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USMED: BROADENING THE IMPACT OF SIMULATION ANALYSIS METHODOLOGY (PANEL)

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ABSTRACT

This panel considers the broad applicability of discrete event simulation analysis methodology to engineering design. A successful prototype multidisciplinary course, "Using Simulation Models for Engineering Design," is examined and discussed. Issues related to the implementation of such a course at other institutions are considered, for both graduate and undergraduate versions.

1 INTRODUCTION

This panel will investigate the thesis that analysis methodology developed by the discrete event simulation community can be applied in a broader simulation context. For the purposes of this discussion, a *simulation* model is defined as any computer program that attempts to predict the performance of a real product or system. This definition includes discrete event simulation models of queueing systems in manufacturing, computing, communications, transportation, etc., but also includes finite element models of mechanical components, boundary element models of heat transfer, circuit simulation models, and so forth.

Engineers from all disciplines use simulation models iteratively to construct, analyze, and improve product and process designs. The iterative use of engineering simulations for design evaluation and optimization is becoming increasingly common as computing resources continue to increase in power and decrease in cost. In traditional engineering disciplines such as mechanical, electrical, and chemical engineering, graduate research and instruction includes issues associated with model development, and in some cases on deterministic optimization. Excluding deterministic optimization, techniques for the iterative use of models for design of products and systems has not been addressed in these disciplines. These more general issues include metamodeling, the design of experiments, incorporating random variations, and robust design.

Much of the applicable research in these latter areas has been conducted by the discrete event simulation community. This panel examines a prototype graduate course that provides an opportunity to broaden the impact of this research to simulation applications in other disciplines. The course, "Using Simulation Models for Engineering Design," (USMED) has been taught at the graduate level at The Pennsylvania State University and Cornell University. Components of the course are being considered for a graduate course at Georgia Institute of Technology and for an undergraduate course at Purdue University. The panel will discuss i) what is covered in the course, ii) the relevance of the material from a simulation user's perspective, iii) the difficulties anticipated in offering the course at another institution, and iv) the potential for an undergraduate version.

2 USMED COURSE STRUCTURE

Today there exists a broad array of validated engineering simulation/analysis codes, and fast inexpensive workstations. As a result, engineers make multiple runs to analyze/design products and systems. Using Simulation Models for Engineering Design is a multidisciplinary graduate course that exposes engineers to the current state of research on the efficient iterative use of simulation models. The syllabus appears below.

USMED: Course Syllabus

Model Taxonomy and Case Introductions

Incorporating Random Variations
Motivation
Computer Generated Random Variables

Sensitivity Analysis
Methods for Deterministic Models
Methods for Stochastic Models

MetaModeling
Purpose: speed, insight, validation
Metamodels: polynomial, neural networks, splines, radial basis functions, spatial correlation
Experiment Designs for Metamodels and Validation
Special Issues for Stochastic Models: correlation induction strategies and sample size determination

Optimization
Formulating a Response Function
Statistical Issues in Selecting the Best Design
Overview of Deterministic Optimization
Robust Design and Yield Optimization: Taguchi metamodels based on mean and variance, stochastic derivative methods, Nelder-Mead and response surface methods

The syllabus has four major topics: incorporating random variations, sensitivity analysis, metamodeling, and robust design. The techniques that are presented are applied by the students in groups of three to four to case study simulation models. Each case study is based on actual simulation code used in industry. Detailed descriptions of the course appear in Barton and Schruben (1992a, 1992b).

The cases are selected to reflect a broad range of simulation model types. One case uses a finite element model of a small truck exhaust system. The design objective is to minimize exhaust system vibrations that have frequencies near the resonant frequencies of the cab, through control of the exhaust system hanger positions and hanger stiffness. Incorporating random variations requires the students to identify appropriate probability distributions for hanger placement accuracy and material stiffness, as might be expected when the exhaust system was replaced. Data collection required trips to local muffler shops. Metamodels reduce the run time from several minutes on a 486PC to a few seconds. This allows students to study the likely variations in performance through Monte Carlo runs of the metamodel. A second case uses circuit simulation to estimate the frequency response of a microwave stripline filter as a function of the lengths and widths of the strips, the height of the circuit cover, and the thickness of the substrate. A third case study is a discrete event simulation model of a diesel engine manufacturing line. Students allocate buffer space and choose tool quality to maximize the net profit of the facility, which depends on throughput. Detailed descriptions for two case studies appear in Moosbrugger and Rhodes (1993) and Ramesh and Barton (1993).

The multidisciplinary composition of the class provides an opportunity for students from many disciplines to see common activities in the use of simulation models. To capitalize on this opportunity, students present their case study work to the entire group at mid-semester and again at the end of the semester. Student discussions during the presentations are encouraged. There are no course assignments other than the case study exercises, which require the students to implement a subset of the methodologies covered in each of the four course topics. Oral midterm and final examinations focus on the case study project and the supporting mathematical and statistical models. The oral exams encourage full participation of all members of each case study team.

There is no textbook available for the course, but a complete set of lecture notes has been prepared. At this writing, the user interface to the case study software is being simplified, and documentation is being improved.

3 RELEVANCE FROM A USER'S PERSPECTIVE

Military environments dictate that the design selection process gravitate towards robust design solutions as opposed to optimal design solutions. This is because most military systems are required to operate at some minimal level throughout the design space, e.g. regulations require the M16 round to operate from -60F to 140F. To assess potential designs, special purpose software is often used to simulate processes which are costly in terms of human and environmental resources. These include projectile launch, flight and impact; propellant formulations; and ergonomic considerations for soldier's Battle Dress Units (BDU's). Software which is used to address these considerations sometimes use commercial products such as ANSYS and RS1, but primarily, simulation models are developed in-house or by contract to meet a very specific need.

