Proceedings of the 1994 Winter Simulation Conference
ed. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila

SIMULATION AND UNDERGRADUATE ENGINEERING EDUCATION: THE TECHNOLOGY REINVESTMENT PROJECT (TRP)

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ABSTRACT

This paper discusses an undergraduate engineering education program recently funded by the Advanced Research Projects Office (ARPA) Technology Reinvestment Project (TRP) to add more hands-on experience for undergraduate engineering students.

1 INTRODUCTION

Engineering education in the United States underwent a significant change in the early 1950's. According to an article in *ASEE Prism*, "the post-World War II curriculum model, heavy on math and science and relatively light on engineering design, comes in for its share of reproof." (Hubband, 1993). The reduction in design courses was accompanied by a similar reduction in hands-on laboratory courses. Currently, the Accreditation Board for Engineering and Technology (ABET) requires a minimum of 16 semester credit hours of design courses for undergraduate engineering degrees.

Over the years, reaction from U.S. industry, the employer of 70 percent of all engineering graduates, has been that considerable in-plant training is needed before newly minted engineers can be effective in design assignments. It is interesting to see how this problem is being handled in the other major industrialized nations. After World War II, Japan patterned its recovering industries after the then dominant U.S. model. The Japanese decided to copy the postwar U.S. model of engineering education. Consequently, newly graduated Japanese engineers have little capability for hands-on design. This problem was noted more than two decades ago. The Japanese solution was not to change the engineering curriculum, but rather to provide hands-on design experience on the job. Thus, in a Japanese manufacturing plant, newly graduated engineers are assigned various tasks, such as acting as foremen on the production floor. These hands-on assignments account for the first two years of employment. Only after this period are the engineers given design assignments.

In Germany a different approach has been taken. About 95 Fachhochschulen have been established in recent years. These four year institutions are college level schools that provide practice-oriented engineering education. The faculty of these institutions are required to have a minimum of five years of industrial practice (Willenbrock, 1992). In German technical institutes, the professors who head these organizations are called to these positions after ten or more years of industrial experience (Eder, 1993).

The lack of hands-on training and design experience for U.S. engineering undergraduates has been recognized by the federal government in the March, 1993 solicitation by the Advanced Research Project Agency's Technology Reinvestment Project (ARPA-TRP). This solicitation asked for proposals in the area of manufacturing engineering education. The University of Alabama in Huntsville (UAH) and Alabama A&M University won a contract award in the area of undergraduate manufacturing teaching/learning laboratories.

2 MANUFACTURING EDUCATION PROGRAM

The manufacturing education program is a joint program between the University of Alabama in Huntsville's (UAH) College of Engineering and Alabama A&M University's School of Engineering and Technology. The two UAH departments participating are Mechanical Engineering and Industrial and Systems Engineering. The participating department at A&M is Engineering Technology.

The objective of the program is to provide more hands-on experiences to engineering and engineering technology undergraduate students. The plan is to use the Alabama Industrial Development Training (AIDTraining) Alabama Center for Advanced Technology Transfer (ACATT) as an off-campus manufacturing teaching/learning laboratory. ACATT is a state facility equipped with modern manufacturing equipment and a vast amount of application software. In addition, ACATT has a team of highly qualified instructors and technicians trained in the operation of the equipment.

In summary, UAH and A&M will develop undergraduate lab manuals based on the resources at ACATT. These lab manuals will be integrated into existing engineering and engineering technology courses at both institutions. ACATT will assist in the development and review of the lab manuals, provide lab instructors, provide its facilities as teaching/learning labs, and co-sponsor the Summer Engineering Residency Program which will field test the lab manuals.

A team of industrial partners has been assembled to provide input and to review the lab manuals. The partners are:

- Boeing, Huntsville, AL
- Motorola, Phoenix, AZ
- Hughes Aircraft, El Segundo, CA
- MagneTek, Huntsville, AL
- Chrysler Electronics, Huntsville, AL
- Alabama Society of Professional Engineers
- Alabama Board of Registration for Engineers and Land Surveyors
- Alabama Department of Economic and Community Affairs

3 ALABAMA CENTER FOR ADVANCED TECHNOLOGY TRANSFER

ACATT is a state facility operated by Alabama Industrial Development Training (AIDTraining) that is nine interstate miles from the UAH campus and 17 miles from the A&M campus. Since 1971, AIDTraining had designed and delivered training for more that 800 companies in Alabama. With more than 80,000 successful completers of pre-employment and upgrade training programs, AIDTraining knows first-hand the impact that well-trained employees can have on manufacturing quality, quantity and cost. AIDTraining operates three fixed training centers, one of which is ACATT in Huntsville.

