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

TEACHING MANUFACTURING SYSTEMS SIMULATION IN A COMPUTER AIDED TEACHING STUDIO

Charles R. Standridge

Padnos School of Engineering
Grand Valley State University
301 West Fulton
Grand Rapids, MI 49504-6495, U.S.A.

ABSTRACT

A computer aided teaching studio provides a unique environment for teaching an introductory simulation course to manufacturing engineers. Each meeting can consist of an appropriate combination of lecture and computer-based activities, depending on the topic. Assigned exercises aid students in learning methods. Emphasis can be placed on the solution of case problems that serve as metaphors for realistic simulation projects. Since students have co-op or full time industrial experience, an industry-based project of the student's own definition serves as a course capstone. The case problem and project orientation of the course supported by the computer aided teaching studio makes examinations unnecessary. Case problems are based on a set of case studies derived from topics of interest to practicing manufacturing engineers. Cases are organized into four modules: basic systems organizations, lean manufacturing, material handling, and supply chain management. Only the simulation methods needed to support the case studies are presented.

1 INTRODUCTION

A computer aided teaching (CAT) studio is a particularly well suited environment for an introductory course in manufacturing systems simulation. Such a studio includes an instructor's station with a computer connected to a video display device, audio output, and a VCR as well as one computer for each student or pair of students.

This teaching environment provides unique instructional opportunities for a manufacturing systems simulation class. Each class meeting can consist of an appropriate combination of lecture and computer-based activities depending on the topic. Exercises can be assigned to aid students in learning methods. Simulation examples can be presented in animated form. Emphasis can be placed on the solution of case problems that serve as metaphors for realistic simulation projects. Since students have co-op or full time industrial experience, an industry-based project of the student's own definition can serve as a course capstone.

Case problem and project reports, models, and spreadsheets used for statistical analysis and other computations are submitted electronically. Grading includes running models and debugging them if necessary as well as a detailed review of formulas and computational procedures. Students are able to submit work at the time the instructor has set aside for grading, generally the day before the class meeting. The instructor provides immediate feedback via comments entered electronically into the submitted documents. In addition, all student work is archived by the instructor. General patterns of performance are discussed at the subsequent class meeting.

This paper presents an approach for defining the content of introductory undergraduate and graduate simulation courses for manufacturing engineers based on the capabilities of a computed aided teaching studio. The courses emphasize the manufacturing engineering problems addressed by simulation and a simulation project process (Standridge and Brown-Standridge, 1994) used to solve such problems. The simulation modeling and experimentation topics included in the course are those needed to address the manufacturing engineering problems of interest.

Manufacturing engineering problems and corresponding simulation solution approaches are presented in a series of case studies. Students are required to complete a series of case problems. Each case problem is based on a case study. The difficulty of the case problems increases throughout the course. A term project drawn from the industrial work experiences of students, or the instructor if necessary, completes the course.

The topical content of the undergraduate and graduate simulation courses is described. The operation of each course in the CAT studio is discussed.

2 BACKGROUND

Several texts reflect the typical content of simulation courses for manufacturing engineers, industrial engineers, and management scientists.

Law and Kelton (2000) as well as Banks, Carson, and Nelson (1996) are typical texts appropriate for a simulation course emphasizing experimentation topics. Both begin with a general overview of simulation modeling without presenting in great detail the constructs of any particular simulation language. The remainder of the texts thoroughly discuss and present basic concepts concerning simulation statistical and experimentation issues: fitting distribution functions to data, random number generation, sampling from distribution functions, analyzing the results from the simulation of one alternative, and comparing simulation results between alternatives as well as verification and validation.

Other texts are appropriate for a course based on the concepts embodied in a commercial simulation environment. Pritsker and O'Reilly (1999) describe the AweSim simulation environment. Emphasis is placed on the modeling capabilities of the Visual SLAM simulation language. Some discussion of optimizing system parameter values, random sampling from distributions, and simulation statistical issues is provided.

Kelton, Sadowski, and Sadowski (1998) present the ARENA simulation environment. Emphasis is placed on using ARENA capabilities to conduct a simulation study including model building, fitting distribution functions to data, statistical analysis of simulation results, and animation. Some discussion of random number generation, sampling from distribution functions, and variance reduction is provided.

Harrell, Ghosh, and Bowden (2000) present basic simulation modeling and experimentation concepts: fitting data to distribution functions, model building, validation, verification, and the analysis of simulation outputs. Laboratory assignments are provided to assist student in learning these concepts through their implementation in the ProModel simulation environment. Term projects drawn from industrial applications are included.

