3
4	fixed at STA4
5	moves between STA6 and 5
6	moves between STA7 and 6

Run 11

Operator	Assignment
1	fixed at STA1
2	moves between STA2, 3, and 1
3	moves between STA3, 2, and 1
4	moves between STA4, 5 and 6
5	moves between STA6, 5, and 4
6	fixed at STA7

Figure 7 summarizes the results. Production was 232 for Run 9 with five operators, 225 for Run 10 with six operators, and 259 for Run 11 with six operators. Production increased from Run 10 to Run 11 by only changing the operator movement rules and adding a machine at stations 1 and 5. As the production increased, operator utilization also increased to 100 percent for Run 11.

6 CASE STUDY

Table 4 shows a comparison of the most promising module configurations. In summary, the following conclusions are:

- SSE3 validated that a daily production of 286 garments was achievable based on the current process (Alternative A).
- Manufacturing module design (Alternative C) based on the TSS system (using simulator SSE6) resulted in a daily production of 234 garments with five rather than six operators. The production per operator averaged 47 garments with no WIP.
- Manufacturing module design (Alternative E) based on some operators fixed and others moveable (using Simulator SSE5) resulted in a daily production of 259 garments with six operators. However a daily production of 232 garments was achieved (Alternative D) with only five operators and a lower WIP of 99 garments.
- Alternatives C or D appear to be most promising in terms of production per operator and WIP. Alternative C had no work-in-process. Both of these alternatives resulted in twenty percent less production than Alternative A. However, the production per operator per day was only one to two garments less than Alternative A. Therefore, the labor cost per garment is about the same for Alternatives C and D.

7 INDUSTRY RESPONSE

Experience with industry (and as the case study illustrates) demonstrates that the advantages of using manufacturing simulators, such as the SSEs, are:

- Requires only minimal knowledge of a simulation language.
- Simulators are a very effective tool for modeling domain specific manufacturing systems. Most of the models developed using the SSEs were written in less than fifteen minutes.
- Changing manufacturing module layout, operator assignment, and machine allocation required only minor changes to the simulator spread sheets and were done in minutes.
- Sensitivity analyses can be performed in minutes.

Simulators also have several disadvantages, including:

- Simulators are domain specific requiring that manufacturing systems fit the design constraints and assumptions of the simulator.
- Modifying a simulator is very time consuming, since most simulators are written in a programming language such as C or FORTRAN.
- Considerable time is necessary to develop a simulator. This time is increased significantly if graphics, printing, and statistical capabilities are added.