ACATT is equipped with state-of-the-art manufacturing equipment, including Intergraph CAD workstations, 3D System's stereolithography apparatus, Hitachi Seike CNC mill and turning centers, Numerex coordinate measuring machine, and a variety of industrial robots.

ACATT has 15,000 square feet of laboratories and offices (Figure 1). The laboratories include:

- Engineering design lab (eight Intergraph workstations)
- PC lab (twelve 386 PCs)
- Sun lab (twelve Sparc workstations)
- Macintosh lab (eight MacIIs)
- Stereolithography lab (3D Systems SLA-250)
- Flexible manufacturing system lab (Hitachi Seike 4-axis CNC mill and 2-axis CNC turning center, Numerex CMM, AS/RS, and several robots)
- CIM lab (CAD; CAM; CAPP; MRPII, production, planning, and control; scheduling; simulation; and data base software along with various workstations and PCs)
- Electrical/mechanical lab
- Distributive control system lab
- Machine shop (manual lathe, mill, grinder, etc.)

4 UNDERGRADUATE LABS

Table 1 lists the undergraduate labs that have been identified and the courses that could use the labs in the Industrial and Systems Engineering Department. Each lab manual is being developed by a team of faculty from both institutions, research staff in the UAH Center for Automation and Robotics, and ACATT staff. A faculty member leads each team. The status of several of these labs is discussed in the following sections.

4.1 CAD/CAM Lab

Several labs are constructed around the manufacturing equipment at ACATT (Figure 2). In these labs a student can design a part on a CAD workstation, conduct a detailed analysis of the part using such software as finite element modeling (FEM), generate the NC software to "cut" the part, electronically transmit the NC program file to a CNC machining center and watch the part being made, and electronically transmit the CAD design file to a stereolithography apparatus and watch the part be "grown" from a tank of liquid polymer. The finished part is inspected using a coordinate measuring machine.

In addition, the student can reverse engineer a part by going backwards from the part and create the drawings. The coordinate measuring machine is used to obtain a set of points which are then entered into a post processor that attempts to connect as many of the points as possible. This file is then entered into a CAD system and the remaining points connected. The result is a finished drawing.

4.2 Foam Manufacturing Lab

The UAH Consortium for Materials Development in Space (CMDS) is a NASA Center for Commercial Development of Space. The CMDS sponsors a variety of industry supported projects in materials development that show commercial potential. One of the CMDS's research projects has been the manufacturing of polymer foams in space. A variety of experiments for making foams have been conducted on suborbital rockets, the space shuttle and Spacelab.

LAB MANUALS	ISE COURSES*						
	378	326	327	428/429	430	390/490	423
Machining fundamentals	X						
CNC programming	X				X		
CAD to CAM							
CAD stereolithography		demo			X		
CMM							
Reverse engineering		demo			X		
Manufacturing simulators				X			
Job shop scheduler				X			
Robot programming					X		
Foam fabrication		X		X	X	X	
Non-destructive evaluation					X	X	
GPSS/PC simulation system				X			
Electronics manufacturing/prototyping		demo			X		
Manufacturing planning & control			X				
ISE9000							X

* ISE378 Materials and manufacturing processes
ISE326/ISE327 Production and operations systems I and II
ISE428/ISE429 Systems analysis and design I and II
ISE430 Modern manufacturing/production systems
ISE390/490 Probability and statistics I and II
ISE423 Statistical process control