Simulation may play a prominent role in teaching an application area course. For example, Dessouky et al. (1998, 2001) describe a prototype Virtual Factory Teaching System (VFTS) for use in a manufacturing engineering production scheduling and control course. An AweSim model represents the factory. Students learn about a variety of factory design and operation issues as well as how to address them by building and interacting with factory simulations.

Shore and Plager (1978) call for the use of cases in simulation education, emphasizing real-world applications. Standridge (2000b) discusses the application of the case based approach to simulation instruction. Case studies show promise in providing a link between methods and their applications. Case studies can show how methods assist in a decision process involving design, operations, and management issues. Furthermore, properly constructed cases provide a "metaphor' for real engineering problems and allow students to "simulate" the role of a practicing engineer or manager (Shapiro, 1984).

Richards, et al (1995) discuss the use of cases in engineering education. The following benefits of cases are identified:

Relevance. Actual representation of real design and operations issues faced by engineers and managers.

Motivation for students. The realism of the cases provides an incentive for the students to become more involved in the material they are studying.

Consolidation/Integration. Each case requires the application of multiple concepts and techniques in an integrated fashion to address a single set of issues.

Transfer. Cases give students experience that can be applied to subsequent cases, other course work, and on the job situations.

Based on Shapiro (1984), they conclude:

> "All three pedagogical approaches (lectures and readings, exercises and homework sets, and case studies) are needed in combination to create a learning experience appropriate for technology intensive disciplines, the careers these students will enter, and the capabilities of the students themselves."

Electronic submission of completed assignments is employed in the classes presented in this paper. Standridge (2000a) discusses the electronic submission of student work in simulation classes. Benefits identified include the following:

1. Submission of assignments other than at class meeting times.
2. Return of assignments as soon as grading is completed.
3. Support for a short submit-evaluate-correct-resubmit cycle.
4. Examining simulation models and the statistical analysis of simulation results to provide a more detailed evaluation as well as to develop corrections and suggestions for improvements.
5. Avoidance of printing voluminous complex information that can be better transmitted and assessed in its electronic form.
6. Support for archiving assignments.

3 COURSE CONTENT AND STRATEGY

The Padnos School of Engineering at Grand Valley State University is located in urban Grand Rapids, MI. One of the missions of the school is to educate engineers to work within the west Michigan industrial base. Thus, the school has an applied focus in both its undergraduate and graduate degree programs. All undergraduate degree programs, including manufacturing engineering, require 1500 hours of co-operative education that usually involves working in a west Michigan industrial setting. The vast majority of manufacturing engineering graduate students are employed full time within the local industrial base. Their job assignments typically include a wide variety of manufacturing engineering related tasks.

This context gives rise to the following requirements for undergraduate and graduate simulation courses in manufacturing engineering.

1. The courses must discuss the application of simulation to manufacturing engineering problems found in local industry.
2. Students should be able to immediately apply what they learned in their full time or co-op job settings.

From these basic requirements, the following learning objectives were derived:

1. Students should learn the types of manufacturing engineering problems that simulation addresses.
2. Students should learn and practice a process for solving problems using simulation.
3. Students should learn simulation methods needed for solving manufacturing engineering problems.
4. Students should learn how to effectively use one commercial simulation environment.

Each course is comprised of modules. The first four modules address the first course objective. The scope and content of each of these modules were derived in the following way.

A workstation is the fundamental operating element of a manufacturing system. A workstation processes one or more individually identifiable items at a time.

Most systems consist of multiple workstations. In a serial system, each item typically visits all of the workstations in the same sequence as every other item. If the processing time is close to the same at each workstation, the serial system is paced. If the processing time varies among the workstations, the serial system is unpaced. In a job shop a variety of items are processed. Each type of item visits a subset of the workstations in a prescribed order. Which stations are visited and in what sequence varies among the types of items processed.

Thus, one module must cover modeling and experimentation of basic manufacturing systems organizations: work station, unpaced serial line, paced serial line, and job shop.

Lean manufacturing issues are important. Topics in this area include: pull (just-in-time) versus push operations, one piece flow, flexible manufacturing, cellular manufacturing, and complete automation. Thus, a second module must cover modeling and experimentation related to these topics.

Material handling topics include conveyors and automated guided vehicles. The modeling and simulation of material handling systems is covered in a third module.

