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TEACHING SIMULATION USING CASE STUDIES

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ABSTRACT

We have developed and implemented a case-based approach for introducing discrete event simulation to undergraduate and graduate manufacturing engineering students. Students learn only the simulation methods necessary to support the case studies. Case studies are derived from topics of interest to practicing manufacturing engineers. Cases are organized into four modules: basic systems organizations, systems operating strategies, material handling, and supply chain management. Course instruction is based on active learning. Tutorials and laboratories assist students in comprehending the simulation methods. Courses are taught in a computer-aided teaching studio, so that the mix of passive and active learning can be adjusted as appropriate to each class meeting. An industry-based project serves as the course capstone.

1 INTRODUCTION

Systems simulation is an important topic for both undergraduate and graduate programs in manufacturing engineering, industrial engineering, and management science. System simulation provides information about the temporal dynamics of systems that is available from no other source. This technique is vital in addressing system design and operation problems commonly dealt with by engineers and management scientists. These problems have to do with capital equipment requirements, labor requirements, meeting throughput targets, and scheduling as well as operational policies concerning routing, sequencing, and task assignments.

Case studies can be used as metaphors for the Industrial versions of problems allowing students to "simulate" the role of a practicing engineer or management scientist (Shapiro, 1984). 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.

The following benefits of cases have been identified (Richards, et al., 1995):

1. *Relevance*. Actual representation of real design and operations issues faced by engineers and managers.
2. *Motivation for students.* The realism of the cases provides an incentive for the students to become more involved in the material they are studying.
3. *Consolidation/Integration.* Each case requires the application of multiple concepts and techniques in an integrated fashion to address a single set of issues. A simulation project process is the integration mechanism.
4. *Transfer.* Cases give students experience that can be applied to subsequent cases, other course work, and on the job situations.

Case studies allow students to tackle problems set in realistic environments in the classroom using their cognitive and intuitive skills complemented with their verbal and learned skills. Shore and Plager (1978) call for the use of cases in simulation education, emphasizing real-world applications. They characterize a case as involving a description of a complex operational environment, a difficult to define decision problem, incomplete and perhaps ambiguous information, insufficient structure, and the need to make a decision.

This paper discusses the curriculum development strategy as well as the teaching strategy for the undergraduate and graduate simulation courses in the manufacturing engineering program at Grand Valley State University (GVSU). The use of case studies in the courses is discussed. Simulation methods that are prerequisite for the case studies are given. The teaching context of GVSU is presented. The teaching approach presented in this paper is contrasted with more traditional simulation teaching methods.

2 GVSU TEACHING CONTEXT

Preparing students to address design and operation problems is a fundamental requirement for the system simulation courses taught in the undergraduate and graduate manufacturing engineering programs in the Seymour and Esther Padnos School of Engineering at Grand Valley State University. The school is located in urban Grand Rapids, MI. 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 is employed full time within the local industrial base.

Specifying the content of undergraduate and graduate simulation courses in this context involves identifying the specific industrial issues that manufacturing engineers must address. These issues involve:

1. *Manufacturing systems organizations* such as work stations, serial lines, and job shops.
2. *System operating strategies* including pull (just-in-time) versus push operations, flexible manufacturing, cellular manufacturing, and complete automation.
3. *Material handling mechanisms* such as conveyors, automated guided vehicle systems, and automated storage/retrieval systems.
4. *Supply chain management* including automated inventory management, logistics, and multiple locations for inventory.

Students expect a simulation course both to provide fundamental knowledge about simulation methods and applications as well as to yield information that is immediately applicable to their work context.

An introductory course in manufacturing system simulation is required of all bachelor of science level manufacturing engineering students. 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 computed-aided teaching (CAT) studio, 2 times for 2.5 hours each. Each class meeting is an appropriate mixture of lecture and laboratory activities with the percent time devoted to each depending on the topic. The course consists of five modules, one for each of four sets of case studies preceded by a module covering the simulation project process and simulation methods.

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.

The vast majority of these students are employed full time in manufacturing engineering positions in local industry.

The course meets once per week for 3 hours in a CAT studio. Each class meeting is an appropriate mixture of lecture and laboratory activities with the percent of time devoted to each depending on the topic. The course consists of the same modules as the undergraduate course though some case studies are not covered due to time constraints.

3 SIMULATION METHODS

An understanding of simulation methods is prerequisite for understanding the case studies. Only the simulation methods required by the case studies are covered.

All case studies follow the same simulation process (Standridge and Brown-Standridge, 1994):

1. Define the issues and solution objective.
2. Build models.
3. Identify root causes and assess initial alternatives.
4. Review and extend previous work.
5. Implement solutions and evaluate.

The first strategic phase in the simulation project process is the definition of the system design or improvement issues to be resolved and the characteristics of a solution to these issues. The construction of models of the system under study is the focus of the second phase. The third strategic phase involves identifying the system operating parameters, control strategies, and organizational structures that impact the issues and solution objectives identified in the first phase.

The fourth strategic phase begins with a review of the work accomplished in phases one through three. This review is performed by a team of simulation analysts, system experts, and managers. In the fifth phase, the selected improvements are implemented and the results monitored.

The iterative nature of the simulation project process is emphasized. At every phase, new knowledge about the system and its behavior is gained. This may lead to a need to modify the work performed at any preceding phase.

Performing the first and last steps in the simulation process requires knowledge of the context in which the system operates as well as considerable time, effort, and experience. Typically in classes, the first step is given as part of the statement of a problem and the last step assumed to be successful.