Table 1. Proposed Industrial and Systems Engineering Lab Manuals

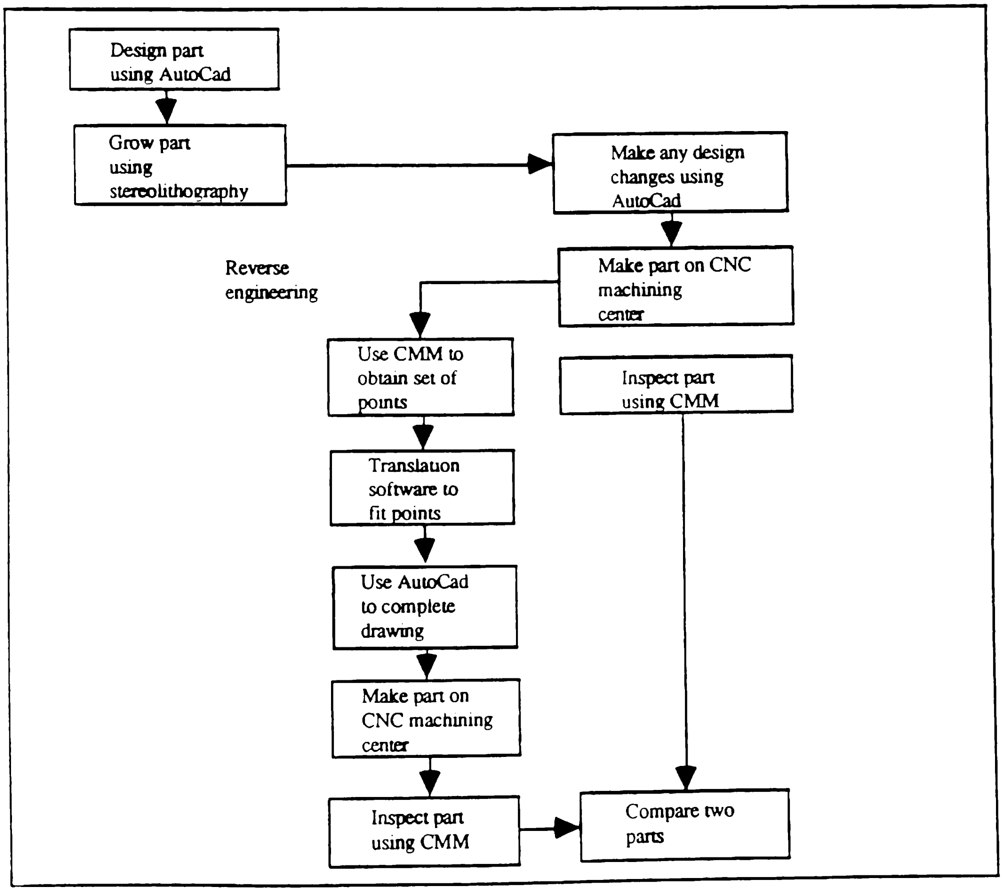


Figure 2. CAD/CAM and Reverse Engineering

The UAH Center for Automation and Robotics has taken the foam technology and established a facility for transferring this technology to firms in Alabama. The selected foam is a polyurethane foam using a chemical blowing agent that does not depend on CFC's and is therefore benign to the environment. The foam is made of polyisocyanurates and polyisocyanates that is blown with carbon dioxide. The foam shows excellent dimensional stability, high strength to weight ratio, good solvent resistance, inertness to mildew and rodents and moldability. The foam can be reinforced with such materials as fiberglass and silica.

UAH has signed an agreement with the NASA Marshall Space Flight Center (MSFC) that permits access to the MSFC Productivity Enhancement Complex's foam lab. This lab is used to develop foam applications for space. One such foam is the insulation on the space shuttle's external tank.

The use of this lab manual by a student includes:

- Selecting a foam recipe
- Selecting a parameter or parameters to vary
- Selecting a response variable or variables and designs an experiment (ANOVA)
- Making appropriate number of foam samples
- Interfacing with MSFC Productivity Enhancement Complex to conduct analysis
- Performing ANOVA and writing report

4.3 Manufacturing Simulators Lab

The apparel industry is undergoing significant changes. One area experiencing change is the method of apparel manufacturing. This change 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. Many apparel firms are now beginning to experiment with the concepts of modular manufacturing to improve the process, minimize system variability, improve quality, and reduce cost. In modular manufacturing the operators are interchangeable among the operations and compensation is based on the module's output of quality products (Ziemke and Schroer, 1992).

UAH has developed two simulators to assist apparel firms design and analyze manufacturing modules. The simulators are based on technology developed at NASA/MSFC. The simulator SSE6 can be used to simulate an apparel manufacturing module based on the TSS (Toyota Sewing System) concept where all operators stand and move between stations. Work is done in lots of one garment.