Supply chain management, including inventory management and logistics, is significant manufacturing support issue. Topics include: plant to customer transportation, automated inventory management, and warehousing. This material is covered in the fourth module.

Case studies organized according to a simulation project process provide a desirable structure for the above modules by addressing both the first and the second learning objectives. The benefits of case studies, previously discussed, meet the two fundamental course requirements. The simulation project process is the mechanism for creating the consolidation/integration benefit of the case study.

Performing the simulation project process requires an understanding of simulation methods. These include model building, experimentation, and fitting distribution functions to data. In addition, understanding how the simulation engine conducts a simulation experiment is helpful.

Model building topics include various simulation world views as well as modeling approaches for the various components of a manufacturing system:

1. Arrivals of parts, orders, or other production requirements.
2. A variety of operations at work stations including breakdowns and scheduled maintenance.
3. Routing among the work stations comprising a manufacturing system.
4. Batching.
5. Inventories.
6. Assembly

These component models (Standridge, 1986) are presented using flow charting symbols without reference to any particular simulation language.

Experimentation topics include:

1. Verification and validation.
2. Design and analysis of terminating simulation experiments.
3. Variance reduction using common random numbers.
4. Animation.

Two processes for fitting distributions functions to data are presented: the traditional process of selecting a family of distributions, estimating distribution parameters, and conducting statistical goodness of fit tests, as well as an interactive, computer based process as implemented in distribution function fitting software. Characteristics and common uses of the probability distribution functions typically employed in a simulation model are also discussed.

The simulation engine processes a model and conducts the simulation experiment transparently to the user. However, students seem to benefit from an overview presentation of what the simulation engine in doing. This overview prevents the computations involved in executing a simulation from becoming a mystery and yields an appreciation for how the simulation engine produces results from the model, experimentation specification, and the input data.

Thus, the fifth module covers simulation methods: project process, modeling, experimentation, fitting distribution functions to data, and simulation engine operations. This module meets the third learning objective

In summary, a manufacturing simulation course may be divided into the following modules:

1. Simulation methods.
2. Modeling and experimentation for basic manufacturing systems organizations.
3. Modeling and experimentation for lean manufacturing.
4. Modeling and experimentation for material handling.
5. Modeling and experimentation for supply chain management.

Students practice simulation methods as well as building models and conducting experiments using a commercial off-the-shelf simulation environment appropriate for the students in the course. This meets the fourth learning objective.

4 COURSE OPERATION

A course consists of the simulation methods that are included from the first module in addition to the case studies that are covered from modules 2, 3, 4 and 5. Assignment submission and evaluation policies and procedures are required. The selection of the simulation environment for the course is important.

The same text (Standridge, 2001) is used in both the undergraduate and graduate simulation courses.

4.1 Undergraduate Course

An introductory course in manufacturing system simulation is required of all bachelor of science level manufacturing engineering students in the Padnos School of Engineering at Grand Valley State University. This course complements the optimization methods and analytic models presented in a required production scheduling and control course. Courses in basic statistical methods and quality control are prerequisite for this class.

All students in the course have completed a minimum of 500 hours of co-operative education. Some are concurrently engaged in a second 500 hours of work experience. Thus, all students have had some experience working in a manufacturing environment.

The course meets 5 hours per week in a CAT studio, 2 times for 2.5 hours each. Assignments are submitted electronically via e-mail and due at the time the instructor has set aside for grading. Assignments are graded and returned prior to the next class meeting.

The manufacturing oriented simulation environment AIM (O'Reilly and Lilegdon, 1999) and the distribution function fitting package ExpertFit (Law and McComas, 1999) are employed.

Experimental results are transferred from AIM reports to an Excel spreadsheet via a text file. The Excel spreadsheet program is used for additional statistical processing of information such as the computation of confidence intervals and hypothesis testing to compare alternatives. Time series plots and histograms are generated within Excel as well.

The nominal topical coverage of the course is as follows:

1. Simulation methods: 4 weeks.
2. Basic systems organizations: 3 weeks.
3. Lean manufacturing: 2.5 weeks.
4. Supply chain management: 1.5 weeks.
5. Material handling: 1.5 weeks
6. Term project: 2.5 weeks.

The simulation methods module includes the simulation process, modeling, experimentation, fitting distribution functions to data, and the operations of the simulation engine. Tutorials introduce the AIM simulation environment and ExpertFit. Laboratory exercises assist students in learning experimentation methods as well as the operation of the simulation engine.