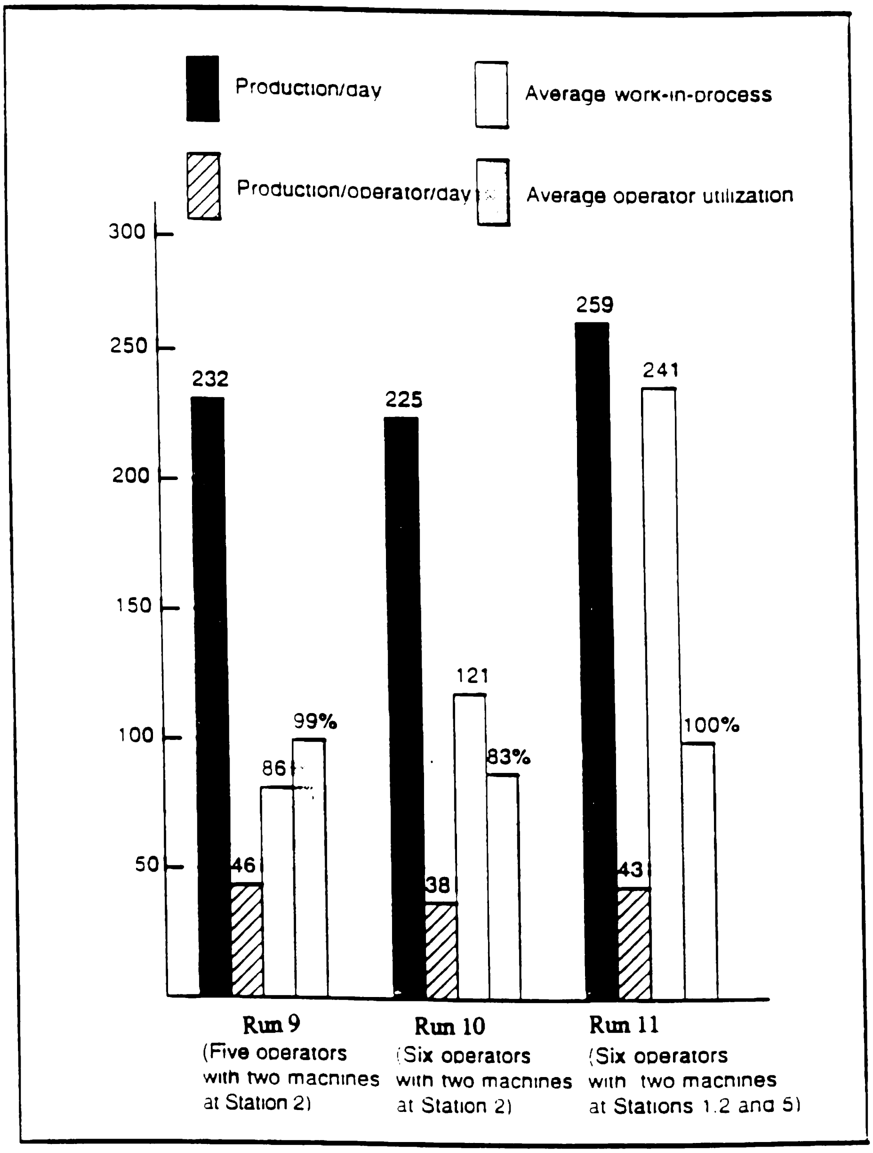


Figure 7: Simulator SSE5 Results

	A	B	C	D	E
	SSE3	Model B (SSE6)		Model C (SSE5)	
		Run 2	Run 7	Run 9	Run 11
Stations	7	7	7	7	7
Machines	10	6	7	7	9
Operators	6	4	5	5	6
Daily production	286	169	234	232	259
Daily production/ operator	48	42	47	46	43
Average operator utilization	unknown	94	83	86	100
WIP	unknown	93	0	99	241

Table 4 Comparison of Alternatives

Since 1993 over 350 apparel firms have requested copies of the SSE simulators from the NASA Marshall Space Flight Center Technology Utilization Office. A followup survey was conducted to determine how the software had been used by the firms and to measure the economic impact of the use of the software. In summary:

- 227 questionnaires mailed
- 39 responses (17.2% responses rate)
- Of the 39 responses...
    - 27 firms had used the software (69.2%)
    - 11 firms had not used the software (28.2%)
    - 1 firm had not received the software (2.6%)

Question 1 of the survey stated "How has the software been used?" Some of the responses were:

- To simulate a sewing module before installation
- To determine staffing and move assignment, as well as projected production
- Instruction purposes/setup analysis
- To simulate possible improvements and provide theoretical basis for improvements
- To run different configurations for setting up a modular line
- In process of converting progressive bundle system to modular and used software to assist in transition
- Setup and balance lines
- To determine best parameters for module size, cross training and theoretical output
- To get better understanding of modular concepts
- To evaluate balancing, number of machines required, and optimum number of people in modular line
- To confirm line capacity of newly established module unit

Question 2 of the survey stated " What effect will the software have on your firm?" The responses were:

- Convert or planning to convert to modular (44%)
- Reduce operating costs (33%)
- Increase market share (7%)
- Increase sales (7%)
- Improve competitive position (30%)
- Opportunity to expand operations (11%)
- Increase profit margin (19%)
- Introduction of new products (15%)
- Opportunity to hire new employees (4%)

Question 3 of survey also asked the firm to estimate the reduction in operating costs. Five firms responded with the following cost savings:

• Firm A	$300,000
• Firm B	$100,000
• Firm C	$5,000
• Firm D	$5,000
• Firm E	$2,500,000

ACKNOWLEDGMENTS

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Technology Utilization Office/AT01
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812
Attention: Mr. Harry Craft

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AUTHOR BIOGRAPHIES

PHILLIP A. FARRINGTON is Assistant Professor of Industrial and Systems Engineering at the University of Alabama in Huntsville. He has a Ph.D. in industrial engineering from Oklahoma State University. He is a member of IIE, SME, ASQC, Tau Beta Pi, and Alpha Pi Mu. His research interests include design and analysis of manufacturing systems.

BERNARD J. SCHROER is Associate Vice President for Research and Professor of Industrial and Systems Engineering at the University of Alabama in Huntsville. He has a Ph.D. in industrial engineering from Oklahoma State University. He is a member of SCS, NSPE, Technology Transfer Society, and a Fellow of IIE.

JAMES J. SWAIN is Assistant Professor of Industrial Systems Engineering at the University of Alabama in Huntsville. He has a Ph.D. in industrial engineering from Purdue University. His research interests include Monte Carlo methods and variance reduction, statistical modeling, and output analysis. He has been active in the WSC and TIMS College on Simulation and served as the proceedings editor for WSC 1992.

YUN-CHENG FENG is a Professor in the School of Management at the Beijing University of Aeronautics and Astronautics. His research interests are neural networks, expert systems and simulation.