The simulator SSE5 can be used to model an apparel module where some operators are fixed at machines while other operators move between several machines. The moveable operators move based on a defined set of rules, such as time limit, bundle limit, lower WIP and upper WIP.

The simulators are being distributed by MSFC. Over 350 apparel firms have requested copies of the software. Students are given a copy of the *Design and Analysis of Manufacturing Modules Lab Manual* and copies of the software. Figure 3 outlines one of the student lab experiments using the simulators.

PROBLEM 2: MANUFACTURING MODULE A

Given the following manufacturing module which is being proposed for an apparel manufacturer:

Assume the cycle time distributions to be triangular with b=mean, a=90% of b, and c=120% of b.

Given the following assumptions:

1. All operators are cross trained.
2. All operators work at 100% at home station, 95% at second station in priority list, 90% at third station in priority list, etc.
3. Unlimited space for WIP between stations.
4. Work done in lots of one part.
5. Always at least one part in front of Station 1.
6. Only one machine allowed at Station 1. Multiple machines are allowed at other stations.

Design a manufacturing system using the simulators to maximize production and at the same time, minimize the number of operators, number of machines, and WIP. Plot the results of your alternatives. For example, the plots could include a comparison of production, production/hour, WIP, operator utilizations, machine utilizations, and time operator spent at each station.

Figure 3. Student Lab Exercise Using Simulators

4.4 Job Shop Scheduler Lab

Job shop scheduling is a non trivial problem. The problem becomes more complex as the size of the job shop, as well as the number of jobs, increase. Furthermore, the addition of constraints such as machines, machine routing, operators, operator skill levels, and tooling requirements also add to the complexity of the scheduler.

UAH has developed a relatively simple computer based job shop scheduler for the first time user of computer scheduling. The scheduler has evolved from working with Campbell Engineering in Huntsville which is a small job shop.

The scheduler is being distributed to firms in Alabama as part of the Southeast Regional Technology Transfer Center (RTTC). Students are given a copy of the *Job Shop Scheduler Lab Manual* and the software.

4.5 GPSS/PC System Lab

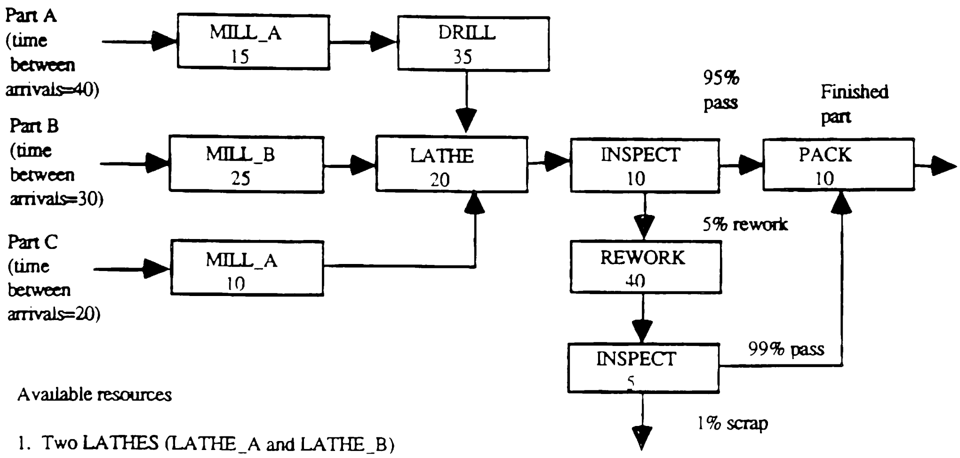
UAH has been conducting simulation seminars for industry in Alabama. As a result of these seminars, a 200+ page GPSS/PC lab manual has been developed. Included in the manual are the basics that a beginning student would need to execute the system, a description of the most frequently used blocks, and a set of sixteen sample models. Students are given a copy of the lab manual, a disk containing the sixteen sample models, and a copy of the limited version of GPSS/PC.

The models are initially very simple. Additional block types are then added to the subsequent models. As a result, most of the GPSS/PC block types that are used in manufacturing models are included in the examples. The following lab experiments have been designed and are included in the lab manual:

- Manufacturing cell (Figure 4).
- Factory consisting of three departments each with multiple machines
- Inventory control system.
- Bombing run over target with x and y errors of bomb sights.
- Reliability network.
- Prelaunch countdown sequence (Figure 5).
- Bicycle assembly plant.
- Outpatient clinic.