The second module includes the basic organizations of manufacturing systems: single work stations, serial lines, and job shops. Case problems require all students to modify existing models and perform all of the steps of a simulation project as well as reaching and defending conclusions as to buffer space requirements and capital equipment requirements.

The third module covers lean manufacturing issues. Topics include the pull production strategy, one piece flow, flexible manufacturing, highly automated manufacturing, and cellular manufacturing. Case problems require students to develop new models from scratch about systems that are similar to but not exactly the same as those covered in the case studies.

The fourth module covers material handling. Topics include conveyors and automated guided vehicles. Case studies are of the same kind as those in module 3.

The fifth module covers supply chain management. Topics include transportation between facilities, automated inventory management, and logistics. Case studies are of the same kind as those in module 3.

The term project provides a capstone for the course. Projects are defined by the students based on their work experience, solicited by the instructor from local industry, and extracted from the instructor's industrial experience.

Grades are determined in the following way. Each of the four tutorials and laboratories in module 1 counts 6 points for a total of 24. Each of the case studies in modules 2, 3, 4, and 5 counts 14 points for a total of 56. The term project counts 20 points.

4.2 Graduate course for practicing engineers

An introductory course in manufacturing system simulation is required of various students in the masters degree program:

1. All manufacturing engineering students who enter the program with an undergraduate engineering degree,
2. All manufacturing operations students who enter the program without an undergraduate engineering degree,
3. All students seeking a three-course certificate in production operations.

Almost all students are employed full-time in manufacturing engineering or operations positions in west Michigan industry. A typical student would not take both the graduate and the undergraduate course.

Most graduate students would also take a course in production operations models that includes optimization, inventory models, and a discussion of alternative organizations for manufacturing systems. In addition, students may take a material handling and facilities layout course concurrently with the simulation course. Since material handling system designs are generally proven using simulation, students are encouraged to complete a single project for both courses. Knowledge of basic statistical methods is prerequisite for this course.

The graduate simulation course meets once per week for 3 hours in a CAT studio. Assignments are submitted electronically via e-mail and due at the time the instructor has set aside for grading. Assignments are graded and returned prior to the next class meeting.

The manufacturing and material handling oriented simulation environment AutoMod (Banks, 2000) and the distribution function fitting package ExpertFit are employed.

The nominal topical coverage of the course is as follows:

1. Simulation methods: 5 weeks.
2. Basic systems organizations: 2 weeks.
3. Lean manufacturing: 3 weeks.
4. Material handling: 1 week.
5. Supply chain management: 2 weeks.
6. Term project: 2 weeks.

The simulation methods module includes the simulation project process, modeling, experimentation, fitting distribution functions to data, and the operations of the simulation engine. Tutorials introduce the AutoMod simulation environment and ExpertFit. Laboratory exercises assist students in learning experimentation methods as well as the operation of the simulation engine.

The second module includes the basic organizations of manufacturing systems: serial lines and job shops. Case problems require all students to modify existing models and perform all of the steps of a simulation project as well as reaching and defending conclusions as to buffer space requirements and capital equipment requirements.

The third module covers lean manufacturing issues. Topics include the pull production strategy, one piece flow, flexible manufacturing, highly automated manufacturing, and cellular manufacturing. Case problems require students to develop new models from scratch about systems that are similar to but not exactly the same as those covered in the case studies.

The fourth module covers material handling. Topics include conveyors and automated guided vehicles. Case studies are of the same kind as those in module 3.

The fifth module covers supply chain management. Topics include transportation between facilities, automated inventory management, logistics, and project management. Case studies are of the same kind as those in module 3.

The term project provides a capstone for the course. Projects are defined by the students based on their work experience, solicited by the instructor from local industry, and extracted from the instructor's industrial experience.

Grades are determined in the following way. Each of the four tutorials and laboratories in module 1 counts 7.5 points for a total of 30. Each of the three case studies in modules 2, 3, 4, and 5 counts 15 points for a total of 45. The term project counts 25 points.

5 SUMMARY

A CAT studio provides an ideal environment for conducting an introductory simulation course. The instructor may present material in a visual and animated form. The instructor may freely interact with students as they perform exercises and case problems on a computer. Electronic submission and grading of assignments is facilitated. Each class meeting may be an appropriate combination of instruction presentations and student active learning assignments.