Modeling methods are the next course topic. 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 assembly, breakdowns, and scheduled maintenance.
3. Routing among the work stations.
4. Batching.
5. Inventories.

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

At the same time, in order to understand the case studies and do the case problems, students must learn how to effectively perform a simulation study using a commercial simulation environment. These environments typically provide tools for model building, experimentation and animation as well as data collection and export to other tools, such as spreadsheets, for post simulation statistical analysis and presentation preparation. The undergraduate simulation course employs the general purpose simulation environment AweSim (Pritsker and O'Reilly, 1999) while the graduate simulation course uses the manufacturing specific environment FACTOR/AIM (O'Reilly and Lilegdon, 1999).

Verification and validation are discussed next. A hypothesis testing approach is taken (Balci, 1994).

Verification involves making every effort to find evidence to reject the following hypothesis: The computer implementation of the model agrees with the on paper specification of the model. Saying that a model is verified is the same as admitting failure in finding such evidence.

Similarly, the hypothesis for validation is the following: The computer implementation of the model and the model as specified on paper as well as all values used in the model agree with the system as designed or as it exists.

Simulation experimentation topics follow. These include:

1. Design and analysis of terminating simulation experiments.
2. Design and analysis of steady-state simulation experiments.
3. Variance reduction using common random numbers.
4. Animation methods.

The commercial simulation animation tool PROOF (Henriksen, 1999) is employed.

Fitting distribution functions to data is covered as a separate topic. Fitting distribution functions to data is accomplished using a commercial off the shelf software package, in this case ExpertFit (Law and McComas, 1999).

Finally, the operations of simulation engine are discussed, including:

1. Random sampling from distribution functions.
2. Uniform random number generation.
3. Ordering of entities in lists.
4. Event-by-event processing of the simulation experiment.
5. Computation of statistical summaries.
6. State event detection.

4 CASE STUDIES

A series of case studies covering the manufacturing engineering issues discussed in section 2 has been developed (Standridge, 2000b). The case studies are organized according to the simulation-based project process described in section 3.

The first five case studies cover a wide variety of industries: service, electronics assembly manufacturing, consumer products, and metal cutting manufacturing as well as a wide variety of system types: unpaced serial lines, paced serial lines, and job shops. In addition, both terminating and non-terminating experimental designs are included. Design issues include determining buffer sizes, staffing requirements, and capital equipment levels. Thus, the first set of case studies illustrates all of the simulation methods plus showing the breadth of simulation applications.

The other three sets of cases studies concentrate on topics of interest to manufacturing engineers.

The second set deals with manufacturing system operating strategies. Topics include pull production, flexible manufacturing, highly automated manufacturing, and cellular manufacturing. The combined use of optimization and simulation models is illustrated. Design issues include setting work-in-process levels, determining an appropriate mix of machines, machine scheduling, and evaluating operational policies.

The third set of case studies deals with material handling issues including locating workstations around a conveyor, designing an AGV system, and determining the size of a storage area linked to an AS/RS system.

The fourth set of case studies covers the area of supply chain management. Topics include automated inventory management for a retailer by a supplier, capital equipment requirements for a logistics system, and inventory management across multiple locations in a supply chain.

5 SIGNIFICANT ASPECTS OF CASE-BASED TEACHING

1. *Course content is based on the problems commonly addressed by simulation.* Most text books, and therefore courses based on them, cover either a particular commercial simulation environment (Harrel, Ghosh, and Bowden, 2000; Kelton, Sadowski, and Sadowski, 1998; Pritsker and O'Reilly, 1999) or emphasize simulation experimentation (Banks, Carson, and Nelson, 1996; Law and Kelton, 2000). In other words, the case-based simulation courses emphasize problems of interest and cover only the simulation methods needed to address those problems. Traditional courses emphasize modeling and simulation methods, illustrating these with examples and perhaps cases.
2. *Course requirements are based on an active learning strategy.* Students complete multiple case problems, each based on a particular case study. For each, the student performs all steps of the simulation process, including modeling, experimentation, statistical analysis, and conclusion drawing. Students perform tutorials to learn the simulation environment and distribution function fitting software used in the course. Additional laboratory exercises cover verification, validation, statistical analysis of simulation results, and the operation of the simulation engine. Passive learning, especially through lecturing, is minimized. Traditional forms of evaluation, such as paper-based homework and examinations, are not used.
3. *Courses are taught in a computer-aided teaching (CAT) studio*. Each student has access to a computer for the entire duration of all class meetings. Each meeting is an appropriate mixture of lecturing and active learning, based on the topic. More lecturing occurs at the beginning of the course when simulation methods are presented. Case studies and case problems require less lecturing and more active learning.
4. *Laboratories and cases are submitted and graded electronically.* Standridge (2000a) identifies the benefits of this approach including: submission and return of graded assignments other than at class meeting times; support for detailed evaluations including suggestions for improvements; avoidance of voluminous printing; and archiving.
5. *An industrial-based project is the capstone course experience.* Students are required to formulate a project statement based on their work experience. A simulation-based solution to the problem is developed and presented in written and oral form.

6 SUMMARY

This paper describes the curricular requirements and content of introductory simulation courses in manufacturing engineering at Grand Valley State University. Educational requirements are based both in simulation fundamentals and the problems of interest to local industry. A set of case studies that serve as metaphors for industrial problems has been developed. Only the simulation methods required for understanding the case studies are taught. The unique aspects of these case-based simulation courses are discussed.

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