PROBLEM 1: MANUFACTURING CELL

A manufacturing cell makes three parts: A, B, and C. Routing for part A is MILL_A, DRILL, LATHE, INSPECT, and PACK. Routing for part B is MILL_B, LATHE, INSPECT, and PACK. Routing for part C is MILL_A, LATHE, INSPECT, and PACK.



Available resources

1. Two LATHES (LATHE_A and LATHE_B)
2. Unlimited number of PACK stations
3. Three INSPECT stations
4. One REWORK station, one MILL_A station, one MILL_B station

Other problem constraints

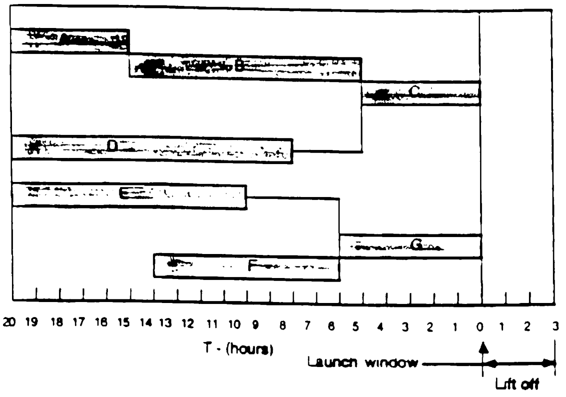
1. All arrival and service times are constants and in minutes.
2. LATHE station has two lathes: LATHE_A and LATHE_B. The incoming part will always attempt to seize LATHE_A first. If LATHE_A is busy, the part will attempt to seize LATHE_B. If both are busy, the part will wait and repeat the cycle.
3. Unlimited number of packing stations. The part chooses a packing station at random.
4. No machine breakdown.
5. Operators are at fixed stations.

Write a GPSS/PC simulation model of the above manufacturing cell. Stop the model after making 200 good parts. Where are the bottlenecks? What can be done to reduce the bottlenecks and increase production? Plot the results for the different alternatives.

Figure 4. Student Lab Exercise Using GPSS/PC

PROBLEM 7: COUNTDOWN

The following countdown sequence is for the launch of a space vehicle. The countdown starts at T-20 hours. Launch is at T-0 hours. The launch window is three hours.



Activity	Duration (hours)	MTTF (hours)	MTTR (hours)
A	5	8	1
B	10	15	2
C	5	8	1
D	12	16	3
E	10	15	2
F	8	12	1
G	6	9	2

MTTF = mean time to failure (hours)
MTTR = mean time to repair (hours)

Write a GPSS/PC simulation model of the above countdown sequence. Determine the probability of launching within the launch window. Simulate 1,000 launches. Assume a maximum of one failure per activity per launch attempt.

It is possible to start the countdown earlier up to T-26 hours. However, there will need to be a hold at T-3 hours to get the countdown back on schedule because at T-3 hours the sequence begins an automatic countdown for launch. Redesign the countdown by varying the start of the countdown to maximize the probability of launching within the three hour launch window. Plot your various design alternatives and compare them against the baseline countdown of T-20 hours.

Figure 5. Student Exercise Using GPSS/PC

5 FIELD TESTS

The lab manuals will be field tested in the summer 1994 as part of the UAH/ACATT Summer Engineering Residency Program. Students will be participating in a two week hands-on learning experience at ACATT. UAH and A&M faculty and ACATT instructors and technicians will teach the labs. A followup evaluation will be made at the end of the program.

6 CONCLUSIONS

At this point in the project, the following observations are made:

- Cooperative Research and Development Agreements (CRADAs) are an excellent vehicle for obtaining access to manufacturing equipment and personnel at federal laboratories.
- State training centers have equipment that is current and maintained and have highly qualified instructors and technicians.
- Manufacturing simulators are excellent education tools to provide students with open ended design problems.
- Very simple simulation experiments which are open ended can be designed using simulation languages such as GPSS/PC.

7 ACKNOWLEDGMENTS

The ARPA TRP award is being administered through a NASA/MSFC cooperative agreement. Also, funding is being received from the NASA Southeast Regional Technology Transfer Center and Alabama Industrial Development Training.

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