Based on the CAT studio environment, one way of determining the topical content of introductory simulation courses for undergraduate and graduate manufacturing engineering students has been presented. Course content is derived from the manufacturing engineering issues that simulation addresses. Case studies serve as metaphors for actual industrial problems. The case studies are partitioned into modules that deal with basic manufacturing systems organizations, lean manufacturing, material handling, and supply chain management. A fifth module introduces a simulation project process as well as the simulation methods required to address the issues raised in the case studies.

Students perform a series of laboratories and software tutorials to learn the simulation methods and a set of case problems of increasing difficulty that reflect the issues addressed in the case studies. A term project drawn from the industrial experience of the students or the instructor serves as a course capstone.

REFERENCES

Banks, J, 2000. *Getting started with AutoMod.* Bountiful, Utah: AutoSimulations, Inc.

Banks, J., J. S. Carson, and B. L. Nelson, 1996. *Discrete-event systems simulation, 2nd edition*. Upper Saddle River, NJ: Prentice Hall.

Dessouky, M. M., D. E. Bailey, S. Verma, S. Adiga, G. A. Bekey, and E. J. Kazlauskas, 1998. Virtual factory teaching system in support of manufacturing education. *Journal of Engineering Education*, 87(4): 459-467.

Dessouky, M. M., S. Verma, D. E. Bailey, and J. F. Rickel, 2001. A methodology for developing a web-based factory simulator for manufacturing education. *IIE Transactions*, 33(3): 167-180.

Harrell, C., B. K. Ghosh, and R. Bowden, 2000. *Simulation using ProModel.* New York: McGraw-Hill.

Kelton, W. D., R. P. Sadowski, and D. A. Sadowski, 1998. *Simulation with Arena*. New York: McGraw-Hill.

Law, A. M. and W. D. Kelton, 2000. *Simulation modeling and analysis, 3rd edition.* New York: McGraw-Hill.

Law, A. M. and M. G. McComas, 1999. Expertfit: total support for simulation input modeling. In *Proceedings of the 1999 Winter Simulation Conference*, ed., P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 261-266. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

O'Reilly, J. J. and W. R. Lilegdon, 1999. Introduction to Factor/Aim. In *Proceedings of the 1999 Winter Simulation Conference*, ed., P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 201-207. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

Pritsker, A. A. B., and J. J. O'Reilly. 1999. *Simulation with Visual SLAM and AweSim, 2nd edition***.** New York: Halsted Press.

Richards, L. G., M. Gorman, W. T. Scherer, and R. D. Landel, 1995. Promoting active learning with cases and instructional modules. *Journal of Engineering Education*, 84(5): 375-381.

Shapiro, B. P., 1984. *An Introduction to Cases*. Harvard Business School, 9-584-097.

Shore, B. and D. Plager, 1978. Simulation: a case approach. In *Proceedings of the 1978 Winter Simulation Conference*, ed., H. J. Highland, N. R. Nielsen, and L. G. Hull, 361-370. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

Standridge, C. R., 1986. An approach to model composition from existing modules. In *Modeling and simulation in the artificial intelligence era***,** ed., M. S. Elzas, T. I. Oren and B. P. Zeigler. Amsterdam: North-Holland.

Standridge, C. R. and M. D. Brown-Standridge, 1994. Combining total quality management and simulation with application to family therapy process design. *Journal of the Society for Health Systems*, 5(1): 23-40.

Standridge, C. R., 2000a. Electronic assignment submission and grading: benefits and applications. In *Proceedings of the American Society for Engineering Education 2000 Spring Conference North Central Section*, ed., C. J. Gunn, W. Booth, and C. W. Somerton, Session 104.

Standridge, C. R., 2000b. Teaching simulation using case studies. In *Proceedings of the 2000 Winter Simulation Conference*, ed., J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1630-1634. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

Standridge, C. R., 2001. *Simulation in Practice: An Introduction*, under development.

AUTHOR BIOGRAPHY

CHARLES R. STANDRIDGE is an associate professor in the Padnos School of Engineering at Grand Valley State University. He has over 25 years of simulation experience in academia and industry. He has performed many simulation applications, developed commercial simulation software, and taught simulation at three universities. His current research interests are in the development of modular simulation environments (MSE). He is working with industry on the application of MSE to supply chain management problems emphasizing strategic and tactical logistics. His simulation teaching interests are in the use of computer aided teaching studios for instruction of introductory undergraduate and graduate courses using a case-based approach. He also teaches courses in production scheduling and control as well as engineering data analysis. He has a Ph.D. in Industrial Engineering from Purdue University. His email address is <standric@gvsu.edu>.