These models are not necessarily intended to be used iteratively, but instead are based on a strategy of sequential experimentation typically involving a screening phase and a predictive model building phase. For instance, this approach has been used in determining the response of propellant to chemical and mechanical loads. This allows the identification of key variables in the propellant formulation in the screening phase, and then developing a predictive capability for the influence of these variables on the performance of the propellant formulation. Another example is the assessment of hardware design configurations such as barrel length, breech volume, charge weight, sabot design, and propellant burning rates upon the overall performance of a tank cannon.

Unfortunately, entry level personnel do not generally have either sufficient simulation skills for design, perspective about design, or an appreciation of the unique design requirements of the military to effectively apply existing modeling capabilities. USMED is a means of addressing the first item: simulation skills. The lack of development of these simulation skills for design use in engineering can be attributed in part to 'curriculum inertia': the difficulty of modifying a curriculum to include new material in an existing design course or of adding a new course, especially at the undergraduate level where the course load is already extremely high. The result of this deficiency is substantial time can be spent simply (re)exploring simulation strategies with a model rather than utilizing these strategies to develop an understanding of model capabilities and applicability in design.

There is a need to teach iterative design techniques so that individuals can quickly identify and evaluate capabilities of existing software for design use, understand how to approach the design process to determine relevant design criteria, and ultimately to quantify relationships between design factors and the design goals.

4 OFFERING USMED AT OTHER INSTITUTIONS

The USMED curriculum can be effective for classes made up entirely of Industrial Engineering graduate students, as well as for classes with graduate students from other engineering disciplines. In the first course offering, the class at Penn State was multi-departmental, while the class at Cornell consisted solely of M.Eng. candidates from the School of Operations Research and Industrial Engineering.

In trying to develop a version of the USMED prototype course at Georgia Tech, we have encountered some difficulties, none of which are insurmountable. First, the course does not have a text, nor does it have a collection of homework assignments. To address the first problem, a detailed set of notes for 33 lectures have been prepared in computer form. Homework assignments are replaced by a set of four structured case study assignments, which are reviewed as the semester progresses.

The second difficulty is that the professor (or a teaching assistant) must be comfortable with the multidisciplinary software that is used. The exhaust system case requires students to run a finite-element code; the microwave filter case requires students to run a circuit simulation code; the diesel engine case uses SIMAN discrete event simulation software.

The third issue relates to the second. Although individual runs of any of the case study simulations are not difficult, the course focuses on multiple, iterative exercise of those models. A workstation environment is necessary to provide adequate computing support.

Finally, the means for assessment place a substantial burden on the professor. In addition to grading mid-term and final presentations and reports, oral midterm and final examinations consume significant amounts of time. In addition, periodic progress meetings with each student group require significant faculty effort.

As mentioned above, none of these issues are insurmountable, but they must be addressed for a successful transfer of the USMED curriculum.

5 AN UNDERGRADUATE COURSE IN USMED

Purdue's School of Industrial Engineering has a long history of distinguished contributions to simulation methodology and its application in engineering, particularly manufacturing. The strong interests and expertise of the faculty are reflected in four graduate level course offerings in simulation related topics. Two are master's level courses. The first is a language-based introduction to simulation modeling methodologies and their application to industrial engineering design and analysis problems. The second is an introduction to the probabilistic and statistical aspects of designing, conducting, and analyzing output from simulation experiments. Both courses emphasize the development of skills essential to simulation practitioners. Two Ph.D. level courses offer more advanced treatments of this material with the focus being on methodological issues.

While there is currently no course devoted to simulation at the undergraduate level, there is an ongoing concerted effort to provide an exposure to simulation related topics at various places in the curriculum. A student's first exposure comes in a sophomore level course dealing with computer methods and their application to industrial engineering design and analysis problems which includes an introduction to discrete-event dynamic systems simulation modeling. Also, Monte Carlo exercises are being employed in our introductory probability and statistics course as a means to provide fundamental insights into the methods used for modeling and analyzing the outcomes of uncertainties as well as to make apparent the practical implications of important theoretical results like the central limit theorem and law of large numbers. Attempts are also made in our introductory course in stochastic processes to emphasize the complementary role of simulation and analytical modeling techniques.

There is also consensus in the desire for an elective senior level undergraduate course devoted to simulation that would bring together these concepts and explore their application in engineering design and analysis settings. This part of the panel discussion focuses on the consideration of ways in which the graduate level USMED course might be restructured to meet the needs of such an undergraduate course. Many of the goals that have guided the design of the graduate course are pertinent to an undergraduate version. There is, however, more to designing a successful undergraduate version than simply softening the presentation to account for the difference in mathematical sophistication between graduate and undergraduate students.

A first step would be to identify topics in the graduate course that might be omitted or consolidated in the undergraduate version, but the presentation of material should also reflect an increased focus on the practical aspects of the different methodologies and their implementation

Both courses are best served by the multidisciplinary case based structure of the course but the studies must necessarily be modified to reflect changes in course content or depth of coverage. The relatively heavy course load of undergraduate students will also dictate that case studies be less ambitious. One alternative would be to limit computer exercises to pieces of the graduate-level case studies. Another option would be to have students analyze completed versions of the graduate case studies.

In addition to a general discussion of these issues, we will report on the status of current efforts in designing such a course.

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